Electrical energy consumption in refrigerated produce storages

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Perrin, P. W. 1988. **Electrical energy consumption in refrigeration produce storages.** Can. Agric. Eng. 30: 227–230. Electrical energy consumption by three different refrigerated produce storage systems was monitored over two storage seasons (22 mo). The jacketed storage was the lowest energy user with a mean consumption between 0.8 and 0.9 kW. The Humi-fresh storage had the highest mean consumption of about 2 kW. Monitoring proved effective in detecting a fault in the fan speed controller of a modified conventional storage which otherwise had a mean energy consumption of 1.1–1.2 kW. Energy consumption in all storages did not appear to vary markedly with load. However, the Humi-fresh storage showed a significant correlation of energy use in response to outside temperatures. Although satisfactory produce storage was achieved with both the Humi-fresh and jacketed storage systems, economy of operation would favor the latter, especially if controlled atmosphere storage were desirable.

INTRODUCTION

Maintenance of high quality in freshly harvested produce has been the object of numerous studies reported by Platenius (1939), Pentzer and Heinze (1954), Tomkins (1959), and Lutz and Hardenburg (1968). Consequently, to ensure high quality, a variety of different refrigerated systems has been developed. In warmer climates, such refrigerated systems may be used year-round, while in cool climates, they may be employed to ensure close temperature control or to supplement natural cooling.

It is well-known that in storing produce close to 0°C in mechanically refrigerated storages heat-exchanging systems with a temperature differential of more than 2–3°C remove considerable moisture from the air (Lentz et al. 1971; American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRACE) 1983), causing desiccation of the produce. One solution to this problem has been to package produce to reduce moisture loss (Hardenburg 1974). However, while effective in reducing moisture loss, this technique often limits air circulation around the produce and generates new problems ang and Hruschka 1977; Cheyney 1979). Consequently, a mber of systems have been developed to overcome this prob m of desiccation.

One of the first systems designed to minimize moisture loss utilized the gravity coil (ASHRACE 1980), a large heat exchange unit which relies on increased surface area and decreased temperature differential to achieve the required heat exchange capacity without extreme drying of the air. More recently, another system called a jacketed storage was developed to minimize moisture loss (van den Berg and Lentz 1971; Jorgensen 1974). This system places the cooling unit with circulating air behind the walls, floor and ceiling. These surfaces provide a large heat exchange area and, with adequate vapor barriers, moisture is retained within the room.

In an attempt to resolve the problem of water loss, other systems have been developed that use cold water as the heat exchange medium. One system, the ice bank (Neale et al. 1981; Lindsay et al. 1983), uses a relatively small refrigeration unit to create a reservoir of ice overnight (using low-cost electricity). This ice slowly melts as it cools water circulated over it. Air is passed over the chilled water as the water is dispersed by pumps over a large heat-exchange surface. The chilled and humidified air is then used to cool the produce with little moisture loss. A similar system, known as Humi-fresh (Meredith 1974), also cools water in order to cool and humidify the air, but the water is cooled by passing continuously over cooling coils. While this system is able to respond quickly to load demands, it requires a more powerful refrigeration system.

A third type of cooling system developed by Perrin (1985) was installed and tested at the Agassiz Research Station. This system utilized conventional refrigeration, but had a large evaporating coil which permitted a small temperature differential to be maintained between the air and coil while ensuring sufficient cooling capacity. A hot-gas bypass fed into the coil between the thermostatic expansion valve and the distributor to limit the extent of cooling of the coil. When maximum cooling capacity was not required, the fans were slowed by a solid-state controller as an aid to prevent desiccation. Finally, to maintain the relative humidity in the room, a centrifugal humidifier with electronic humidistat was installed. Hot gas was used for coil defrost.

In addition to the specially designed system, both a Humi-fresh and a jacketed system have been installed at Agassiz. The design of all three systems has been described and a comparison of their ability to store fresh produce has been reported (Perrin 1985). However, in order to evaluate the potential of these systems for commercial application, it was necessary to examine operational costs. Apart from the initial capital cost, the most important cost component is the power consumption. This report examines the power consumption of the three storage systems over two storage seasons and examines the relationship between power consumption and storage quality.

MATERIALS AND METHODS

Three storage rooms approximately 2.3 m wide × 4.7 m long × 3.3 m high were constructed side by side from panels of 10-cm polystyrene foam (U = 0.063) with 0.64-mm aluminum facing as previously described (Perrin 1985). All rooms were located inside a wood-frame building but the exterior of the ceilings and rear walls was exposed to an unheated area. The temperature of this unheated area was monitored and found to closely parallel outside temperatures, exceeding them by 10–12°C year round (Fig. 2). Room 1 was equipped with an externally mounted Humi-fresh Air Handler (Pressure Cool Co., Indio, Calif.), Room 2 was jacketed and Room 3 was equipped with a large but conventional evaporator coil and humidifier described above. Each storage system was subsequently equipped with watt-hour meters to monitor power consumption. For the Humi-fresh equipped room, two meters were used, one to monitor the consumption by the refrigeration equipment and a second to monitor consumption by the fan and pump. The values reported are the totals of both meters. A single meter was used to monitor power consumption by the blower and refrigeration equipment in the jacketed storage and a single meter was also used for Room 3. Each room was equipped with four 100-W incandescent lights which were operated for only a few minutes each week. Power consumption by the lights was not monitored. Power consumption by the principal system components was recorded weekly.

On 1 Oct. 1984, each room was loaded with about 450 kg of cabbage. In addition, each room contained about 250 kg of other produce. Rooms were all maintained at 1 ± 0.5°C and >95% relative humidity. Two days later, installation of watt-hour meters was completed and power consumption measurements were commenced on 3 Oct. 1984. Weekly readings were taken thereafter. On 26 Feb. 1985, produce removal commenced from the various rooms and was complete by 9 Apr. 1985. In September and October 1985, up to 250 kg of produce was again loaded into the Humi-fresh and the jacketed storages and on 1 Nov. 1985, the Humi-fresh and the conventional room were each loaded with about 2 t of fresh cabbage. The jacketed room received a 450-kg tote bin as in 1984. The cabbage temperature at the time of loading was about 5°C. This produce remained in place until 1 Mar. 1986 when the cabbages were removed from storage. All remaining produce was removed from storage by 10 Apr. 1986, representing two complete storage seasons.

The jacketed storage was shut down from 1 July to 27 Aug. 1985 and the conventional storage was not operated between 1 July and 27 July 1985. The solid-state fan speed controller for the conventional storage was repaired on 28 Feb. 1986.

RESULTS AND DISCUSSION

The mean monthly power consumption for each of the storage rooms is shown in Fig. 1. Clearly, the jacketed storage was the lowest energy user, followed closely by the modified conventional system. The Humi-fresh system consumed more than twice the power of the jacketed storage. A fault in the fan speed controller circuitry, which existed over a 10-mo period, resulted in a marked increase in power consumption by the modified conventional system. Examination, in January 1986, of the experimental data presented here led to discovery and correction of the problem. Monthly mean outside temperatures for the storage period are presented in Fig. 2.

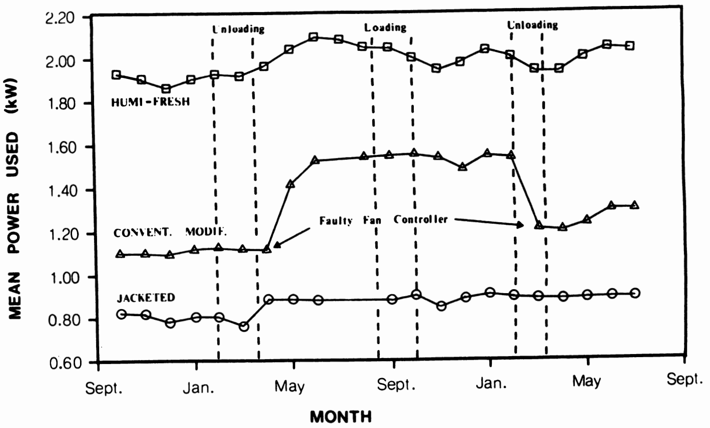

Figure 1. Mean monthly power use by three refrigerated storages beginning in October 1984. As a measure of variability of the weekly readings within months, an analysis of variance was performed. Standard errors of 0.0575, 0.0335 and 0.125 were obtained for the Humi-fresh, jacketed and modified conventional storages, respectively.

Except for the deviation caused by the faulty fan controller, power consumption by the rooms showed only small variations. For the Humi-fresh storage, this variation was sufficient to show a statistically significant correlation to seasonal temperature fluctuations (corrected $r^2 = 0.6025$). However, increased power consumption during the produce-loading period and decreased consumption during unloading periods was not reflected in the storage room energy use patterns. Outside temperatures influenced the Humi-fresh system to the extent that mean power consumption decreased at the rate of 16 W per week over the loading period and increased by 4-7 W per week during unloading. Door openings were infrequent and of short duration and would not account for this increase during unloading, although door openings would have a more pronounced effect on these relatively small chambers compared to commercial storages. Neither the jacketed nor the modified conventional storage showed significant response to seasonal temperature fluctuations (corrected $r^2 = 0.2634$ and 0.0599, respectively).

The obvious significant factor for the Humi-fresh system was the combined power rating of 6 kW for the refrigeration system components (Table I). The inherent inefficiency of chilling water for heat exchange with air would undoubtedly result in higher energy usage. The strong influence of outside temperature may be partly explained by the location of the Humi-fresh water chiller, which, although inside a minimally heated building, was external to the storage room. The chiller itself was constructed of fiberglass over 3.8 cm of polyurethane foam insulation. Exposure of the exterior of the rear wall and ceiling to unheated areas and the location of the compressors was the

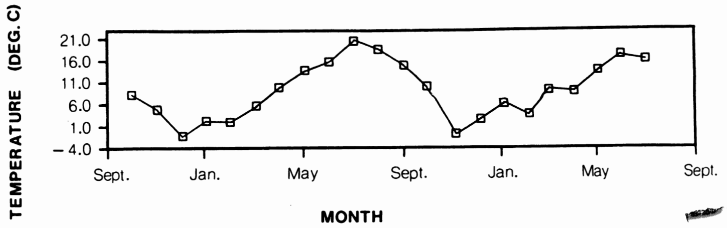

Figure 2. Mean monthly temperatures recorded outside at the Agassiz weather station beginning in October 1984.

Table I. Nominal power requirements (kW) for the components of refrigeration systems tested at Agassiz Research Station

System	Condensing unit	Air-circulation unit	Water pump/ humidifier	Total
Humi-fresh	3.75	1.5	0.75	6.0
Jacketed	2.25	0.75	—	3.0
Modified conventional	1.5	0.25	0.25	2.0

same for all rooms and does not account for the response to outside temperatures.

The modified conventional system was nominally rated at 2.0 kW (Table I), while the jacketed storage was rated at 3.0 kW. Consequently, the measured power consumption by these units cannot be explained on the basis of equipment power ratings alone. Undoubtedly, the inefficiency and reduced evaporator/room temperature differential imposed by the hot gas bypass in the modified conventional system, which also caused continuous operation of the compressor, resulted in higher power consumption by this unit. The cyclic operation of the compressor of the jacketed storage resulted in the lowest overall energy use by this system.

When these results are examined with respect to the earlier findings for vegetable keeping quality in the same three storages (Perrin 1985), the advantages of a small-scale jacketed system become even more obvious. In that study, the jacketed system proved to be equivalent to the other two systems in maintaining a 100% marketable yield of rutabagas after 24 wk of storage. In addition, parsnips gave the highest yield after jacketed storage, while the marketable yield of beets and carrots was higher than in the modified conventional system. Overall, the Humi-fresh storage yielded the highest marketable weights but produced the highest moisture losses as well. The after-storage yields must be examined carefully in light of these findings relating to energy consumption and the earlier observations of moisture loss. On the other hand, commercial experience with large-scale jacketed storages in Eastern Canada has revealed problems with vapor tightness and water entering underfloor ducts, while Australian users have criticized the limited potential for field heat removal (Giffels Associates Limited 1981).

Ultimately, however, the lower operating costs, the generally satisfactory performance and the relatively lower construction costs associated with Modified Jacketed Storages (Giffels Associates Limited 1986) may encourage the conversion of many existing conventional systems to jacketed systems. Moreover, a carefully constructed jacket could give sufficient gas-tightness to permit the simultaneous use of controlled atmospheres to further enhance the storage of many commodities.

CONCLUSIONS

There are few opportunities for the direct comparison of energy consumption in different storage systems and the approach adopted here provides insight into the energy use by three systrems operating under as close to similar conditions as practical. The results reinforce the knowledge that energy consumption does not necessarily show a direct relationship to the nominal rating of the refrigeration equipment and that system efficiency has a strong impact on energy use.

Energy use patterns showed no apparent relationship to storage room loading or unloading and only in the case of the Humi-fresh system was there any relationship to outside temperatures. This leads to the conclusion that for systems of this size and construction, the temperature differential between the inside and outside of the chamber has the strongest influence on energy use. Because of the relatively low inherent respiration rate of the produce both at time of loading and after cooling and because of the relatively slow (24 h) cooling period the produce load was not detected.

The lowest energy use by the jacketed system is apparently a reflection of the simplicity and efficiency of the refrigeration system around which the jacketed unit is built. Additionally, the earlier studies revealing low moisture loss from produce and above-average keeping quality would suggest that small jacketed systems (maximum 10 t) are an effective and efficient means of produce storage, where rapid field heat removal is not a strong requirement. Several small systems erected side by side could provide a grower with enough capacity, flexibility and suitable quality for cost effective storage of 6 mo for the vegetables tested.

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