Prevention of weight loss of pome fruit during CA and conventional storage

Ian Tuena
CA Refrigeration Pty Ltd

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RESEARCH PROJECT.

Project Number: AP97032

PREVENTION OF WEIGHT LOSS OF POME FRUIT DURING CA & CONVENTIONAL STORAGE

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INDUSTRY SUMMARY & RECOMMENDATIONS.

Cold storage is a significant infrastructure item in horticultural production. Few operations operate without some form of facility. Few facilities have more than basic control and are rarely cost effective operations. Key issues for consideration in the purchase and establishment of cold storage are:

- Choose reliable and well-represented contractors.
- Purchase equipment suited for the recommended tasks.
- Provide technical data of requirements.
- Carefully cost and determine that the outcomes desired are correct and realistic.
- Growers traditionally supply or sell their production on a bin delivered basis.
- Many packers sell their production on a packed weight basis. (Cartons & trays when packed).
- Production packed is sold regionally, nationally or internationally. In most cases all three.
- Few end users purchase in any other form than cents per kilo.
- The lowest grade production is processing and juicing and is still critically sold by weight.
- Respiration losses in produce are higher in some product types than others.
- Maturity holds a significant key into weight loss and the severity of such loss after harvest.
- There are many ways to eliminate losses of produced fruit types after harvest.
- Mechanical means of cooling requires a quick and adequate means of cooling the produce whether it be by the use of the cooling of air, ice, or hydro cooling. All however, require significant engineering to maintain correct outcomes.
- Rapid cooling however can create problems also in damaged cell and skin abnormalities.
- The industry has a varied understanding of the needs and requirements of coolstores and in turn waste vast amounts of their potential income.
• The seasonality of production will always require cool storage when faced with large production and marketing requirements that enable long periods to sell products nationally or international.

• Weight loss would be the highest cost loss of any farm-based activity in this country; few people care or know of the potential savings that are available.

• Most coolstore operators typically believe they are doing a great job and it is only the competition that is failing.

• This project and any future outcomes should be targeted at all industry sectors and bring recommendations and information transfer to the forefront of discussion markers so as to develop profitable product from paddock to consumer.

• The grower or cool store operator needs to take a far more active role in the operation of his or her facility. It is essential that when offering a new project out for tender that the operator must ensure that the refrigeration contractor has a full understanding of their requirements and the technical aspects required to ensure minimal loss of weight from the produce and if necessary, ensure a performance specifications is included for the project. Documentation from the refrigeration contractor should include:

  o System operating conditions.
  o Capacities and specifications of compressors, evaporators, condensers, TX valves, evaporator pressure regulators, and pipe work.
  o Total / sensible ratio of evaporators.
  o Room loading rate / 24 hours.
  o Airflow throughout room.
  o Design room temperature.
  o Alternative offers.
  o Design evaporating temperature.
  o Design air off temperature.

• It is most important the grower evaluates the data supplied and if unsure, seeks professional advice, as there are many pitfalls. Refrigeration systems and design are a dynamic science and when any one parameter is changed then all nominated capacities of the specified equipment will change. It is very difficult for the laymen to detect variations in tender documentation and their subsequent impact on the system operation. Price although important, should be the last criteria evaluated and although difficult, the grower needs to determine the best value for money options.

• There are many things which need to be considered if a high quality outcome is to be achieved, however, there is a financial benefit and a definite return on
investment for cool store operators who are prepared to closely monitor their facility and make the necessary adjustments to ensure a high quality product is produced at the point of sale.
TECHNICAL SUMMARY.

- Coolstores are a long-standing means to cool and store horticultural products.

- Modern process and techniques have and are changing.

- Industry has little chance to understand and manage this change and keep up the new technology.

- End users are demanding the highest quality produce and want consistent trouble free supply.

- Horticultural produce when incorrectly cooled and stored show significant detrimental affects on shelf life and influences follow up orders and customer satisfaction.

- Outcomes can be significantly increased when the correct understanding and positioning of equipment and mechanical inputs are made.

- Minimal cost is incurred in most cases to vastly improve outcomes.

- Weight loss can be significantly reduced.

- Weight loss can run as high as 6% in some produced crops with significant difficulties in long-term outcomes of difficulty to overcome.

- Cost effective control of energy and improved financial outcomes with input from this and other information from an ever-changing environment.

- Refrigeration design of this project is of 4 types:
  - Flooded ammonia including static coils
  - Recirculated ammonia
  - Direct expansion Freon / HCFC
  - Direct electronic expansion ammonia or Freon

- There have been some larger ammonia systems using direct expansion electronic TX valves installed in recent times and this has been possible with the advances in electronic TX valve design. This system allows for a lower capital expenditure when installing an ammonia system, however it does have limitations as mentioned later in this paper.

- Rooms and facilities including management are considerably different with facility capacity. They range from 400 to 8000 bins.

- Variable speed driven evaporator fans are fitted to a wide portion of coolstore facilities. This is not considered in this project or the collected information from participating operators.
NOTE:
Secondary Refrigeration Systems: Although often used in Europe, these systems are in fact rarely built in Australia, even though they can achieve significant benefits, provided careful equipment selection is made when the initial design is being drafted.

CASE STUDY SITES.
For the purpose of this study three (3) systems, which are currently widely used in the Goulburn Valley, were monitored for this paper.
INTRODUCTION.

In the mid 1990’s there was a change in the thinking of Goulburn Valley coolstore operators in the way they handled and stored their product. Growers and fruit handlers were continually costing infrastructure and developing facilities.

Pre-sizing, especially Pome fruit was developing rapidly which eliminated the requirement for additional storage and handling in most cases. This practice increased market acceptance by providing on time to order specifications.

Examples of fruit stored both in conventional and controlled atmosphere storage highlight the volume of weight lost from fruit bin capacities when removed from their holding chambers, full bins were now lower in volume than when placed in storage.

We were approached by various operators to further develop a strategy to minimize the less than satisfactory outcomes of this long-term problem.

Loss’s that have been and continue to restrict the industry for some time can now be addressed and a successful outcome be produced and transferred to all industry participants that are willing to take on the challenge of maintaining relative humidity and preventing the loss of horticultural weight loss and evaporating monetary returns.

Project activities have largely been based in the Goulburn Valley, Victoria, however the principals are identical in all horticultural commodities and storage facilities.
PROJECT WORK SUMMARY.

- Relative humidity loggers were purchased to monitor Pome fruit in storage.
- Monitoring initially concluded that testing would need to be expanded to determine an outcome that was to be relative to a broad range of operators.
- Monitoring continued for three (3) seasons primarily to support findings and allow for a greater understanding of the difficulties industry was facing.
- Transfer of technology activities included grower / packer group participation. Grower meetings and individual one on one discussion, this activity was of the utmost importance to allow for new results and technical advancements to be known by industry.
- Quality monitoring and testing had been undertaken after products were removed from storage. Tests included weight, firmness, texture and size.
- Research and development testing has been conducted and to date is still continuing where information continues to be of vital importance.
- Weight loss research has been undertaken in other agricultural areas, mainly the Australian Meat Industry, with exceptional measured outcomes to date.

HUMIDITY DATA MONITORING EQUIPMENT.

- The monitoring equipment has been chosen over other brands and types of equipment specifications, with durability, serviceability and back up of the utmost importance.
- Data retrieval software and programs and the accuracy of hard copy information had allowed for a trouble free annalistic period of information gathering.
- Ten (10) loggers had been purchased through the company and its supply base.
- Data monitoring is rarely used for relative humidity. Few operators if any continually monitor the performance of their equipment or facilities.
- Few people actually believe the retrieved information. Mistrust in the information is apparent and will take some time to overcome.
- Any future work in this area could well be monitored on a continuous basis with slight modification to current available data equipment.
RELATIVE MONITORING ACTIVITIES.

- Humidity testing has been carried out across a broad industry sector of both small and large operators. This testing regime has been conducted utilizing wide refrigeration parameters and differing session conditions and activities.

- Once the information had been retrieved consultation had taken place with the facility management team to outline findings and to discuss outcomes and industry improvements.

- Example 1 highlights the activities of the period of monitored data over 1 years collection

- Example 2 outlines typical information collected and is to be read in conjunction with appendix one. This information will be provided to show how data can be used by industry to improve outcomes and understanding of working conditions.

HARVEST.

- The objectives of this trial are to follow the movements of harvested product from the field to cold storage. Many growers have different views on best handling processes for their products. Examples are grower packers tend to be more aware of time frames from field to storage even if storage is to have product in a sheded area. Before cool storage takes place example 2 growers who generally supply packhouses don’t find it as important to deliver harvested product to storage and its not unusual to have found harvest product our of storage for 2 days.

- Weight loss occurs from the point of harvest and factors such as slow field movements, poor cooling techniques, incorrect coolstore stacking are all common difficulties, which prevent ideal outcomes and salability of products.

- Harvest maturity again holds enormous input to ideal outcomes. Respiration rates at high maturity are significantly higher than green or semi mature. This holds its own importance to weight loss and poor outcomes.
EXAMPLE 1.

A. 1997 – 1998 STORAGE YEAR.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Storage</th>
<th>Year</th>
<th>No of Loggers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packham Pears</td>
<td>Site 1</td>
<td>02/02/97</td>
<td>2</td>
</tr>
<tr>
<td>Williams Pears</td>
<td>Site 2</td>
<td>28/01/98</td>
<td>2</td>
</tr>
<tr>
<td>Packham Pears</td>
<td>Site 2</td>
<td>04/02/98</td>
<td>2</td>
</tr>
<tr>
<td>Beurre Bosc Pears</td>
<td>Site 3</td>
<td>06/02/98</td>
<td>2</td>
</tr>
<tr>
<td>Packham Pears</td>
<td>Site 4</td>
<td>06/02/98</td>
<td>2</td>
</tr>
<tr>
<td>Packham Pears</td>
<td>Site 5</td>
<td>06/02/98</td>
<td>2</td>
</tr>
</tbody>
</table>

B. 1998 – 1999 STORAGE YEAR.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Storage</th>
<th>Year</th>
<th>No of Loggers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packham Pears</td>
<td>Site 1</td>
<td>13/02/99</td>
<td>2</td>
</tr>
<tr>
<td>Williams Pears</td>
<td>Site 1</td>
<td>01/02/99</td>
<td>2</td>
</tr>
<tr>
<td>Granny Smiths</td>
<td>Site 2</td>
<td>15/03/99</td>
<td>2</td>
</tr>
<tr>
<td>Pink Lady’s</td>
<td>Site 2</td>
<td>28/04/99</td>
<td>2</td>
</tr>
<tr>
<td>Pink Lady’s</td>
<td>Site 4</td>
<td>29/04/99</td>
<td>2</td>
</tr>
<tr>
<td>Lady Williams</td>
<td>Site 5</td>
<td>14/05/99</td>
<td>2</td>
</tr>
</tbody>
</table>

PRECOOLING.

- Significant weight gains are to be achieved if adequate precooling is managed. Correct precooling is one of the most important functions to minimize weight loss. Ideally all incoming bulk fruit is to be managed through a precooling process. This process can be achieved in a number of ways, which is to be outlined further in this report.

- Precooling of pear types for controlled atmosphere storage can be the most important function of the pears storage life as bulk bin deliveries are to be capped in most cold stores. To help maintain moisture, precooling is necessary to cool fruit before capping, as heat transfer is too slow otherwise typical problems exist when on opening a C A room the last 1/3 of a bin is showing signs of ripening or in extreme cases break down of the fruit products. This problem is not uncommon. Fruit types should be cooled to +2°C ranging to
+5°C removed from the cooling chamber then capped and returned to cool storage.

- Precooling bulk fruit delivery’s takes on new meanings in the harvest peak. Often deliveries exceed mechanical capabilities of the facility, however deliveries continue to be made and pull down times increase, increasing the weight loss of all products.

- The temperature differential across the evaporator is too wide and limits the overall capacity of the facility and limits acceptable cooling.

- This practice is very common in the Goulburn Valley, I expect however this is an industry wide issue also. Not one easy repair however the need to adequately plan and cost facilities is essential.

**METHODS OF PRECOOLING.**

- Most common, placement of bulk fruit delivery’s spread across the floor of one or more rooms. This method is believed to be acceptable however; cold air short circuits across the tops of stacked bins and does not cool quickly any of the product in this chamber. Expensive loss of moisture can occur at this time and reduction in core temperature is slow in comparison to forced air-cooling.

- Force air cooling is more common in this region and has been used extensively with Williams Pears and Packham Pears and now stone fruit.

- This method is time consuming to set up and remove however with adequate capacity is very efficient and if managed correctly limits loss of moisture and weight. Force draught cooling in poorly managed facilities can however increase weight loss through air movement over and through the product in excess of the desired speed and temperature difference which draws additional moisture from product.

- Additional relative humidity data needs collection in the precooling of fruit types to adequately assess the precise mode of cooling for the best outcomes.

- Hydro precooling is not common in the fruit industry of this country. South America and USA utilize this method extensively with continued successes. The vegetable industry and stone fruit industry are increasing their needs to Hydro cool and have excellent outcomes. This method does not always suit all products i.e. pears as dip materials are not suitable to cold water or fruit so the opportunity to hydrocool Pome fruits in our conditions are not practical in all cases.

- Fruit cool stores built in Australia to date have generally been designed to perform to specific temperature and heat loads imposed upon them by the orchardist or his representatives. Very few coolstore operators have the technical background or the resources to fully evaluate tender submissions or
the technical merit of various quotations received for a fruit coolstore construction and therefore price tends to be the overriding factor in determining the successful contractor.

- The net result of this style of project evaluation is that the coolstore can often reflect the poor assessment of the project with subsequent, less than acceptable out turns of produce from the facility. The major problem is weight loss from the fruit which impacts on both the physical appearance of the fruit and the net return to the grower or wholesaler.

- This paper will try to evaluate and quantify the net impact of fruit weight loss in post harvest storage and takes into consideration the equipment used, the climatic conditions prevailing at the time of harvest and cost benefits associated with good equipment selection and pre-building evaluation.

- There are significant returns on investment and savings in ongoing operational costs if careful consideration is made when selecting equipment for fruit cool storage.

- There is currently a wide variance in weight loss for coolstores within Australia and there are many factors which need further investigation to ascertain their true impact on the net weight loss whilst fruit is held in storage, however there is abundant evidence that the primary determining factor for weight loss is the refrigeration system.

TECHNOLOGY TRANSFER.

This project clearly points out that knowledge of relative humidity and psychometrics is not clearly understood. Continued data collection that has the capabilities to transfer accurate data to operators is essential. This enables the operator to deal with the issue of continued moisture loss and the hidden financial impacts that are clearly adjoined to this problem.

Meetings between project facility managers had taken place throughout the two-year period of data collection. Continuous contact with project participants takes places frequently as the facilities are continually upgraded as technology changes and coolstore operators understand the benefits.

A recent field day conference had been held with a number of both Stone and Pome fruit producers, key packers, industry field personnel consultants and industry materials providers in attendance. The ½ day seminar had been held in the Goulburn Valley.

Further information transfer has been undertaken in the Swan Hill area with stone fruit growers, packers, and cool store operators on a number of occasions over the past two years.

Training and information periods have been conducted with five field technicians including apprentices. The two-hour sessions have been highlighting the principal of relative humidity and the disadvantages industry face when faced with the ongoing presence of this issue of weight loss.
The informal discussions have been important as technicians in the Goulburn Valley regularly maintain facilities in this and other growing regions.

NETWORKING.

- Whilst carrying out this project many opportunities arose to meet and discuss matters relative to this project. Growers, operators, and markets all have a key stake in moisture loss and on every occasion Healthy discussion has taken place so as to have a greater understanding of the problems with greater awareness an outcome.

- One on one discussion is the key element of information transfer as each outcome has a very different starting point and mechanical input.

EXPANSION.

- 1999 has seen a self-funded expansion of this type of project, which has seen typical type of data collection from the processed meat industry. This operational structure has been based upon export and national throughput and on current findings with clear goals and outcomes with overwhelming client outcomes. Gains in weight and financial outcomes have seen payback on expenditure within a 12-month period.

- Financial input has been in excess of $ 500,000.00 with immediate outcomes for the processor and end user.

- This work continues to be useful as information gathered and the network of people and companies interested in developing and improving outcomes continues in Shepparton and other horticultural districts.
PROJECT WORK: SUMMARY, METHODS AND RESULTS.

SITE 1: 400 BIN X 2 ROOMS DIRECT EXPANSION R22 SYSTEM.

- TOTAL STORAGE: 800 bins.
- STORAGE: Conventional style air storage using mechanical style TX valves with backpressure regulation.
- FRUIT: Packham Pears
  Beurre Bosc Pears
  Granny Smith Apples
  Williams Pears.

SITE 2: 400 BIN X 9 ROOMS AMMONIA LIQUID RECIRCULATION SYSTEM.

- TOTAL STORAGE: 3,600 bins
- STORAGE: CA rooms using Store Fresh Propane type system. Refrigeration control using manual expansion valves and liquid feed solenoid with evaporator pressure regulators fitted with dual function operation (High load fully open mode & Storage modulation mode) 4 rooms were fitted with variable speed drives (VSD’s) to evaporator fan motors.
- FRUIT: Williams Pears
  Packham Pears
  Granny Smith Apples
  Pink Lady Apples.

SITE 3: COMBINATION SITE: 2 STYLES OF SYSTEMS.

SYSTEM 1: 400 BINS X 7 ROOMS DIRECT EXPANSION R22 SYSTEM.

- TOTAL STORAGE: 2,800 bins.
- STORAGE: CA Rooms using oxygen scrubber with evaporators fitted with mechanical TX Valves and back-pressure regulation, with dual function operation (High load fully open mode & storage modulation mode)
- FRUIT: Williams Pears
  Packham Pears
  Granny Smith Apples
  Pink Lady Apples.
SYSTEM 2: 400 BIN X 6 ROOMS AMMONIA LIQUID RECIRCULATION.

- TOTAL STORAGE: 2,400 bins.
- STORAGE: CA Rooms using oxygen scrubber refrigeration control using manual expansion
- FRUIT: Williams Pears
  Packham Pears
  Granny Smith Apples
  Pink Lady Apples.

SITE 4: 400 BINS X 16 ROOMS AMMONIA LIQUID RECIRCULATION.

- TOTAL STORAGE: 6,400 bins
- STORAGE: C.A rooms using Store Fresh Propane type system. Refrigeration control using manual expansion valves and liquid feed solenoid with evaporator pressure regulators fitted with dual function operation (High load fully open mode & Storage modulation mode). There were 4 rooms fitted with bare pipe ceiling coils 5 rooms fitted with large capacity induced draught evaporators and 4 rooms fitted with smaller forced draught evaporators. There were also 3 working rooms which were liquid recirculation and forced draught evaporators. These rooms processed all packing lines and cartoned fruit ready for dispatch.
- FRUIT: Williams Pears
  Packham Pears
  Nectarines
  Plums
  Peaches
  Granny Smith Apples
  Pink Lady Apples.

SITE 5: 400BINS X 2 ROOMS DIRECT EXPANSION R22 SYSTEM.

- TOTAL STORAGE: 800 bins.
- STORAGE: C.A rooms using Store Fresh Propane type system. One room was fitted with mechanical TX valves; the other was fitted with Danfoss electronic TX valves. Both rooms were with evaporator pressure regulation and C A facility.
- FRUIT: Packham Pears
  Nectarines
  Plums
  Peaches
  Granny Smith Apples.
EXAMPLE 2.

SITE 1: 400 BIN X 2 ROOMS DIRECT EXPANSION R22 SYSTEM.

EVALUATION.

Work practices when receiving hot fruit from the orchard to be placed into cool storage involved first placing the fruit into a pre-cooling room for up to 12 hours, and then putting this fruit into the storage room.

This is an acceptable and well-proven method to pre-cool fruit prior to it entering the storage facility. The refrigeration theoretical capacity was in excess of the actual loading rate of the room and the system was relatively well balanced. The evaporator’s capacity matched the compressor capacity. The system had evaporator pressure regulation and featured a wide fully open valve function, when loading the room.

The evaporating pressure/temperature - 6°C to -10°C when the evaporator pressure regulator was set on fully open and the system was operating in pull down mode.

- Room storage temperature = 0°C
- Relative Humidity Average Year 1 = 82%
- Relative humidity Average Year 2 = 86%

WEIGHT LOSS.

The average weight loss experienced over 2 seasons at this site was approximately 5.3% in year 1 and 4.0% in year 2.

Estimated yield loss for year 1 was approximately:

\[
\text{Estimated yield loss for year 1 was approximately:} \\
450kg/bin \times 5.3\% = 23.85kg/bin \times 780 \text{ bins} = 18,603kg \\
18,603kg @ \$ 0.50 \text{ average return to grower} = \$ 9,301.50 \\
or \$ 27,904.50 \text{ if using this as the average loss over a trial period of 3 years.}
\]

Estimated yield loss for year 2 was approximately:

\[
\text{Estimated yield loss for year 2 was approximately:} \\
450kg/bin \times 4\% = 18kg/bin \times 780 \text{ bins} = 14,040kg \\
14,040kg @ \$ 0.50 /\text{kg average return to grower} = \$ 8,520.00 \\
or \$ 25,560.00 \text{ if using this as the average loss over a trial period of 3 years.}
\]

Site one management procedures for fruit received appeared to be reasonable and well structured. Relative humidity readings appeared to be unusually low, although the system parameters were altered for year 2, which achieved a 1.3% improvement on yield weight.

There was still excessive moisture being removed from the produce, which consequently reflected such losses in physical appearance and net yield after storage.
Investigation into the coil circuitry revealed incorrect circuitry for operating temperatures and the coil blocks were subsequently changed at the end of this season.

Early indications are that this site has much improved operating conditions within the room with a more stable temperature regime and higher relative humidity.

**CONCLUSION.**

It would appear that the coil geometry has played a significant role in the poor performance of this facility in regards to weight loss whilst the fruit is in storage. The high initial weight loss in year 1 was rectified only marginally with adjustment to evaporator pressure regulator and the superheat adjustment on the thermostatic expansion valves (TX Valves). The temperature tended to fluctuate throughout the room and it was difficult to maintain an even temperature distribution within the room. The higher pressure drop within the evaporator coil consequently caused a lowering of the evaporating temperature within the coil and therefore resulted in a high diffusion through the coil and more moisture being stripped out of the air circulating within the room. Thus decreasing the relative humidity within the room and increasing the subsequent high transpiration rates held in storage, resulting in high weight loss of product stored. Further monitoring is required from the site to ensure that the new coil geometry installed produces the desired results.
SITE 2: 400 BIN X 9 ROOMS AMMONIA LIQUID RECIRCULATION SYSTEM.

EVALUATION.

This site used its facility to cool down and store fruit for cannery purposes on short-term storage of Williams Pears and also for long term storage of Packham Pears, Pink Lady Apples and Granny Smith Apples. There was little or no pre-cooling done on site and the majority of the coolrooms were fully loaded with “hot” fruit either straight from the orchard or from cannery delivery trucks.

The refrigeration capacity in each room exceeded the theoretical capacity of the room loading. All rooms were fitted with water defrost, evaporator pressure regulation, liquid solenoid feed control and the entire system was linked to a PLC which fed data directly into the office based PC operating an “Adroit” Scada package which had full data logging and supervisory capacity. The system was an ammonia liquid recirculation system. The refrigerant evaporating temperature was -6°C to -10°C when the facility was under full pull down load and each room was subsequently raised to -3°C when the rooms required long storage mode. Relative humidity ranged from 85% on pull down mode through to 98% on storage mode after the fruit core temperature pulled down to approximately 0.5°C. Temperature and relative humidity remained relatively stable throughout the trial period.

The average weight loss over a 3-year period on site 2 tended to reflect some inconsistency, which may be attributed to seasonal climatic conditions. Certainly the smaller sized fruit, particularly pears had a higher weight loss ratio than that of the larger fruit sizes. This is most likely due to the higher surface / to volume ratio in smaller fruit.

Most short term fruit (i.e. fruit stored for cannery purposes over a 6 to 8 week period), showed signs of weight loss. As mentioned earlier, there was a degree of inconsistency with this site with some bins within the room losing up to 3% and some bins losing nothing at all.

There is some anecdotal evidence that the orchard irrigation program had an impact on the rate of moisture loss in that there were some bins that showed a higher weight loss (1.2%) than the room sample average and the bins that indicated this loss had been picked from a block that had very recently been irrigated, which was felt consequently raised the internal water vapour pressure of the fruit, thus increasing the transpiration rate. However, more work needs to be conducted into this area in order to establish a direct correlation if any.

WEIGHT LOSS.

The average weight loss experienced over site 2 was approximately 1.8% and was relatively consistent for the three (3) years of the trial period. As previously mentioned, some bins showed a higher rate of weight loss, yet some bins indicated minimal weight loss. If we take the average weight loss for this site of 1.8%, the cost estimation for this is:
Estimated yield loss was approximately:

\[
\frac{450\text{kg}}{\text{bin}} \times 1.8\% = 8.1\text{kg/bin} \times 3,600\text{ bins} = 29,160\text{kg}
\]

\[
29,160\text{kg} @ \$0.50 \text{ average return to grower} = $14,580.00
\]

\[
or \quad $43,740.00 \text{ if using this as the average loss over a trial period of 3 years.}
\]

CONCLUSION.

Site 2 represented some diversity in the cool storage facility usage with the rooms being turned over twice for the year. The cannery stored Williams Pears were stored for a relatively short period and it was generally felt that the short-term nature of the storage reflected the lower weight loss for this site. The rooms were well catered for with refrigeration capacity, which appeared to assist with the control of weight loss. The evaporating pressure was altered during pull down which effectively increased the capacity of the room evaporators, which subsequently reduced the cooling period for the fruit, which again assisted with the control of weight loss.

As the facility was turned over twice it meant that the fruit that was to be stored for a longer period of time was put into storage when the ambient temperature was lower and thus the initial pull down load was less and the time frame to pull the fruit down was also less. This meant that exposure time to lower evaporating temperatures and lower vapour pressure within the surrounding air was also reduced. Hence the subsequent lower weight loss average per bin for this site.
SITE 3: COMBINATION SITE: 2 STYLES OF SYSTEMS.

EVALUATION.

This site used its facility to cool down and store fruit for cannery purposes on short-term storage of Williams Pears and also for long term storage of Packham Pears, Pink Lady Apples and Granny Smith Apples. There was little or no pre-cooling done on site and the majority of the coolrooms were fully loaded with “hot” fruit either straight from the orchard or from cannery delivery trucks.

This site had two of systems on the site. System 1. was a direct expansion Freon 22 System fitted with standard TX Valves and evaporator pressure regulation. System 2. was an Ammonia Liquid Recirculation System. The rooms were also utilised for the short-term storage of cannery fruit. Both systems utilised a similar pull down mode to that employed at site 2, whereby the rooms were filled quickly then allowed to pull down to temperature and minimal pre-cooling of the fruit prior to storage was conducted. The site did however use a forced draught pressure cooler for some produce.

The rooms evaporating temperature varied from -10°C sst to -6°C sst on pulldown mode with the evaporator pressure being raised to -5°C on the Freon rooms and -3°C on the ammonia rooms once the produce core temperature had been reached. Relative humidity for this site varied between 72% and 80% with a room temperature of –0.5°C to +0.5°C.

WEIGHT LOSS.

The average weight loss experienced over this site was approximately 4% for pears over the 3 seasons with the yield loss for apples being approximately 2.8%. Storage ratio was 60% apples / 40% pears.

Storage loss for pears:

\[
450kg / bin \times 4.0\% = 18.0kg/bin \times 1,600\ bins = 28,800kg
\]

\[
28,800kg @ $ 0.50\ average\ returning\ to\ grower = $14,400.00
\]

or $43,200.00 if using this as the average loss over a trial period of 3 years.

Storage loss for apples:

\[
400kg / bin \times 2.8\% = 11.2kg/bin \times 2,400\ bins = 26,880kg
\]

\[
26,880kg @ $ 0.50\ average\ returning\ to\ grower = $13,440.00
\]

or $40,320.00 if using this as the average loss over a trial period of 3 years.

The total combined loss of earnings over the 3-year period is $ 83,520.00
CONCLUSION.

Like site 2 there was some diversity in the facility usage. Again the rooms were turned over twice for the year with cannery fruit being stored at the start of the season and CA fruit being stored later in the season. The Freon rooms had reasonable refrigeration capacity, however it would appear that the ammonia room coils were not performing to full capacity, hence the evaporating pressure was lowered below acceptable levels during pull down. The result was a higher weight loss ratio for this facility. This is most likely due to the air within the store having a lower relative humidity 72 – 80% therefore the transpiration rate within the fruit to air seems greater. It would appear that although one system is liquid recirculation, more thought is required within the system as to its operating parameters as there appears to be similar weight losses in both systems and theoretically the ammonia plant should perform better than the Freon plant. However, this is currently not the case.
SITE 4: 400 BINS X 16 ROOMS AMMONIA LIQUID RECIRCULATION.

EVALUATION.

This site processed fruit primarily for the fresh fruit market – the management procedure for pears was that the fruit was pre-cooled in high capacity coolrooms using Forced Air Cooling and then placed in ceiling coil style rooms for long storage. Apples were placed in high capacity coolrooms for pull down then placed in rooms fitted with Forced Draught Evaporators. This management system meant that the fruit most susceptible to weight loss was placed in rooms with the highest RH (i.e. cooling coil style rooms) and the fruit least susceptible to weight loss (i.e. granny smith apples) were placed in rooms with a lower RH (i.e. Rooms fitted with Forced Draught Evaporators). This management style certainly had significant benefits with the weight loss in the fruit being consistently lower and the RH within the room being higher – 80 to 90%.

The rooms evaporating temperature ranged from –5°C on pull down mode to –2°C on storage mode. The system had a PLC control operating with a Wizcon Scada Package.

It was most interesting to note that at this site the operator would note the amount of times each room solenoid was turned on and then adjust the evaporator pressure regulator accordingly. In some instances this reduced the room cycling from 160 times per day to 8 times per day and at times even less. Initial investigations tend to suggest that if the evaporative pressure regulator is not adjusted correctly then the air only was cooled within the room and not the bulk mass of fruit. However, once the bulk mass of the fruit is cooled, then the room tends to stay “off” for a considerably longer period of time. This tends to stabilise all conditions within the room and this produced an excellent outcome for the room.

WEIGHT LOSS.

The average weight loss for the site was the lowest of all sites averaging 1.5% for pears and less than 0.8% for apples. However, there were still some rooms that the weight loss was as high as 2.4%, which we feel was attributable to evaporator capacity being to small and therefore the evaporator pressure regulator needing to be set at a lower setting which caused a higher diffusion through the coil increasing the coil capacity and decreasing the room RH, thus increasing weight loss.

Storage loss for pears:

\[
450\text{kg} / \text{bin} \times 1.5\% = 6.75\text{kg/bin} \times 2,400\text{ bins} = 16,200\text{kg}
\]

\[
16,200\text{kg} @ \$ 0.50 \text{ average return to grower} = \$8,100.00
\]

or \$ 24,300 if using this as the average loss over a trial period of 3 years.
Storage loss for apples

\[400\text{kg/bin} \times 0.8\% = 3.2\text{kg/bin} \times 4,000 \text{ bins} = 12,800\text{kg}\]

\[12,800\text{kg} @ $ 0.50/\text{kg average return to growers} = $ 6,400.00\]

or \$ 19,200.00 if using this as the average loss over a trial period of 3 years.

The total combined loss of earnings over the 3-year period is \$ 43,500.00

**CONCLUSION.**

Site 4 involved some excellent management practice that enhanced the fruit quality and assisted in reducing the weight loss from the facility. The use of large capacity evaporators to pre-cool the fruit and then the placement of the fruit most susceptible to weight loss i.e. pears into rooms with low temperature diffusion (coil rooms) ensured this facility a successful outcome.

The use of trending graphs and key issue reporting assisted in making good and measurable adjustments to the refrigeration equipment. Again it was reiterated that the relationship between cooling incoming fruit quickly and ensuring the refrigeration system operates with the highest possible relative humidity within the rooms is imperative for a good outcome. It was evident that rooms fitted with small capacity evaporators necessitated the need to run at a lower evaporating temperature and therefore lower relative humidity, hence higher weight loss.
SITE 5: 400BINS X 2 ROOMS DIRECT EXPANSION R22 SYSTEM.

EVALUATION.
Site 5 was almost identical in configuration to site 1 with the one exception being that one room was fitted with a standard TX valve and the other with an electronic TX valve. There was no pre-cooling conducted on this site with Packham pears being the main product stored. There was a CA facility installed using a store fresh type unit. The refrigeration capacity was in excess of the loading rate with the evaporating temperature operating between -8°C sst and -6°C sst.

WEIGHT LOSS.
The average weight loss for this site was approximately 4.4% with no significant difference between the two rooms.

Estimated yield loss:

\[
450\text{kg/bin} \times 4.4\% = 19.8\text{kg per bin} \times 780\text{ bins} = 15,840\text{kg}
\]

\[
15,840.00\text{kg} @ $ 0.50/\text{kg average return to grower} = $ 7,920.00 \text{ per annum}
\]

or $ 23,760.00 if using this as the average loss over a trial period of 3 years.

CONCLUSION.
It would appear that there may be some grounds to more accurately record the ongoing performance of this facility, paying particular attention to the relationship of the air off the coil, the air on the coil and the diffusion throughout the coil and to establish the comparison between the evaporator fitted with electronic TX valves and the evaporator fitted with standard TX valves.

There is evidence that there is a better performance from the room fitted with the electronic TX valve, however a standardised procedure needs to be developed when loading both rooms to ensure that base 0 is identical for both rooms, the ongoing data collection and monitoring to evaluate the difference in performance for each room.
SUMMARY.

Weight loss in fruit has been an ongoing problem for many years and there have been many attempts to resolve the various root causes of these problems. Some of the solutions have technical merit and some have a certain element of myth about them. Most growers however stumble across good storage practices rather than develop them specifically with their refrigeration contractor.

For each storage facility and the varying climatic conditions presented by each season – i.e. dry, hot, cool, wet, etc. – most growers supply little if any technical specifications required for their facility and they invariably rely on the refrigeration contractor to provide their solution at the lowest base cost.

The refrigeration contractor on the other hand tends to focus on the specific cooling loads imposed by the produce and fails to grasp the true requirements of the facility or orchardist. The net result is a facility that is functional and cools the product, then stores the product in conditions that are less than acceptable if high quality outcome is required.

Most cool store facilities fail to identify clearly the key criteria required for the storage of high quality produce and also fail to ensure that the ongoing operating parameters are monitored and either maintained or adjusted accordingly. The primary interest from both the grower and the maintenance personal is that of temperature. However, focusing only on temperature often comes at the expense of other criteria i.e. relative humidity and prevailing climatic and season conditions. For example – If the incoming crop has a high level of rust then more care is required in storage as rust affected fruit is susceptible to high moisture transpiration or weight loss rates. Thus the refrigeration system must be able to be adjusted to ensure that the optimum conditions are met within the cool store and the operations manager must avoid at all costs putting such fruit in a room that had lower relative humidity – a ceiling coil style room would be more suitable for this product than a Forced Draught or Blower room.

In all facilities studied for this paper, all growers’ aims were very similar – they all wanted the best possible outcomes for their product. In all but one facility, the growers fully understand the mechanics and the fundamental requirements of their stores that enable them to achieve the best outcome for their facility. Each grower had varying levels of expertise ranging from good to poor. It is therefore imperative that growers who are operating a cool storage facility gain a better understanding of these fundamentals if they are to improve the outturns from their cool stores.

There are many things that cool store operators must consider when storing fruit. They must also constantly monitor the cool rooms if they are to achieve the best possible outcome from their facility, especially if the product has a high moisture content and are susceptible to weight loss. This process must be instigated at the initial planning of any cool storage facility that intends to store fresh fruit or vegetables.
RESEARCH AND DEVELOPMENT ACTIVITIES.

PHYSICAL LAYOUT.

Stable temperature within the cool store is imperative. Humidity and temperature are inversely proportional as the temperature within a given space rises, then the relative humidity will fall. The same can be applied to a cool room, which increasing the temperature and reducing the relative humidity results in increasing the transpiration rate of the product. Where ever possible in cool storage layout should consider the following:

INSULATION THICKNESS & THERMAL CONDUCTIVITY.

Use materials that have a poor heat transfer coefficient (don’t transfer heat). This may be thicker “sandwich” panel or use polyurethane rather than polystyrene.
Insulate the floor.
Fit air curtains or automatic closing doors.
Lay out complex with the least amount of wall area facing the western sun.
Fit external cladding to portal frames.
Ventilate ceiling space.

SHED MANAGEMENT.

Pre cool fruit before placing in storage.
Don’t leave fruit exposed to ambient conditions, particularly the sun.
Don’t leave fruit out in field.
Use Forced Air Coolers to reduce field heat.
Use hydro cooling to reduce field heat.
Evaluate incoming varieties and conditions. Don’t place varieties like Golden Delicious Apples or Beurre Bosc Pears in rooms with low humidity. Remember russeted fruit is subject to high moisture loss.

REFRIGERATION DESIGN.

The evaporator (IDC, FDC, Ceiling coils). The evaporator circuitry, surface area, capacity, temperature difference across the coil (diffusion) and air volume all impact on the storage of fresh fruit and need careful consideration. I.e. A small evaporator with a large diffusion through the coil can have exactly the same capacity as a large evaporator with a small diffusion through the coil. However, if weight loss is a consideration, then the later is by far the better selection, but will come at initially a higher capital cost.
Conventional air coolers will inevitably reduce moisture from the air stream as it passes through the cooler and direct expansion systems further complicate this issue, as there are physical limitations, which must be met in order for the refrigerant control device to operate.

A standard TX valve configuration would require a minimum of 6k superheat for the valve to work with any degree of accuracy and efficiency. Thus a chiller temperature of 0°C would require a refrigerant evaporating temperature of -6°C or lower in order for the valve to function properly. However, if our objective is to remove the least amount of moisture from the air within the cool store, then we need to raise the suction or evaporating temperature, which in turn will cause the TX valve to function erratically. In doing this we are locked into a scenario that will automatically remove more moisture from the cool store than we would deem as ideal.

To overcome this scenario, wetted surface heat exchangers were introduced, but not without their own limitations. They can also strip moisture from the air if the water or glycol mixture is at a temperature below the dewpoint of the air passing through it and so again caution is required when making the evaporator selection.

The most important aspect of evaporator design for high humidity rooms is the total heat to sensible heat ratio of the evaporator. We need this ratio to be as low as possible if we are to ensure a high relative humidity. It was evident from our trials that the rooms that had the highest relative humidity and the lowest weight loss were the rooms that were fitted with evaporators that had a low total sensible ratio.

**COMPRESSIONS.**

Big is not necessarily better when it comes to compressor selection. The most important aspect of this component is that the compressor capacity has the ability to match the evaporator capacity, at all times. In layman terms, this means that as the load increases, then so does the compressor capacity and as the load decreases, again, so does the compressor capacity. In doing this, the suction pressure or evaporating temperature remains constant at all times. Plants with multiple sized compressors or plants fitted with Variable Speed Drives (VSD’s) on their compressors significantly assist in this issue. In contrast, plants with single compressors with nil or limited unloading will reduce the evaporating temperature. This causes moisture to be stripped out of the air as it passes through the evaporator, regardless of the total / sensible ratio, by virtue of the fact that the evaporator is now operating at a lower temperature. Caution should be taken when operating screw compressors as although they are able to vary their load from 10 – 100% in 1% increments, their co-efficient of performance is significantly reduced once they start to operate under 55% load and therefore become costly to run in comparison to their refrigeration output.

Again it was demonstrated throughout this trial that those cool stores who monitored their suction pressure and adjusted their plants accordingly, receive a better return with their produce than their counterparts who did not do this.
PIPEWORK & CONTROLS.

It is extremely important to avoid excessive pressure drop in the pipe work installed throughout the systems. If there is any significant pressure drop, particularly in the discharge or suction line, the refrigeration capacity is reduced and poor performance is a result. The use of evaporator pressure regulators ensures that the evaporator temperature does not drop below the evaporator design requirements. If they are fitted in conjunction with electronic TX valves, then it is possible to again narrow the operating range of the evaporator to ensure optimum performance is maintained at all times. However, there are some limitations which cannot be avoided due to the TX valves minimum superheat requirement.

Variable Speed Drives (VSD’s) fitted to evaporator fans also assist in reducing the sensible load upon the room once the room has been achieved to operating or storage temperature.

A data logging system that measures and plots the following:

- Temperature of air on the coil
- Air off the coil
- Suction pressure at the coil
- The number of times that the liquid line solenoid valve is energised per day of operation.
- Relative humidity from each room

Is an important management tool as one can see the results of any parameters that have been altered or changed and allow the operator to adjust the plant to achieve the best possible outcome for the facility.
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APPENDICES.

APPENDIX 1: DATA LOGGING GRAPHS.
APPENDIX 1.1 RELATIVE HUMIDITY IN PEARS DURING LONG TERM CONTROLLED ATMOSPHERE STORAGE.

Diagram 1.1A Relative Humidity Chart.

Diagram 1.1B Temperature Chart.
EXPLANATION.

- Chart shows spikes relative to additional defrost periods within a 24 hour period.

- Ammonia recirculation plant loaded without precooling. Block staked each bin is capped with a plastic bin liner.

- No operator input or checks procedure of humidity or control.

- No additional water added to the chamber either by jets or water over floor area.

- Temperature had been running at 2°C, which was felt not to be ideal. Clients were notified and adjustments made.

- PM3 back pressure regulator fitted.
APPENDIX 1.2. RELATIVE HUMIDITY IN PEARS MEDIUM TO LONG TERM CONTROLLED ATMOSPHERE STORAGE.

Diagram 1.2A Relative Humidity Chart.

Diagram 1.2B Temperature Chart
EXPLANATION.

- Chart show little movement over logged period, limited defrost period.

- Freon TX valve manual not electronic loaded with precooled product. Bins are block stacked with each bin being capped with a plastic bin liner.

- No operator input or check procedure of humidity or control.

- Water added to chamber floor and kept to a level of 50mm.

- Temperature running at 0°C.

- PM3 back pressure regulators fitted.
APPENDIX 1.3. RELATIVE HUMIDITY IN APPLES MEDIUM TERM CONTROLLED ATMOSPHERE STORAGE.

Diagram 1.3A Relative Humidity Chart.

Diagram 1.3B Temperature Chart.
EXPLANATION.

- Chart shows highest readings of relative humidity in project.

- Freon TX Valve manual not electronic, loose stacked each bin is not capped, loaded with the precooled fruit from an additional cooling room.

- No operator input or check procedure of humidity or control.

- Water added to chamber floor and kept at a level of 25mm. Water is not generally added to C A rooms of apples in the Goulburn Valley.

- Temperature running at 1°C.

- PM3 backpressure regulators fitted.
APPENDIX 1.4. RELATIVE HUMIDITY IN APPLES MEDIUM TERM CONTROLLED ATMOSPHERE STORAGE.

Diagram 1.4A Relative Humidity Chart.

Diagram 1.4B Temperature Chart.
EXPLANATION.

- Chart shows significant spikes with poor control and subsequent outcomes.
- Ammonia liquid recirculation, loaded without precooling, block stacked and bins not capped.
- No operator input or check procedure of humidity or control.
- No additional water added to chamber either by jets or water over floor area.
- Temperature operating up to 4°C with poor control and subsequent outcomes, differential set to wide of temperature control equipment.
- PM3 backpressure regulators fitted.
- Multi use site chillers and freezers operate from same plant room.
APPENDIX 1.5. RELATIVE HUMIDITY IN APPLES LONG TERM CONTROLLED ATMOSPHERE STORAGE.

Diagram 1.5A Relative Humidity Chart.

Diagram 1.5B Temperature Chart.

EXPLANATION.
• Chart shows erratic movement for 3 days. This had been caused by movement of data logger from room to be monitored to outside in passageway.

• Ammonia flooded system operating on electronic liquid level controllers. Blocks stacked with no plastic caps on bins.

• Operator input for some control of relative humidity.

• Water added to chamber floor and kept to a level of 25mm.

• Temperature running at 0°C to 1.5°C wide differential setting.

• This site has shown to be the best coolstore for control of relative humidity in the project.

• PM3 backpressure regulators fitted.
APPENDIX 1.6. RELATIVE HUMIDITY IN APPLES DURING LONG TERM CONTROLLED ATMOSPHERE STORAGE.

Diagram 1.6A Relative Humidity Chart.

Diagram 1.6B Temperature Chart.
EXPLANATION.

- Chart shows relative flat line across logged period very spikes and good control.

- Ammonia flooded system operating on electronic liquid level controllers.

- Operator input for some control of relative humidity.

- Water added to chamber floor and kept to a level of 25mm.

- Temperature operating at 2.5°C.

- This site has again shown to be the best coolstore for control of relative humidity throughout the project. Note higher that normal temperature at time of data collection.

- PM3 backpressure regulators fitted.