final report

Project code:	P.PSH.0365
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Date submitted:	November 2009
Date published:	August 2011

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Novel technology for rapid carcase chilling (Stage 1)

Evaluation of pilot scale demonstration unit

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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1 Parties

- MLA Donor Company Limited
- Meat and Livestock Australia Limited
- Food Processing Equipment Pty Ltd
- RB Refrigeration Pty Ltd
- Food Safety Services (SA) Pty Ltd

2 Objective of Milestone Two

Evaluation of pilot scale (stage 1 prototype) demonstration unit constructed in milestone 1.

The project contract requires FPE to evaluate the pilot scale (stage 1 prototype) demonstration unit constructed in milestone 1. This evidence is a key stage of the project to ensure that the process can achieve the desired outcomes of this project for the Meat Industry. Evaluation will consider; meat quality, carcase shrinkage, energy usage, construction costs, opportunities for increased processing capacity and applicability to other meat products. Proposed completion date for Milestone 2 was 13 April 2009. After the unsuccessful 1st meat quality trial in June this date was revised to 30 November 2009.

3 Progress against Milestone Two

Evaluation of pilot scale unit

3.1 Trial series 1

The evaluation of the prototype commenced with a commissioning trial at Prime Valley Pastoral's abattoir on 1st June 2009. This trial processed only 4 carcases and was to confirm that the prototype unit was in full operation ready for the meat quality evaluation. All systems operated as designed and the unit was assessed as being ready for full trialling.

3.1.1 Meat quality trial 1

As a result of the commissioning trial, an initial series of evaluation trials were conducted on the pilot scale unit at Prime Valley Pastoral's abattoir at Two Wells, SA from 8 - 10 June 2009. These have been separately reported by Dr Robin Jacob of Department of Agriculture WA as "Validation of FPE prototype July 17.doc"
The following key points were identified during these initial evaluation trials:

- This experiment involved 2 phases; evaluation of the chilling profile followed by meat quality evaluation.
- Comprehensive testing of 12 carcases chilled in the prototype chiller indicated that the pH temperature profile fell short of the very fast chilling window and was in the cold shortening window. Bearing this in mind the second phase of the experiment to evaluate meat quality was not undertaken.
- The trial report presents the temperature monitoring results from phase 1 along with the recommendations made for future work with the prototype.

As a result of the initial trial the prototype unit was returned to R& B Refrigeration's workshop where it was modified. Modifications centred on increasing compressor capacity. After discussion it was decided not to change the refrigerant gas which was retained as R22.

3.1.2 Recommissioning trials

The unit was returned to Prime Valley Pastoral on 24 August with further trials conducted on 27 – 28 August. These trials were limited to 2 carcase runs to determine the unit's ability to achieve the required time/temperature window for avoiding cold shortening. 3 trials were conducted as follows:

- 27/8/2009 -Light goats 11.5kg HSCW
- 28/8/2009 Trial 1 – Mutton 21.5kg & 27.5kg HSCW
- 28/8/2009 Trial 2 – Average goats 15.5kg HSCW

Figures 1, 2 & 3 below show the outcomes of the three trials respectively.

Figure 1

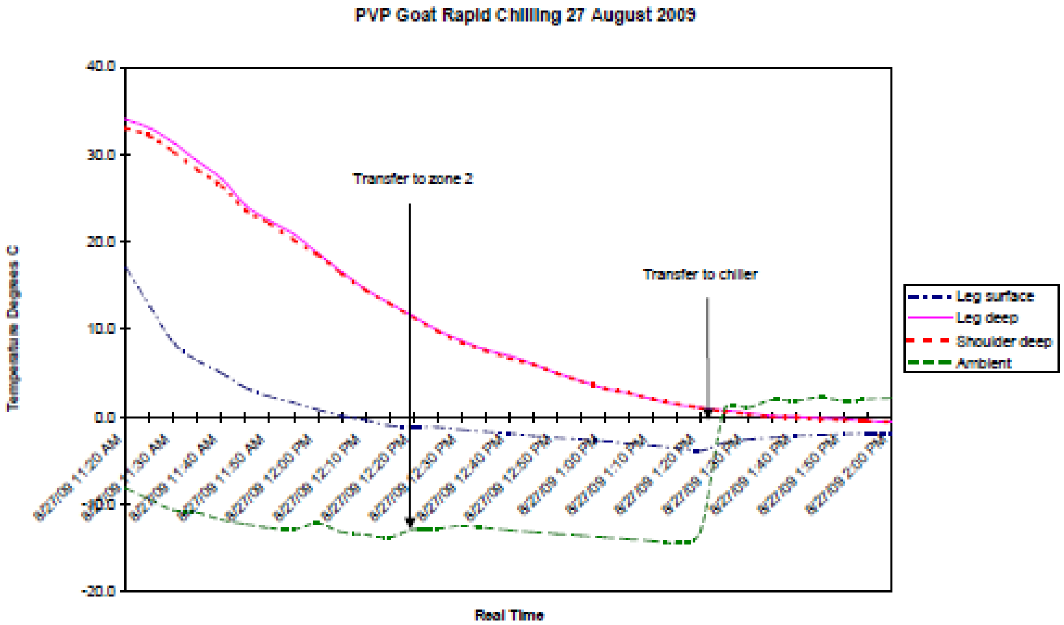


Figure 2

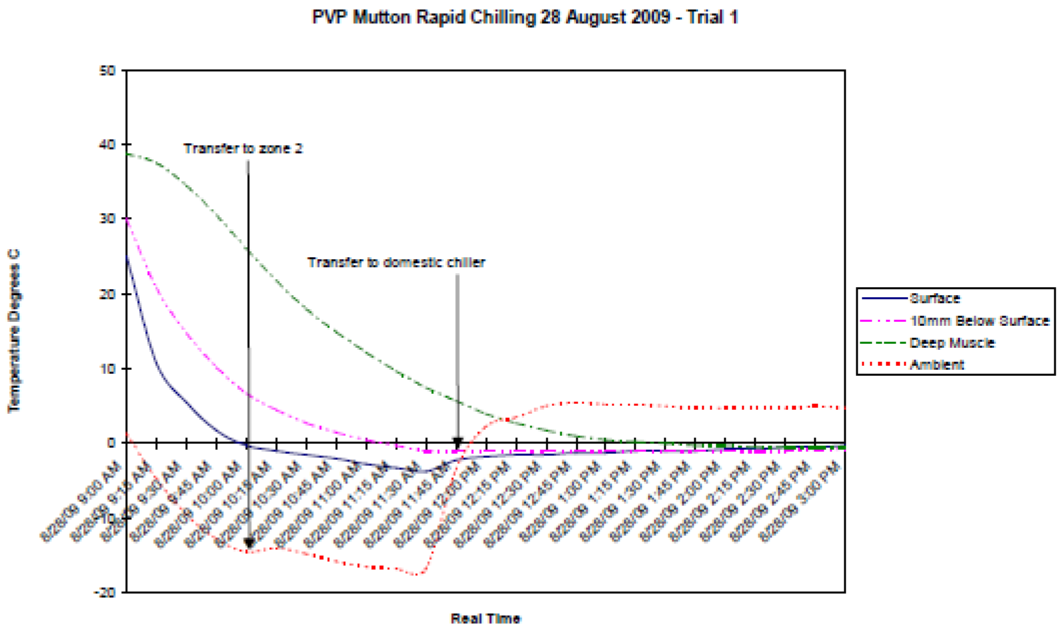
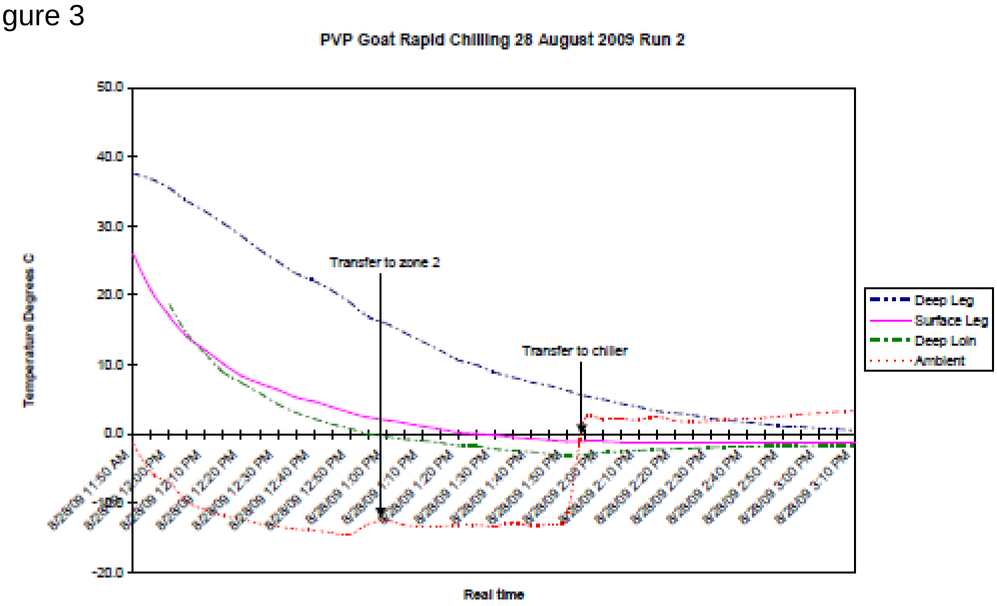


Figure 3

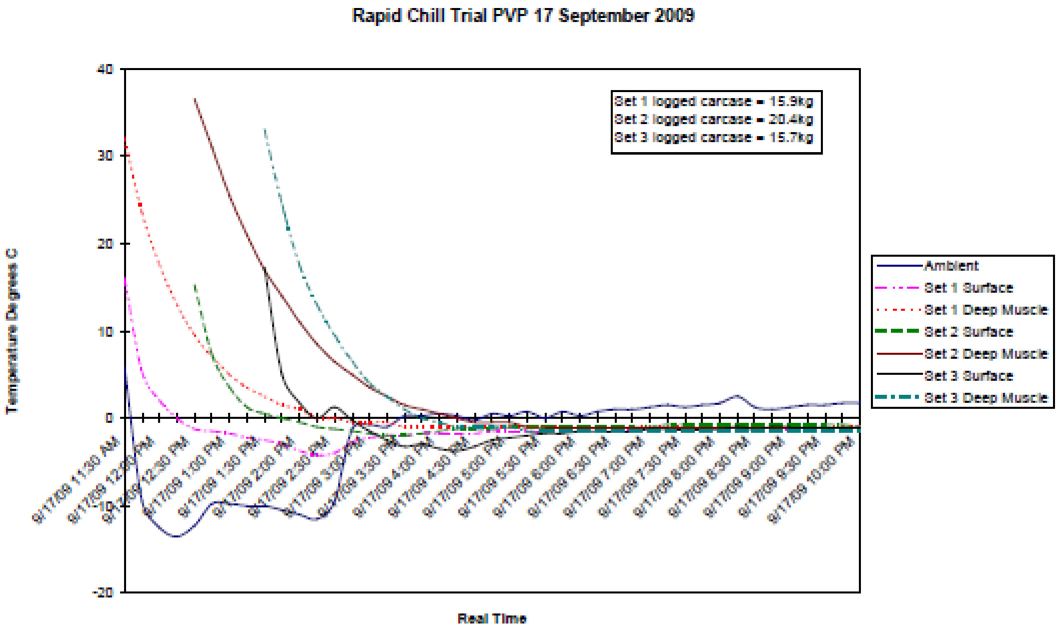


As a result of these trials it appears that the prototype unit may now achieve the desired rapid chilling time/temperature window.

3.2 Trial series 2

The second set of trials commenced with a trial on 17 September in which carcase of target 17-18kg HSCW were run continuously through the unit to determine the sustainability of operation as there was concern that icing up of the evaporator units may occur. Figure 4 shows the outcome of this trial.

Figure 4



This trial identified that:

1. The ability of the slaughter floor to provide the correct weight carcase at the exact time that the trial chiller required to be loaded was extremely difficult. The weight range of carcases being processed is a natural fall of a variable weight range and despite efforts to collect carcases in the 17-18 kg weight range the logged carcases were 15.9 kg, 20.4kg and 15.7kg respectively.
2. Frosting of evaporators to a level that would affect the performance of the trial chiller did not occur.

3.2.1 Meat quality trial 2

On the successful outcome of this trial a second performance evaluation series of trials commenced on 20 October 2009 to evaluate meat quality and other important performance aspects required to complete milestone 2.

This trial processed 32 lamb carcases with 16 through the prototype and 16 conventionally chilled as a comparison. 6 carcases were processed in pairs through each chiller on 20 October with a further 10 carcases processed in pairs through each chiller on 21 October. Carcases processed through the prototype were transferred to the PVP “domestic” chiller immediately after completion of their 3 x 1 hour chilling cycles. Conventionally chilled comparison carcases were held in the PVP “main” smallstock chiller.

All carcases were fitted with temperature loggers to track cooling profiles of deep muscle and surface of loins and legs. Photographs 1 & 2 show goat and lamb carcases fitted with loggers entering the prototype unit. Figures 5 & 6 show the cooling profiles for the VFC carcases and the conventionally chilled carcases respectively. Photograph 3 shows lamb carcases in the conventional chiller. All carcases were tested for pH prior to stimulation, after stimulation prior to chilling and after chilling.
Muscle samples were removed from all carcase 24 hours after chilling and assessed for meat quality attributes at the Department of Agriculture WA laboratories in South Perth.

Details of these trials and the results of meat quality assessments have been separately reported by Dr Robin Jacob of Department of Agriculture WA as “FPE prototype final Nov 26.doc”. (See appendix 1) Figure 5. Cooling profiles from prototype carcase Figure 6. Cooling profiles from control carcases

Photograph 1 – Goat carcases - entering VFC

Photograph 2 – Lamb carcases entering VFC

Photograph 3 Lamb carcases in conventional chiller

Figure5:
cooling profiles from prototype carcases

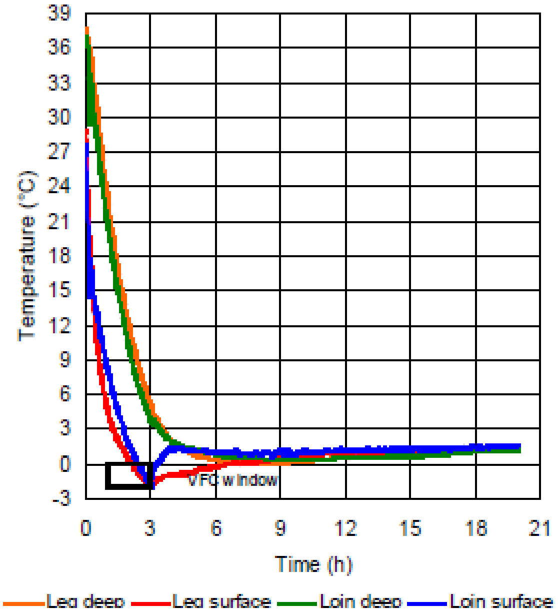
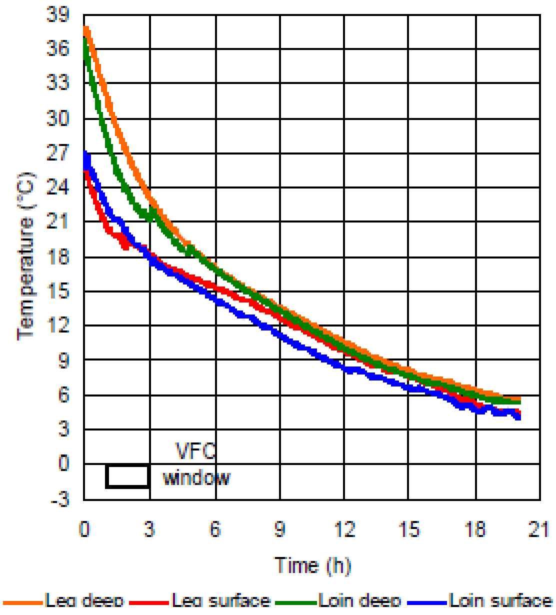


Figure 6:
cooling profiles from control carcases



As can be seen from Figure 5 the surface temperatures for loin and leg achieved the required VFC time/temperature window. However the deep muscle of both loin and leg failed to achieve the window.

The key points from Dr Jacob's executive summary are:

- The mean ambient air temperature in the prototype chiller during the 3 hour VFC period was 11.07°C.
- The average temperature between the surface and deep probes was 0.99°C for the loin and 1.55°C for the leg at the end of the VFC period of 3 hours.

- The rate of temperature decline recorded in carcases chilled in the prototype, albeit faster than in experiment 1 conducted in June 2009, was not within the range of temperature and time specifications required for VFC.
- Meat from carcases chilled in the prototype had shorter sarcomere lengths, higher shear force and lower colour stability values compared to meat chilled in the conventional chiller. This meat quality result was attributed to the temperature time profile being in the "cold shortening" range of the post mortem temperature, pH and time continuum; used to predict lamb meat quality, both during VFC and immediately post VFC.
- Further development and modification of the prototype could allow evaluation of the commercial application of very fast chilling using this system.

During these trials carcases were accurately weighed with a Rinstrum R320 hanging scale accurate to ±10 grams. Carcases were weighed prior to chilling, after 3 hours from entering chilling (this is immediately after completion of prototype chilling cycles) and after 24 hours from commencing chilling. Results from carcase weighing are given in Appendix 2. Summary results are shown in Tables 1, 2 & 3.

As previously identified the weight range of carcases being processed is a natural fall of a variable weight range and despite efforts to collect carcases in the 17-18 kg weight range the logged carcases in this series of trials were heavier than planned and averaged over 20 kg.

Table 1. Summary weight data for all carcases

Treatment	**Average Wgt Loss % @ 3 hrs**	**Average Wgt loss % @ 24hrs**
VFC	1.69%	2.21%
CC	1.42%	2.49%

Overall chiller performance
At 24 hrs there is little difference between prototype & CC (0.28% advantage to VFC). When comparing prototype at 3 hours (immediately ex- prototype unit) with 24 hour CC (current practice) there is a distinct advantage to prototype (0.8%). As the purpose of the development of the prototype unit is to enable same day boning to occur it is reasonable to compare prototype at 3 hours with conventional chilling at 24 hours.

Table 2. Summary weight data for VFC carcases

	Average Wgt Loss % @ 3 hrs	**Average Wgt loss % @ 24hrs**
Day 1	1.66%	3.12%
Day 2	1.71%	1.67%

Table 3. Summary weight data for conventional carcases

	Average Wgt Loss % @ 3 hrs	**Average Wgt loss % @ 24hrs**
Day 1	1.46%	2.58%
Day 2	1.40%	2.43%

Day 1 performance
Between 3 & 24 hours there has been no loss of weight for prototype carcases (-0.05%) compared to CC carcases (1.03%). At 24 hrs there is significant difference between prototype & CC (0.76% advantage to prototype). When comparing prototype at 3 hours (immediately ex-

prototype unit) with 24 hour CC (current practice) there is a distinct advantage to prototype (0.72%)

Discussion regarding weight loss

It is unclear what happens between 3 & 24 hours with prototype when transferred to conventional chilling. Day 1 data indicates a significant weight loss over this period while Day 2 data indicates no further weight loss. While observations and recording of data during days 1 & 2 do not indicate any noticeable difference in operation, results suggest that it is possible something different happened in the VFC between days 1 & 2. It is possible that the moisture levels in the “domestic” chiller used for holding the prototype carcases may have varied from day 1 to day 2, particularly in moisture content. *This is an important issue that needs to be resolved to enable accurate determination of economic viability.*

4 Economic viability

The economic viability of the prototype, subject to the achievement of the required time/temperature prototype window, is dependent on a range of cost related issues. These are discussed below based on a 4,000 carcase per day plant operating a single shift.

4.1 Capital costs

4.1.1 Chiller volume

- Conventional chilling requires sufficient holding volume for a full day’s production. ie 7 hours for 1 x 8hr shift (potentially 14 hours for 2 x 8hr shifts). At say 9 carcases/minute this is 3,780/day for a single shift (potentially 7,560/day for a double shift). For the purposes of this feasibility analysis four chillers each capable of holding 1,000 carcases would provide this capacity.
- The prototype requires at most 3 hours on a continuous chain basis. (Longer than 3 hours will not achieve the target VFC window). At 9 carcases/minute, this is 1.620 carcases.
- Issues to consider
  - Packing volume for a continuous chain will be slightly less dense than for a static rail chiller. Carcases on the moving chain will be passing each other in opposing directions with a risk of contact and entanglement. An estimated additional 20% in volume is likely to be required for the prototype. For 1,620-carcasee capacity this would require the volume of a conventional chiller for 1,000 plus 95%. For the purposes of this feasibility analysis building construction costs for one 1,620 carcase prototype are equivalent to those for 2 x 1,000 carcasee conventional chillers.
  - Equipment requirements for a continuous chain will be different from those for a static rail system. The chain and drive system will add complexity but this will be off-set by the elimination of multiple rail gates (two for each static rail). As a result it is likely that equipment costs will be similar.
  - Washdown/dry time is currently an issue for the operation of static rail chillers, particularly if all carcases are to be cut or boned. To allow adequate time for cleaning/drying between emptying and reloading of a static chiller, additional space is required unless whole carcase loadout occurs. To allow smooth

operation with 100% cutting/boning, additional chiller space of approximately 2 hours production is required. For the purposes of this feasibility analysis one additional chiller capable of holding 1,000 carcases is recommended.
With only a 3 hour cycle, the prototype will always be empty within 3 hours of completion of production. Total prototype usage time during a 7 hour production day will be 10 hours. This will allow adequate time for cleaning and drying. *Note that at the end of production the prototype will always be empty while a conventional chiller will always be full.*

  - While the purpose of the development of the prototype unit is to enable same day boning to occur it is reasonable to expect that some additional or back-up holding chiller space will be required to support prototype operation. For the purposes of this feasibility analysis one chiller capable of holding 1,000 carcases would be adequate.
  - Establishment of prototype viability is based on carcases being cut while remaining at approximately –1.5°C to allow rigor onset after very fast chilling. Options for boning will require further investigation to determine the optimum relationship between very fast chilling, boning and rigor onset.
- Infrastructure required
  - VFC operation
    - 1 x prototype (approx 2 x 1,000 carcase chillers)
    - 1 x 1,000 carcase chiller as holding capacity
  - Conventional
    - 5 x 1,000 carcase chillers
- A prototype operation for a 9 carcase/minute process would require one prototype at approximately twice the volume of a 1,000 carcase conventional chiller plus one 1,000 carcase holding chiller compared to 5 x 1,000 carcase chillers for conventional operation. This is only 60% of the floor space required for a conventionally chilled operation. While this can not be costed into this feasibility analysis, this may have an important impact on the availability of space for construction.

4.1.2 Refrigeration capacity

- A conventional chilling operation requires refrigeration capacity to remove the heat load over say 18 hours and maintain chilled temperatures for an additional 4 hours.
- A prototype requires capacity to remove the same heat load over say 10 hours with minimal maintenance of chilled temperatures. The instantaneous capacity of a prototype refrigeration unit to remove heat load will necessarily be approximately 1.8 times that of a conventional system.
- Issues to consider
  - It is reasonable to expect improved consistency of load, reduced energy usage and hence reduced operating cost from a prototype system compared to a conventional system. As the VFC will fill at a continuous basis, the load would be expected to ramp up at a fixed rate allowing minimising of load peaks. Once fully loaded the prototype system will maintain a constant heat load. A conventional system is known to have high peak loads as chillers are often fully loaded before turning refrigeration on.
  - The pilot plant system has shown that control systems of increased complexity, and cost, are required. Without these controls the required control of rapid chilling without freezing can not be achieved. For the purposes of this feasibility analysis an increased control cost has been allowed.

    - Defrost requirements can not be accurately predicted but with reduced weight loss from carcases during the 3 hour prototype process, it is reasonable to expect some reduction in the time and energy required for defrosting of evaporators.
- Infrastructure required
    - Conventional x 1,000 carcase chiller
        - 60 KW/hour carcase load/chiller
        - 15 KW/hour wall load/chiller
        - additional 15 KW/hour wall load only for 5th chiller for cleaning/drying
        - for 4,000 carcases chilled over 18 hours per day = 5,670 KW/day
        - at 2.6 KW refrigeration from 1 KW of electricity, electricity required = 2,180 KW/day
    - Prototype chiller
        - 460 KW/hr carcases and wall load
        - 100 KW/hr additional fan load
        - Holding room 15 KW/hour wall load only
        - for 4,000 carcases chilled over 10 hours per day 4,750 KW/day + direct fan loading of 1,000 KW/day
        - at 2.6 KW refrigeration from 1 KW of electricity, electricity required = 1,830 KW/day plus 1,000 KW/day (fan loading) = 2,830 KW/day

4.2 Operating costs

- Both systems should require same energy to remove the heat load from the day's kill.
- Conventional chillers will need additional energy to maintain the temperature until boning commences next day (8 hours).
- The prototype requires additional energy to compensate for additional fans to create high velocity airflow.
- Budget energy costs
    - Conventional - 2,180 KW/day @ $0.10/KW = $218/day
    - VFC - 2,830 KW/day @ $0.10/KW = $283/day
- Weight loss – when comparing a conventional chill for 20 hours with a prototype chill for 3 hours, trial series 2 has identified a potential saving of approximately 0.75%. For the purposes of this feasibility analysis a 0.75% savings of weight loss on a 9 carcase/minute line processing average 22 kg HSCW lambs equates to 625kg/day. At an estimated average export lamb price of $7/kg this is approximately $4,375/day or $1.05 million per annum.
- With the automated nature of the prototype it is reasonable to expect reduced labour for a prototype operation compared to a conventional chilling operation. For the purposes of this feasibility analysis one labour unit reduction has been allowed for loading and unloading. The cost saving of one labour unit is approximately $60,000 including on costs.
- With a reduced volume of chillers required it is reasonable to expect a reduction in cleaning time and costs. For the purposes of this feasibility analysis half a labour unit reduction, plus chemical savings of $10,000 per annum, has been allowed.

4.3 Estimated costs

Tables 4 & 5 below show comparative additional costs and/or savings between conventional and VFC operations.

Table 4. Comparative capital costs

Item	**Prototype (prototype + 1 CC)**	**Conventional chiller (5 x CC)**
Construction of buildings *	$175,500	$292,500
Concrete floorings *	$66,000	$110,000
Rail systems *	Comparable	Comparable
Refrigeration plant (including	$658,000	$470,000
electrical & controls)		
Total	**$899,500**	**$872,500**

* Based on a 1,620 carcase prototype being equivalent to 2 x 1,000 carcase conventional chillers

Table 5 Comparative operating costs (only items where there is a significant difference are identified)

Item	**Prototype chiller**	**Conventional chiller**
Electrical energy (p.a.)	$67,920	$52,320
Labour	- $60,000 *	
Cleaning labour & chemicals	- $40,000 *	
Weight loss differential	- $1,050,000 *	
Total	**- $1,082,080 ***	**$52,320**

* - indicates a savings

5 Economic viability

The prototype option requires similar capital to conventional chiller option (CC <5% advantage to VFC above would not be significant in reality).
The prototype option operating costs potentially saves $1.13 million per annum against a conventional chiller option. This is a significant saving that warrants further investigation.

5.1 Operational issues

Some consideration will need to be given to the way the process is operated and the impact that this will have on the entire processing site.

- Conventional chilling operates on a 20-hour delay between slaughter and cutting allowing minimal off-set of slaughter floor and cutting room operating times.
- prototype will operate on a 3 hour delay between slaughter and cutting
- The following key points should be considered:
    - The viability of operating and managing a split shift operation
    - The availability of staff for split shift operation
- The prototype will ensure correct spacing of every carcase. Incorrect spacing is a problem with manually loaded conventional chillers and can result in poor cooling and localised microbial problems where touching occurs
- The prototype will ensure that there is always separation between warm and cold carcases. Separation of warm & cold carcases is recognised as best practice in chiller operation and is often not well achieved with conventional chillers.

6 Conclusions & Recommendations

- The meat quality trials conducted to date have failed to meet the target VFC time/temperature window.
- Trial 2 has however shown that a refrigerated air blast chiller could achieve the target VFC time/temperature window under the correct conditions.
- The FPE/R&B Refrigeration pilot plant prototype could likely have achieved the target VFC time/temperature window provided that the correct weight carcases were processed. The controlling factor in achieving a successful target VFC time/temperature window is:
  - the carcase weight which in these trials was higher than planned due to operational constraints at PVP's abattoir.
  - the refrigeration applied which is limited by the small scale of the pilot plant unit. Any attempt to increase refrigeration capacity is limited by the physical size of the unit and will be offset by increased heat loads that make increasing refrigeration in the current pilot plant virtually impossible.
- Demonstration of the FPE/R&B Refrigeration pilot plant's capability to achieve the target VFC time/temperature window could be done provided that:
  - The weights of the carcases processed in the trials can be limited to less than 17 – 18 kg HSCW as originally planned for Eating Quality Trial 2.
  - The pilot plant unit can be operated on carcase portions only. Some minor modifications will be required to accommodate individual lamb loins and lamb legs through the pilot plant prototype.
- The potential economic viability of the prototype option looks excellent. However further work on a small commercial scale unit will be required to verify the weight loss savings, which account for the major aspect of viability of this system.
- The entire issue of cutting or boning needs further discussion. Dr Jacob's team thinks that it is possible to bone earlier than with a conventional chilling process but it may still be necessary to wait at least until rigor commences. This should be quicker for VFC but may still be 6-10h post slaughter and may need to stay in an air temperature of -1.5°C. That being the case carcase cutting could occur immediately after very fast chilling but boning is likely to present a problem. Hot boning or cutting to primal matches the time constraints with VFC really well and recent work in NZ suggests that hot boning and VFC together delivers good meat quality.

6.1 The Way Forward

The outcomes of this trial and the potential economic viability of the prototype process option strongly suggest that further work is warranted. Further work will require additional funding.
It is recommended that the following approach be taken:

1. Conduct a further series of trials on the existing pilot plant prototype unit using small lamb carcases, lamb carcase sides or lamb cuts, to prove that the required eating quality can be achieved through a refrigerated air blast VFC. The use of small lamb carcases will allow further valuable data on weight loss reduction to be obtained.
   If this option is possible it may be worth investigating the purchasing suitable livestock from a known supplier. If livestock from similar genetics, management and feeding regime were sourced it would enable a generic line of animals to be assessed. The staggering of the kill of these animals across the kill day, to ensure that suitable animals are available for the experiment would have to be considered.
2. Construct a small commercial scale unit to verify the weight loss savings indicated by trials to date.