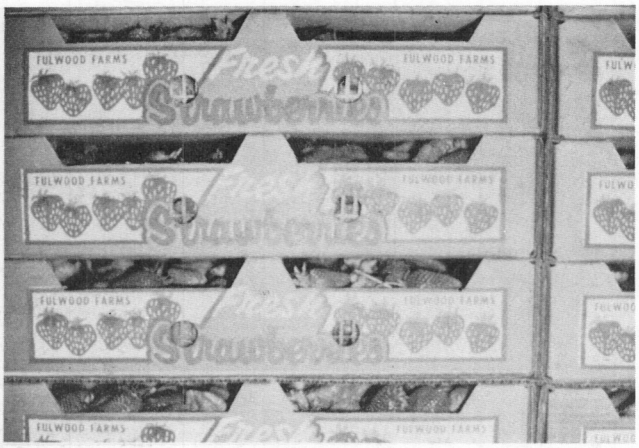

Figure 6. Vent opening in standard catrton.

(Figure 6). The opening represents 14% of the side of carton. Cooling experiment research [1] with other designs, shown in Figure 7 (half-cartons were used instead of full cartons because of the symmetry of the carton design), was conducted to find the effect of different vent hole configurations. Table 1 shows the vent hole sizes and percent openings for each design. The three new vent hole designs were tested against the standard container. All new vent hole designs were found to improve cooling time. There was no significant difference among the new designs. Table 2 summarizes the effects of the new vent hole designs on the cooling time for the last basket (three cartons with three pint baskets per carton) downstream and also for the average of all fruit. The results of the statistical analysis indicated that the three-hole and four-hole designs are significantly better in cooling the strawberries than the standard crate. The increase in cooling efficiency of the new design is more pronounced at the lower air flow rates.

The reason for more efficient cooling with the new designs is probably due to better air flow patterns inside the carton. With the standard carton, the vent hole is cut at the very top edge of the carton. When the air is forced through the vent hole, it tends to continue through the gap between the top of the baskets and the bottom of the carton immediately above, thus by-passing most of the fruit. With the new designs, the vent holes are more uniformly distributed, forcing more air to flow through the fruit. Before the new designs are adopted, however, tests must be conducted to ensure the strength of the new containers.

The cooling research [1] also established the relationship between cooling rate and air flow rate. Table 2 indicates a large increase in cooling rate

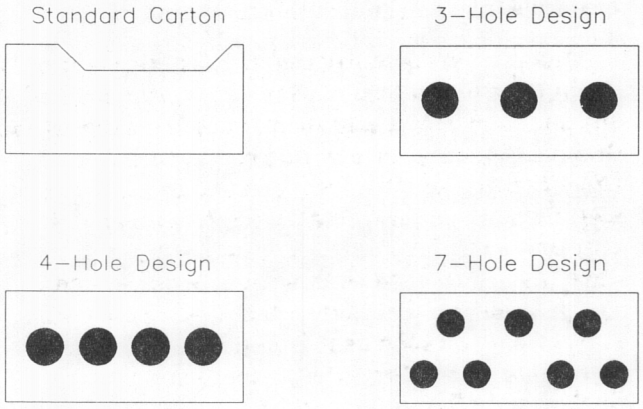

Figure 7. Standard and experimental strawberry carton vent-hole configurations (half-cartons were used instead of full cartons because of the symmetry of the carton design).

Table 1. Vent-hole sizes and percent opening for different designs.

Configuration	Diameter, m (inch)	% Opening
Standard	—	14.0
3-hole	38.1×10^{-3} (1.5)	13.5
4-hole	38.1×10^{-3} (1.5)	18.0
7-hole	25.4×10^{-3} (1.0)	14.0

Table 2. Seven-eighths cooling time (minutes) as function of vent hole designs (basket number 9, and average of all fruit).

	Vent hole configuration							
Air flow rate	std. hole		3 holes		4 holes		7 holes	
m^3/s kg (ft^3/lb min)	last basket	avg. all fruit	last basket	avg. all fruit	last basket	avg. all fruit	last basket	avg. all fruit
1.04×10^{-3} (1.0)	160	122	132	98	136	100	136	100
2.08×10^{-3} (2.0)	82	64	76	52	72	50	82	62
4.16×10^{-3} (4.0)	74	52	70	50	68	46	68	48
6.24×10^{-3} (6.0)	52	34	50	34	46	32	46	32

when the air flow rate was increased from 1.0×10^{-3} to 2.1×10^{-3} m^3/(kg s) (1.0 to 2.0 ft^3/min lb) and a relatively small increase at higher flow rates. Cooling time was shown to also be a function of location of the fruit in the carton with respect to the entering air. The more downstream the location, the longer the cooling time. Table 3 shows the effect of fruit location on cooling time at various air flow rates.

For all air flow rates tested, it took approximately twice as long for the last basket to reach 7/8 cooling as it did for the first basket. Table 4 presents this bed effect in terms of the temperature gradient along the flow path at the time the first pint achieved 7/8 cooling. A temperature gradient of 5 to 6°C (9 to 10.8°F) exists between the first