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DESIGN AND DEVELOPMENT OF A PORTABLE FORCED-AIR COOLER

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Abstract. **A portable demonstration forced-air cooling unit was designed and constructed using off-the-shelf technology. The trailer-mounted cooling unit utilized two 10.5 kW (3-ton) packaged air conditioner units (mobile home type), a high pressure blower, and a self-constructed cooling chamber for cooling a pallet of containerized product. This unit was designed to be energy efficient and affordable to a grower in the range of 2 to 20 ha (5 to 50 acres). This unit will be demonstrated in North Florida and various locations around the state with various commodities. This cooler was intended to encourage the adoption of proper precooling and postharvest handling to help maintain the quality of produce. The design and performance of this forced-air cooling unit are presented.**

During the past five years, there has been a significant increase in the production of fruit and vegetable crops in the twelve county region north of Gainesville. Estimates indicate the acreage will increase more during the next 5 years. The State Farmers' Market in White Springs, provides an excellent marketing opportunity and incentive for vegetable and fruit producers in the region (Crawford, 1991).

The principle crops being grown or considered in the region are squash, peppers, cucumbers, tomatoes, sweet corn, and eggplant. Most of these crops are produced for the fresh market. Produce which is not cooled quickly after harvest degrades in quality (Sargent et al., 1991). Although a few large farmers in the North Florida region have installed precooling systems at packinghouses, there are many small, low-volume growers who are unable to justify the large capital investment. The initial equipment cost for many types of cooling systems can be substantial. In the past, the added investment required and operational costs of precooling systems have been a major barrier to the adoption of this technology. Presently, their only alternatives are to not cool, which severely limits their markets, or to construct homemade precoolers that can be extremely energy inefficient and potentially hazardous from a food safety standpoint.

Many of the produce types grown in North Florida cannot be exposed to water or ice (Sargent et al., 1991). Therefore, forced-air cooling is a preferred precooling method (Baird et al., 1988; Talbot and Baird, 1990; Talbot et al., 1992). Of the crops listed above, forced-air cooling is applicable for all except sweet corn. In addition, forced-air cooling is well suited for peaches, blueberries, and other deciduous fruits grown in North Florida. The ability to retrofit existing cold rooms for use as forced-air coolers is also an economic advantage.

A need was recognized to demonstrate the principles of forced-air cooling and illustrate the investment and operational costs required. The purpose of this project was the design and construction of a small, portable, extension demonstration, forced-air cooling unit that would essentially use off-the-shelf technology. The forced-air cooler unit illustrates how to cool, stressing management practices, and provides a model for growers. It is not intended to be the final design that a particular grower would use to cool all produce harvested in one day. Part of the extension program would be to assist the grower in the design of a system which would satisfy the needs of his operation.

The trailer-mounted cooling unit consists of two air conditioner units (mobile home type) and ducting, a high pressure fan, controls, and a cooling chamber for cooling a pallet of approximately 454 kg (1000 lb) of containerized product. The system design attempts to improve on previously reported designs (Boyette and Rohrback, 1990; Schofer et al., 1992). The unit is energy efficient and affordable to a grower in the range of 2 to 20 ha (5 to 50 acres), and will be demonstrated in North Florida and various locations around the state with various commodities. This design should encourage the adoption of precooling throughout Florida. The objective of this report is to present the design considerations, system cooling performance and system costs of the portable forced-air cooling unit. The results of this project will continue to have a positive impact as additional demonstrations and educational programs are presented.

Materials and Methods

Portable Forced-Air Cooling Unit

The trailer-mounted portable forced-air cooling unit shown in Fig. 1 and 2 can be demonstrated at any location which provides 100 amp, 230 VAC, single phase service. This self-contained unit consists of two 10.5 kW (3-ton or 35,600 Btu) packaged refrigeration units with associated ducting and controls, a high-pressure 1.1 kW (1.5 hp) fan, and a self-constructed 2.4 m (8 ft) cubic cooling chamber. The unit is set up to illustrate tunnel-type forced-air cooling. The interior can be modified to illustrate other types of forced-air cooling.

The basic concept for this forced-air cooler is a modification of the work conducted by Boyette and Rohrbach (1990). Their system used a single, thermostatically con-

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Figure 1. Portable forced-air cooling unit with tow vehicle.

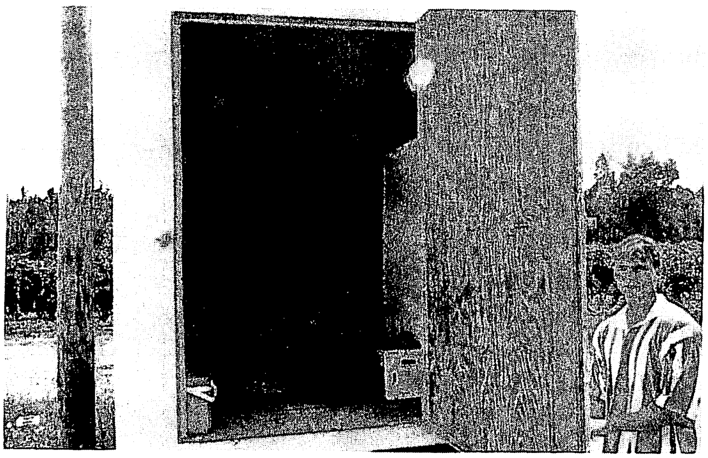

Figure 2. Forced-air cooling unit showing interior of cooling chamber.

trolled 10.4 kW (2.95 ton) residential air conditioner which used the unit's internal air handling fan to provide the static pressure to accomplish the forced-air cooling. This system was used with a reusable cooling and shipping container.

The design criteria for an improved forced-air cooling system required forced-air cooling of a pallets of containerized vegetables in less than an hour. In addition to the energy required to cool the vegetables with a higher flow rate, the larger air conditioner units will handle transmission, infiltration, and miscellaneous cooling loads.

Cooling chamber. Fig. 3 shows the plan and side views of the cooling chamber. The basic design was based on USDA Plan 6380 (1986). The length of the chamber in Plan 6830 was reduced from 3.7 m to 2.4 m (12 ft to 8 ft) in order to fit the chamber onto the trailer. The false wall and 1.1 kW (1.5 hp) high pressure fan were added to provide the pressure difference across the pallet of containerized produce. The construction requirements are simple and materials are available from local building construction stores. Table 1 lists the materials and costs for the cooling chamber construction ($1,313) and other system components.

High pressure fan. The canvas was rolled down over the space between the pallet of containerized produce and the simulated pallet. The pressure produced by the high pressure fan pulled cool air from inside the cooling chamber through the openings in containers of produce and returned the warmer air to the air conditioner units. The 26.7 cm (10.5 inch) backward incline 230 VAC, single phase 1.1 kW (1.5 hp) blower (Dayton model 7H128) operated at 3385 rpm providing between 1.1 m^3/sec (2,300 cfm) at 62.3 Pa (0.25 inches of water) static pressure and 0.8 m^3/sec (1800 cfm) at 747.2 Pa (3 inches of water) static pressure. This fan cost $502 and was selected to match the combined air flow of the two air conditioner units over a range of static pressures.

Cooling units and controls. The cooling was accomplished with two 10.5 kW (3-ton) packaged (mobile home type) air conditioner units (Airquest Model NA2P036A2N). The rated air flow of the evaporator fan for each air conditioner unit is between 0.7 m^3/sec (1,480 cfm) at 24.9 Pa (0.1 inches of water) static pressure and 0.6 m^3/sec (1,275 cfm) at 124.5 Pa (0.5 inches of water) static pressure. Each air conditioner cost $690 and was purchased along with flexible ducts from a local air conditioner company. The cooling units were controlled using both a programmable controller and a timer relay. A schematic of the control wiring is shown in Fig. 4. The microprocessor based temperature/process controller (Love Model 16011) was used instead of two thermostats. A single thermocouple was used to sense the return air temperature and two set points (cut off) were programmed so that each air conditioner was controlled independently. For all tests reported, one air conditioner was set to cut off at a sensed temperature of 4°C (40°F) and the other was set to cut off at 10°C (50°F). The controller cost $194, but for a farm system, two bulb type thermostats could be installed for around $40 each. Since the air conditioners had no defrost capabilities, the variable timer relay was used to control the compressor motor to provide for defrosting. The two switch timer (Newark Electronics Model 62F2006), timing gear, relay and switches cost $169. The power control wiring was arranged to allow the compressor to cycle on and off at a predetermined rate while the evaporator coil fan operated continuously. The timer gear operated on a 10 minute cycle and the typical relay settings allowed the compressor of each air conditioner unit to operate at a 80 percent duty cycle (on 8 minutes and off 2 minutes). The two timer switches were off set 180 degrees to prevent both air conditioner units from cycling off at the same time. Any evaporator coil icing that occurred during the time the compressor was operating was melted by the relatively warm air from the cooling container during the compressor off time.

Electrical wiring and connectors. An electrical cable (extension cord) connected to a local power source provides electric energy to the forced-air cooler (for fan and air conditioner power). The electrical wiring cost was high ($738) due to the design for flexibility and portability. A breaker service panel was installed on the trailer. Each air conditioner unit and the high pressure fan were wired to an individual circuit breaker. A master circuit breaker was also installed. A 47.2 m (100 ft) long size #2/3 600 V electrical cable ($310) was connected to the on-trailer service panel. The other end of this large cable was connected to a 100 amp circuit breaker and this circuit breaker was installed in the on-site electrical service panel. Several 100 amp circuit breakers of common brands were purchased to allow for differing service panels. The actual wiring cost for a permanent system would be much less since 30 amp circuit breakers and size #10 wire with shorter length could

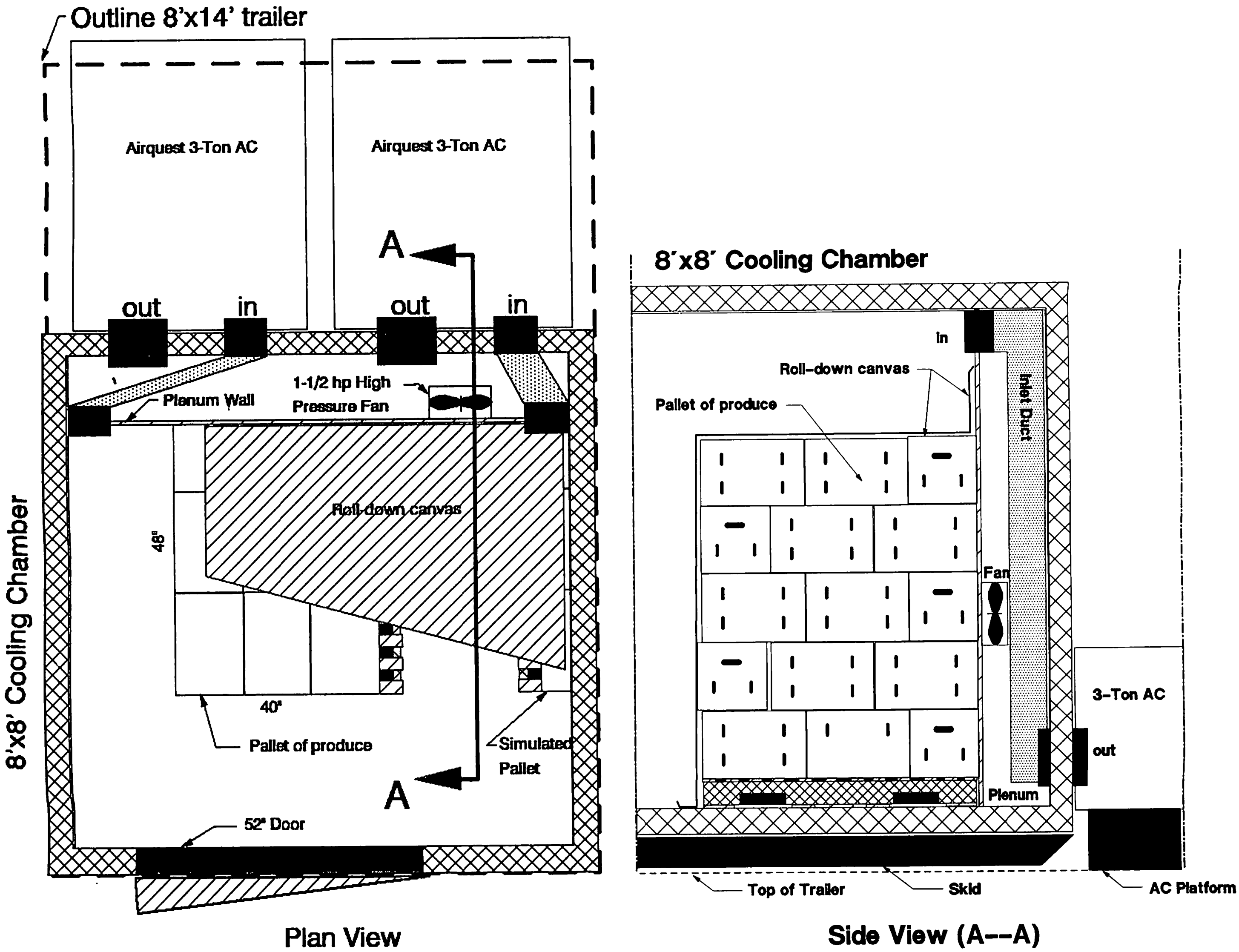

Figure 3. Plan and side view of portable forced-air cooler.

be used to wire each air conditioner unit, and even smaller components could be used for the high pressure fan.

System Performance Evaluation

Operational testing. After completion, the system was operated without a cooling load for several days to insure the proper operation of the fan, air conditioner units, and control circuitry. The inlet (cooling) air, outlet air, evaporator coil, condenser coil, and ambient temperatures were measured using thermocouples. The power requirements were measured using a clamp-type AC ammeter. A digital manometer was used to measure the static pressure loss (drop) across the air conditioner units.

Cooling experiments. The system was used to cool grapes and to compare room cooling to forced-air cooling at a farm near Ft. White, FL. In all five cooling tests, 24-gauge thermocouples and a Campbell Scientific (CR10) data logger with two multiplexers were used to measure up to 64 temperature inputs. Thermocouples were inserted approximately 1 cm (0.4 inch) into the stem end of the grapes, similar to the technique described by Talbot and Baird (1990). After the thermocouples were installed in 4 grapes, these grapes were uniformly distributed in the grape container.

The outside dimensions for the lidded, corrugated grape container were 50.8 cm length × 32 cm width × 16.5 cm height (20 inch × 12.75 inch × 6.5 inch), with a wall thickness of 0.4 cm (5/32 inch). The containers were filled with 10 kg (22 lb) of 1.9 cm (0.75 inch) diameter muscadine grapes, which produced a 2.5 cm (1 inch) space between the top layer of grapes and the container lid. The sides of the containers were vented with two 1.3 cm (0.5 inch) wide by 3.8 cm (1.5 inch) long vertical slots, which provided 1% vent opening area. The ends of the containers were vented with two 1.9 cm (0.75 inch) and three 1.3 cm (0.5 inch) diameter circular vent holes, which provided 1.8% vent opening area. The containers were stacked 7 per layer on a pallet, with 3 containers aligned side to side and 4 containers aligned end to end.

After the thermocouples were installed and the grapes were placed in the containers, 4 layers of containers without thermocouples were quickly hand stacked on the pallet in the cooling chamber. The containers of grapes with

Table 1. Material and price list.

Description of Component		Total
Cooling Chamber		
Lumber, plywood, roofing, plastic, fasteners, paint		$1020.79
Styrofoam Insulation		151.20
Latch handle door and 20 cm (8 inch) T Hinges		74.30
Canvas pallet cover		66.68
SUBTOTAL		**$1312.97**
High Pressure Fan		
26.7 cm (10.5 in) backward inclined 1.1 kW (1.5 HP)		$502.00
SUBTOTAL		**$502.00**
Air Conditioner Units		
10.5 kW (3-Ton) Package Air Conditioner	2@$690.00	$1390.00
Ducting, 30.5 & 35.6 cm (12 & 14 inch) diameter, flexible and metal		134.00
SUBTOTAL		**$1524.00**
Electrical Components		
Wiring, connectors, panel, junction boxes		$738.00
Controller		194.00
Timer, two terminal, relay and gear		169.00
SUBTOTAL		**$1101.00**
Trailer		
Used, 1.8×4.3 m (6×14 ft), 2,721 kg (3-ton) tandem trailer		$200.00
Retrofit and repairs		73.00
SUBTOTAL		**$273.00**
TOTAL		**$4612.97**

thermocouples were stacked on the fifth layer (of 10) and 5 layers of containers of grapes without thermocouples completed the load to be cooled. The cooling load consisted of approximately 698 kg (1,540 lb) of grapes. The thermocouple leads were connected to the data logger, the data logger was started (recording every 3 minutes), the canvas was rolled down and checked for good sealing. The door was closed and the air conditioner units, controller, timer and high pressure fan were turned on. The initial electric meter reading was recorded. The amperage was

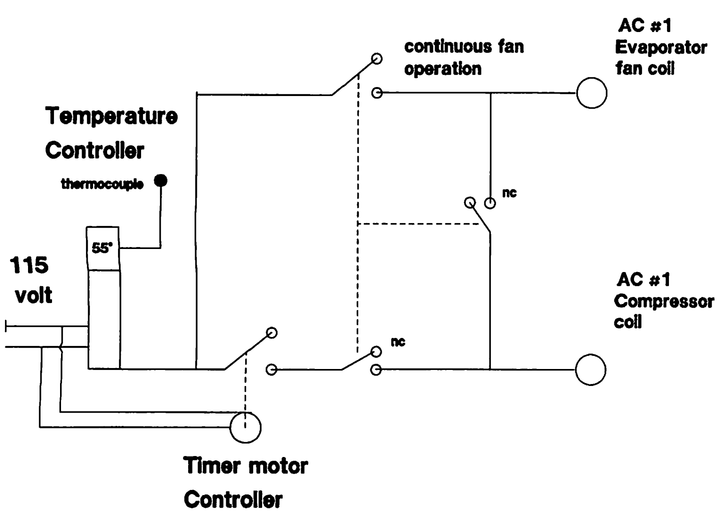

Figure 4. Schematic of the control wiring.

measured for each air conditioner unit and the fan. The inlet (cooling) air, outlet air, evaporator coil, condenser coil, and ambient temperatures were also measured.

During the experiments, cold air was pulled from the cooling chamber, through the containers of grape, the plenum, the fan, and exited through the flexible return ducts to the air conditioner units. The temperature of the cooling air entering the forced-air units was not constant due to the small volume of the cooling chamber and the initial heat load of the grapes. The system was not precooled prior to the cooling tests.

The static pressure loss (drop) across the containers was measured using a hand-held digital manometer with one pressure sensing tube on the inside of the cooling tunnel (floor level at end of the canvas) and the other inside, near the door of the cooling chamber. The pressure drop across each air conditioner unit was measured by inserting one tube in the inlet and one tube in the outlet flexible ducts. The air flow rate was determined using the pressure drop measurements and the manufacturer's performance tables (flow rate versus pressure difference).

The electric energy consumption was measured using the electric meter on the power pole at the test site. The amperage was measured with a clamp-type AC ammeter.

Room Cooling Tests. The cooperator was using the cooling body from an old 907 kg (2,000 lb) meat delivery truck for room cooling. This walk-in cooler was cooled with an old refrigeration unit of less than 3.5 kW (1-ton). A room cooling test was conducted simultaneously with a forced-air cooling test. Thermocouples were installed in 6 grapes, and these grapes were uniformly distributed in the grape container. Two containers were instrumented and stacked on top of one container of grapes without thermocouples, which was on the floor of the room cooler. A fourth container of grapes without thermocouples was stacked on top of the instrumented container. This stack of 4 containers was isolated so that the air in the cooler was in contact with all 4 sides of the stack of containers. The air temperature surrounding the stack of containers was also monitored using 4 thermocouples.

Increased Vent Opening Area and Air Stacking. The grape containers used were not designed for forced-air cooling and provided much less than the recommended vent opening area and causing a high pressure drop. Baird et al. (1988), Talbot and Baird (1990), Talbot et al. (1992), and others recommend a vent opening of 5% for containers used for forced-air cooling. In order to increase the vent opening area, additional vent openings were added to the 70 containers using a 1.9 cm (0.75 inch) diameter metal center punch. Twelve holes were added to the sides of the containers, which increased the vent opening area to 3.3%. Three holes were added to the ends of the containers which increased the vent opening area to 3.4%. A cooling test with a pallet of these modified containers was conducted using the same procedures described above. Despite the increased vent opening area, the containers continued to produce a large pressure drop.

A cooling test was conducted using the same procedures described above except the containers were stacked to allow air flow between containers and only 7 layers of containers were stacked on the pallet. As the unmodified grape containers were stacked on the pallet in the cooling chamber, a 1.9 cm (0.75 inch) wide space was left between each container.

Results and Discussion

Portable Forced-Air Cooling Unit

The cost for the demonstration forced-air cooler is listed in Table 1 as $4,612.97. This does not include construction labor costs since many growers who will adopt this design will use in-house labor. The demonstration forced-air cooler incorporates additional electrical component and controls which required added expense. Also, the additional cost to make the system portable would not be required for a stationary unit. Table 2 presents a simplified economic analysis for the system and indicates a five-year payback based on a precooling charge of $0.02 per kg ($0.01 per lb) for 93 pallets per year.

System Performance Evaluation

Operational testing. The system performed well in various operational modes during testing without a cooling load. The control circuitry functioned as desired. The air conditioner units required 18 amps while the high-pressure fan required 6 amps.

Cooling experiments. A major difference between large commercial force-air coolers and the portable forced-air cooler is magnitude of scale. Normally, commercial systems are of such large volume that a near constant cooling air temperature is maintained. As evident in Fig. 5, 6, and 7, the initial cooling air temperature was not constant. To insure a constant initial grape temperature, the portable forced-air cooling unit was not precooled. If the unit was operated prior to initiation of product cooling, the heat load from walls of cooling chamber would be reduced and the evaporator coils would reach a lower initial operating temperature.

Fig. 5 shows the average pallet grape temperature, the average inlet and outlet air temperatures. The 698 kg (1,540 lb) of grapes were cooled approximately 8.3°C (15°F) in 1 hr. This product load exceeded the design load by 30%, which caused a longer cooling time. The pressure drop across the pallet of grapes was 174.4 Pa (0.7 inches of water). For this pressure, the manufacturer's fan performance curve indicates a flow rate of 1.05 m^3/sec (2,230 cfm). The pressure drops across the air conditioner units were not measured for this test. The spike increases of the average inlet temperature shown in Fig. 5 were caused by opening of the cooling chamber door during the test. A plastic curtain will be added to help reduce this significant energy loss. During the 1.5 hr cooling test, the electric meter on the power pole indicated 19 kWh were consumed. However, this included the power for the room cooling system, a trailer camper, and the electricity used in the packing shed.

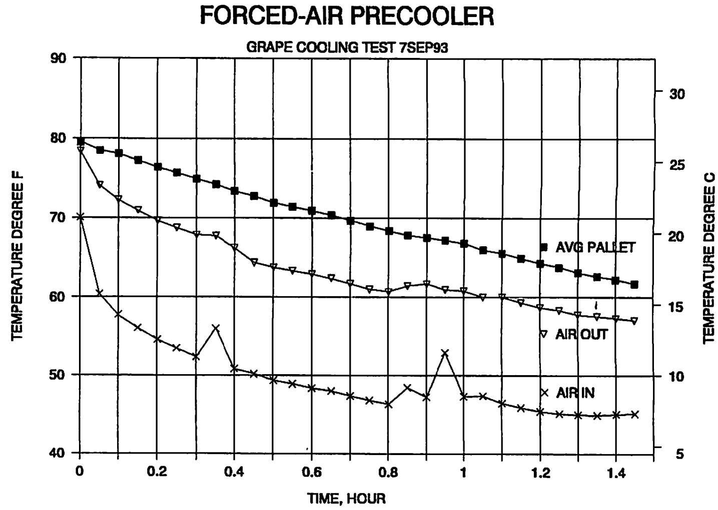

Figure 5. Forced-air cooling curves for 698 kg (1,540 pounds) grapes.

Table 2. Cost and energy analysis.

Fixed Costs:	
Depreciation	
2 AC units, 1 fan & electrical components (cost $3,127; salvage value $300; 10-year life)	$282.70/year
Cooling Room (Cost $1,312.97; 25-year life)	$52.52/year
Interest (1/2 combined cost of equipment, $4,612.97/2 × 14%)	$322.91/year
Repairs, maintenance, taxes and insurance (estimated at 3% of new cost)	$138.39/year
Fixed Cost	$796.52/year
Variable Cost:	
Electricity, 10 kWh per 680 kg (1,500 lb) at $0.10/kWh	$0.67/454 kg (1000 lb)
Labor, 1 hr per 680 kg (1,500 lb) at $5.00 per hr	$3.33/454 kg (1000 lb)
Variable Cost for cooling 454 kg (1000 lb)	$4.00/454 kg (1000 lb) or $0.009 kg ($0.004/lb)

Total Cooling Cost at Various Volumes:

	454 kg (1000 lb) per year							
	30	40	50	60	70	80	90	100
Variable Cost	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
Fixed Cost	$26.55	$19.91	$15.93	$13.28	$11.38	$ 9.96	$ 8.85	$ 7.96
Total Cost	$30.55	$23.91	$19.93	$17.28	$15.38	$13.96	$12.85	$11.96

Payback method. How many 454 kg (1000 lb) pallets must be processed per year to pay off the system in 5 years? Assume a precooling charge of $0.02/kg ($0.01/lb) is applicable (for a 11.3 kg (25 lb) container this amounts to $0.25 or $10 per pallet). Total system cost $4,612.97/$10/pallet/5 years = 93 pallet per year for 5 years. If only 5 pallets are cooled per day, the system would need to be operated (93/5) 19 days per year. The payback period should also be based on the increased profit from higher quality product and reduced spoilage versus the capital investment for the forced-air cooling system.

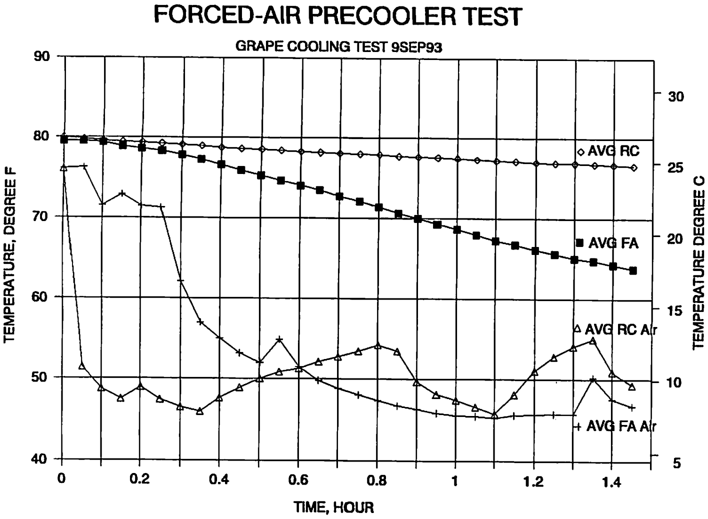

Figure 6. Cooling curves for forced-air versus room cooling of grapes.

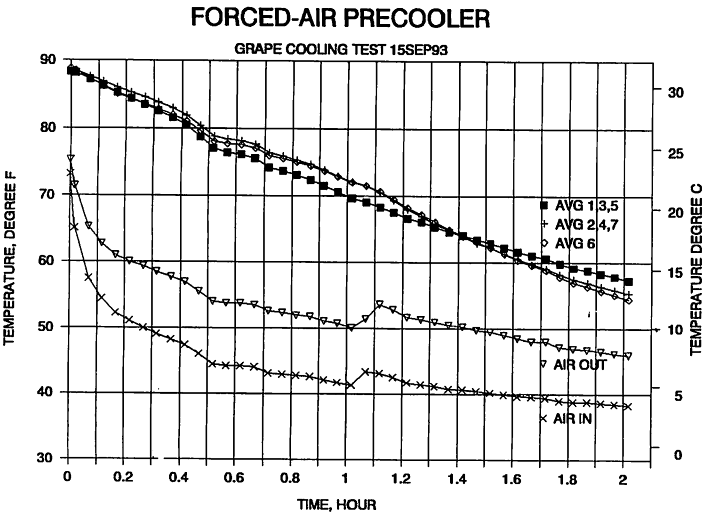

Figure 7. Forced-air cooling curves for 489 kg (1,078 pounds) grapes.

Room Cooling Tests. Fig. 6 shows the average pallet grape temperature for forced-air cooling, the average temperature for two containers of room cooled grapes, the average forced-air inlet and average room cooling air temperatures. The 698 kg (1,540 lb) of grapes were cooled approximately 6.7°C (12°F) in 1 hr, but again, the cooling load was 30% greater than the design load and the cooler was not precooled and the containers provided less than 2% vent opening area. The room cooled grapes were cooled only 2°C (4°F) in 1 hr, indicating the superior cooling of forced-air cooling. The cooling test data were recorded for nearly 3 hr. After 2.5 hr, the forced-air cooled grapes were cooled approximately 14.6°C (26.2°F), while the room-cooled grapes were cooled approximately 3.5°C (6.2°F). Interestingly, the cooperator requested the performance comparison of the forced-air unit and his room cooler before he was informed of this planned test. When the grower was shown the increased cooling by the forced-air cooler, he indicated that many growers would be interested in forced-air cooling.

During the 2.5 hr cooling test, the electric meter on the power pole indicated 16 kWh were consumed, but this included the power for the room cooling system, a trailer camper, and the electricity used in the packing shed. In the future, the power consumed by the cooling unit will be isolated from the local power consumption. The pressure drop across the pallet of grapes was again 174.4 Pa (0.7 inches of water), for which the manufacturer's fan performance curve indicates a flow rate of 1.05 m^3/sec (2,230 cfm). The pressure drops across the air conditioner units were 249.1 Pa (1.0 inches of water) for both air conditioner units with both evaporator coil fans running. This pressure drop exceeds the manufacturer's evaporator fan performance curves. However, the high pressure fan was producing this pressure drop, not the air conditioner unit evaporator fans. Problems with balancing flow rates through the two air conditioner units and the high pressure fan were anticipated, but not significant.

During the later stages of one cooling test, the timer was disengaged and one of the evaporator coils iced. When the evaporator coils freeze up, the air flow resistance increases and the cooling capacity decreases. Using the timer and controller, evaporator coil icing was not a problem. In order to quickly detect evaporator coil icing in the future, a sight window will be installed in the side of the each air conditioner unit.

Increased Vent Opening Area and Air Stacking. A cooling test was conducted with the containers modified to provide 3.3% vent openings (not illustrated). The 698 kg (1,540 lb) of grapes were cooled approximately 5.6°C (10°F) in 1 hr, which was less cooling than anticipated. Again, this product load exceeded the design load by 30% and the cooler was not precooled, which caused a longer cooling time. The pressure drop across the pallet of grapes was reduced to 99.6 Pa (0.4 inches of water). For this pressure, the manufacturer's fan performance curve indicates a flow rate of 1.06 m^3/sec (2,265 cfm). The slight increase in flow through the product was not sufficient to appreciably increase the cooling rate. The increased vent openings were less than the recommended 5%. In addition, the newly added 1.9 cm (0.75 inch) diameter vents were in many cases blocked by the grapes. The importance of properly sized and located container venting was confirmed.

Fig. 7 presents the average container grape temperature for three containers on the inlet air side of the pallet (1, 3, 5), the center container (6), the three containers on the outlet air side of the pallet (2, 4, 7), the average inlet and outlet air temperatures. This illustrates that the cooling air first passed through containers 1, 3, and 5, then passed through container 6, and finally passed through containers 2, 4, and 7. The cooling air is warmed as it passes through each subsequent container; therefore grapes in containers 1, 3, and 5 cool the fastest while grapes in containers 2, 4, and 7 cool the slowest. The containers closest to the entrance of the cooling air cooled slightly faster than the containers near the air outlet, and this is frequently called "bed effect." For this test, the instrumented containers were on the fourth layer of seven layers of containers, rather than the fifth of ten layers. The 489 kg (1,078 lb) of grapes were cooled approximately 10°C (18°F) in 1 hr, which approximated the design load. The cooler was not precooled and the containers provided less than 2% vent opening area, but the containers were stacked (air stacked) with 1.9 cm (0.75 inch) wide spaces between each container. The pressure drop across the pallet of grapes was 99.6 Pa

(0.4 inches of water), for which the manufacturer's fan performance curve indicates a flow rate of 1.06 m^3/sec (2,265 cfm). The pressure drops across the air conditioner units were 249.1 Pa (1.0 inches of water). With the reduced cooling load, the average entering cooling air temperature was lower than the tests with larger cooling loads. Although air stacking did allow a lower static pressure and slightly increased flow rate, the slow grape cooling rate indicates that insufficient cooling air flowed through the containers. In future tests, the proper cooling load and containers with 5% vent openings will be cooled and the cooling response will be much improved.

In addition to demonstrating proper cooling techniques, the demonstration unit has several important management factors incorporated. These management factors include the following: how to precool with forced-air cooling, block air bypasses, proper container vent opening area (5%), proper temperature monitoring and management, proper cooling time determination, and how to measure and use pressure drop readings. The cooling techniques and management factors will be illustrated at future on-farm demonstrations. Besides the hands-on educational experience, the unit provides producers with an example of a precooling system they could economically adopt for their operations.

The portable forced-air cooler appears to be a good demonstration unit that addresses the advantages of energy efficient techniques for postharvest cooling and handling of Florida fresh fruits and vegetables. Energy-use efficiency and grower profitability will be improved because proper postharvest handling helps maintain the quality and shelf-life of the produce, allowing for a surer market.

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STUDIES ON ONION SEED AGING

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Abstract. **Onion (*Allium cepa* L.) seeds are considered to be the shortest lived of all common vegetables. Scanning electron microscopic (SEM) studies were conducted to reveal the fine details of seed coat. The SEM observations of seed coat of onion showed that seed coat was shrunken and damaged. This shrinkage was associated with seed coat cracks where fungal infections were observed. Seed coat cracks and fungal infections were more pronounced near the hilum area. Onion seed embryo was noted to be situated under the protruding part of the seed coat, making it prone to mechanical damage and fungal infection.**

Seed coat is a structure of considerable importance for seed longevity, dormancy, and germination. Hard seed coats protect seeds from microorganisms, and temperature and humidity fluctuations during storage, (Halloin, 1986) and protects seed from hydration injury and electrolyte leakage during the germination process (Fig. 1), (Mohamed-Yasseen, 1991).

Seed aging can be defined as the progressive deterioration of the structure and function of seed which lead ultimately to the lose of viability (Mohamed-Yasseen, 1991). The onion seed is considered to be the shortest lived of all common vegetables. Onion seeds lose viability within two

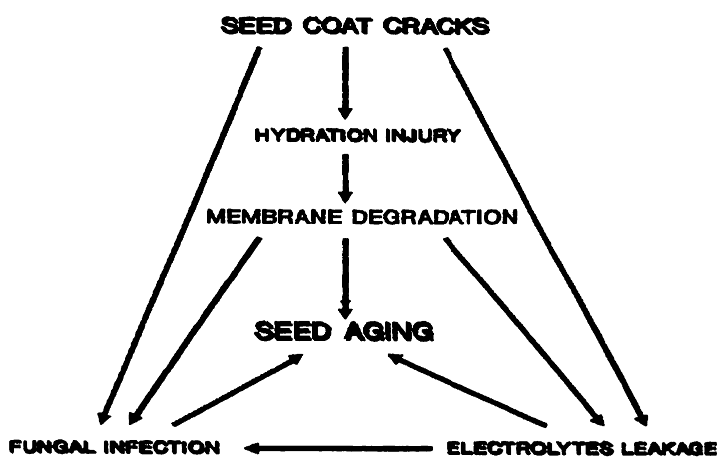

Fig. 1. Scheme to illustrate the role of seed coat in seed longevity.

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