MASSEY UNIVERSITY

Temperature Control and Energy Efficiency in Cold Storage

Don J. Cleland
Centre for Postharvest and Refrigeration Research
Massey UniversityPalmerston North, New Zealand

1st IIR International Cold Chain Conference, Cambridge UK, 2010
31 March, 2010

Objectives

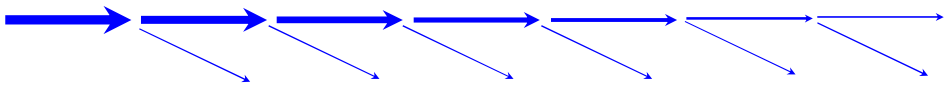
- Provide an introduction to the following aspects of food cold storage facilities
  - temperature variability
  - air flow distribution
  - energy efficiency
- Excluding facilities for product cooling (freezers, chillers and precoolers)

Temperature Variability

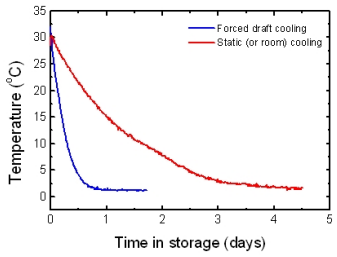
- Time-variation
  - variations in heat loads e.g. time of day, door opening, product cooling
  - refrigeration temperature control system
  - defrost
- Spatial-variation
  - local heat sources
  - airflow distribution
- Importance of airflow
  - collects heat from sources before gets to product
  - delivers heat to refrigeration system
  - product cooling
  - affects fan power

Basic Principles of Airflow

- Air is takes the path of less resistance
  - widest path
  - least corners
  - around rather than through packaging
- There is always friction which results in losses of energy and thus reduced airflow
- The further away from the fan, the less airflow due to continued disipation of some flow



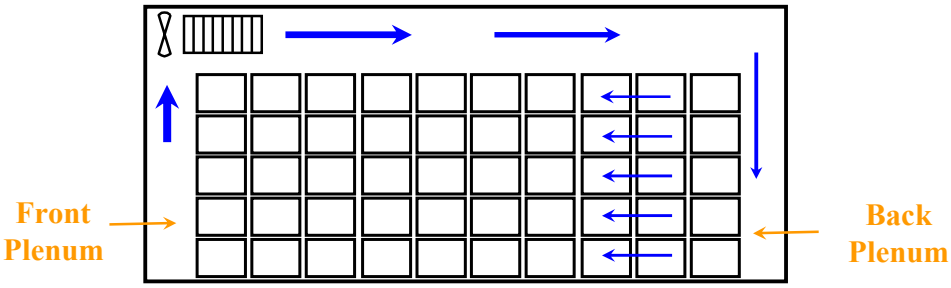
Product Air Flow



- Product at storage temperature
  - airflow around rather than through product unless respiring
  - intercept heat before gets to product
  - lower air flow
  - helps reduce product temperature fluctuations and weight loss
- Product above storage temperature
  - airflow through product to enhance heat transfer (convection rather than conduction)
  - high airflow
  - packaging design and pallet configuration critical e.g. ventilation holes, plastic wraps and liner

Room Airflow Basics

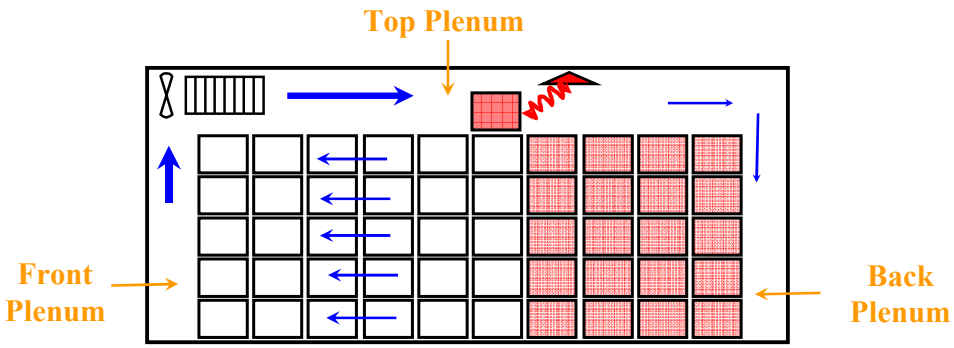
- Air is "thrown" from the evaporator/duct across the ceiling and "falls" down the far wall
- Air "finds" its way through the product stack back to the evaporator/return air duct



- Create spaces for major airflows

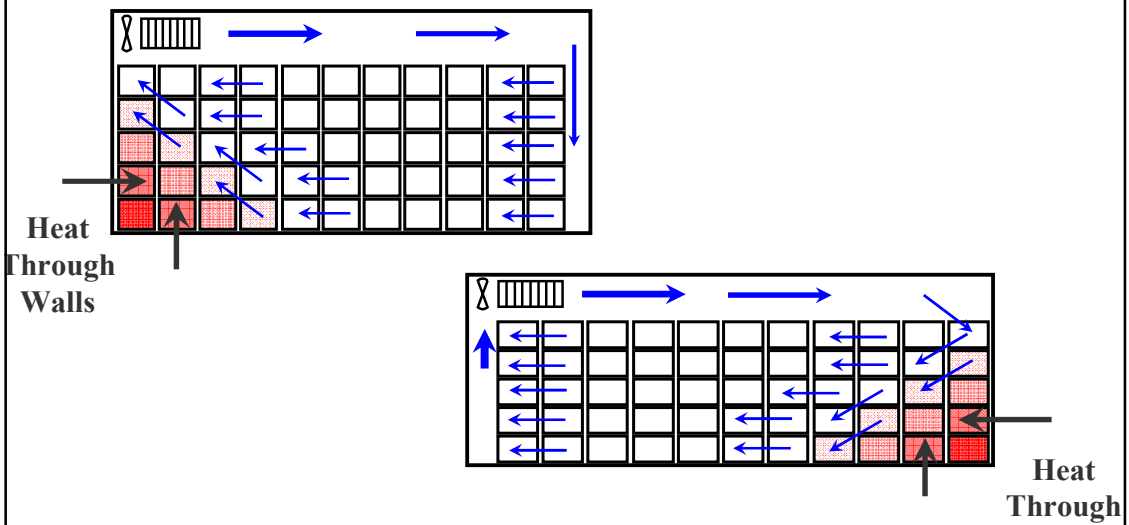
Top Plenum Stacking

- Also risk of excessive radiative heat transfer from lights



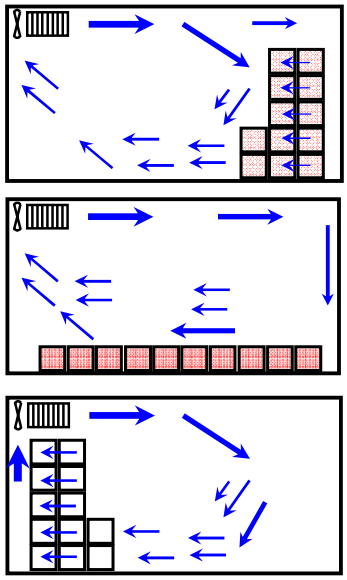
Front and Back Plenum Stacking

- air short circuiting if stack in plenums
- similarly if close side wall gaps



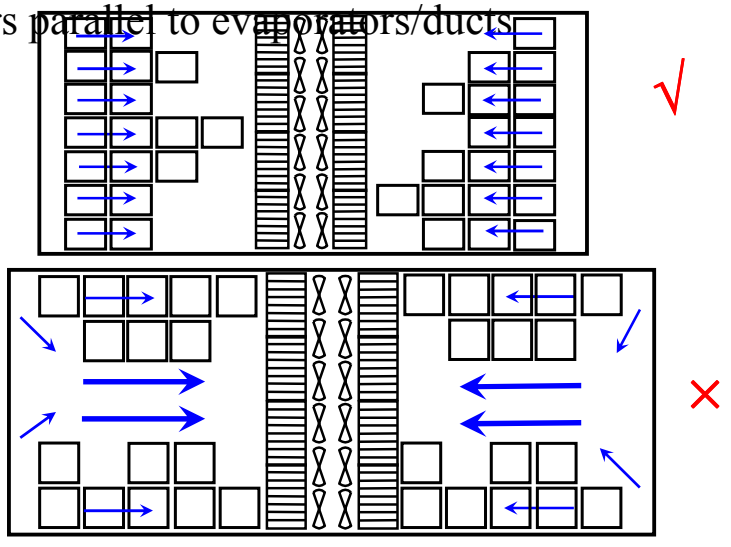
Partial Loading

- Partial loading at the back of the store can lead to short circuiting
- Flat packing can lead to air "shotover"
- The best manner to get airflow close to the fruit is to create the front plenum



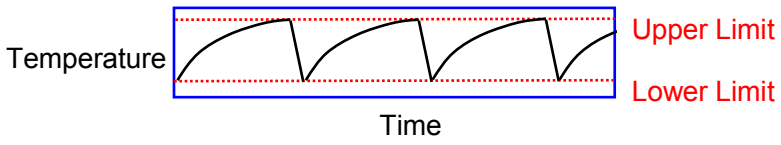
Partial Loading – Plan View

- Provide columns for the airflow to back to evaporator/duct
- Corridors parallel to evaporators/ducts



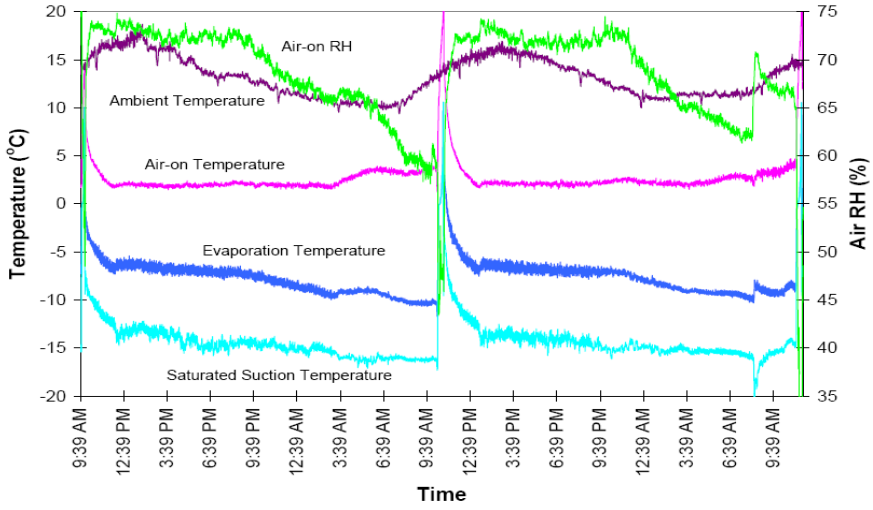
Temperature Control

- On/off via refrigerant solenoid
  - cycling across deadband
  - overshoot due to residual refrigerant in evaporator

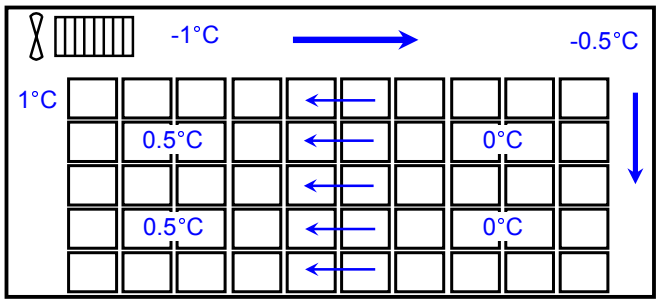


- Modulating evaporator pressure regulators
  - less variation in temperature but
  - extra suction line pressure drop so possible energy penalty
- Variable fan speed
  - energy savings due to fan power cube law with speed
  - risk of poor airflow distribution (often OK down to about 50%)
- Usually based on air-on temperature; air-off if freezing risk

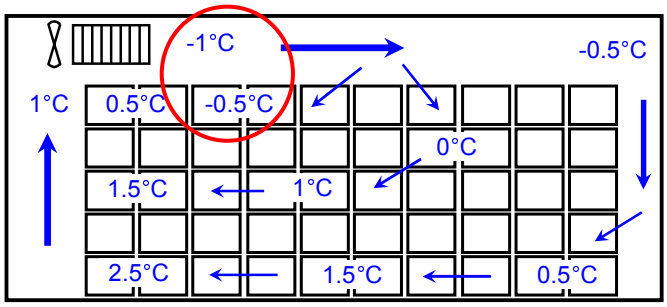
EPR Control and Defrost Effect



Spatial Temperature Variability

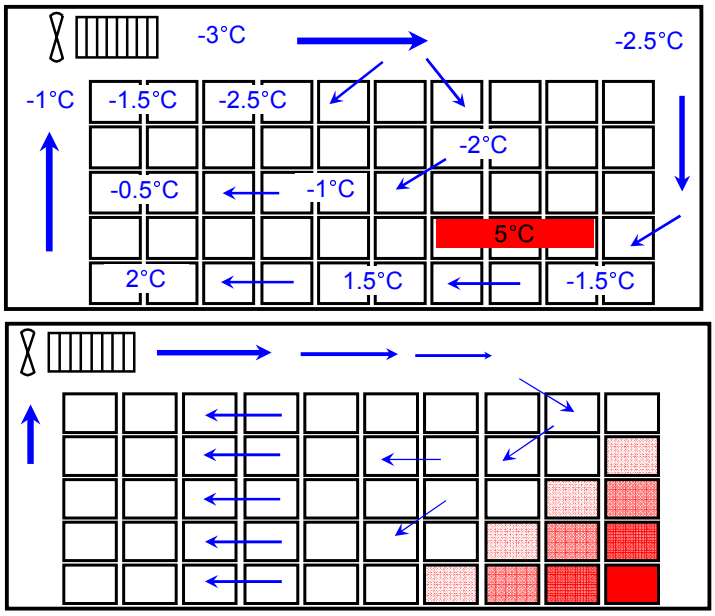


- Air-off evaporator is coldest
- Air warms as it circulates
- Temperature variability ≥ evaporator air split
- Situation if air split is 2°C and perfect air distribution



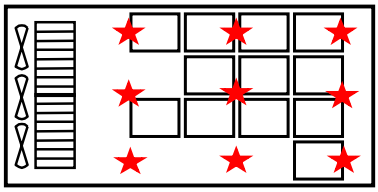
- Air return may not be warmest position if air distribution imperfect
- Risk of product freezing if air-off control
- Higher total air flow reduces air split but may not improve distribution

Poor Air Distribution/Large Local Heat Sources or Fan Speed Control

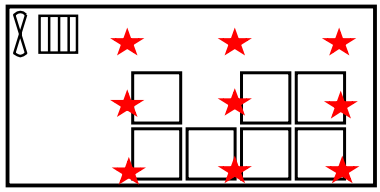


Monitoring of Airflows

- Visual cues
- Anemometer
- Temperature distribution (reflects airflow pattern)



Plan



Elevation

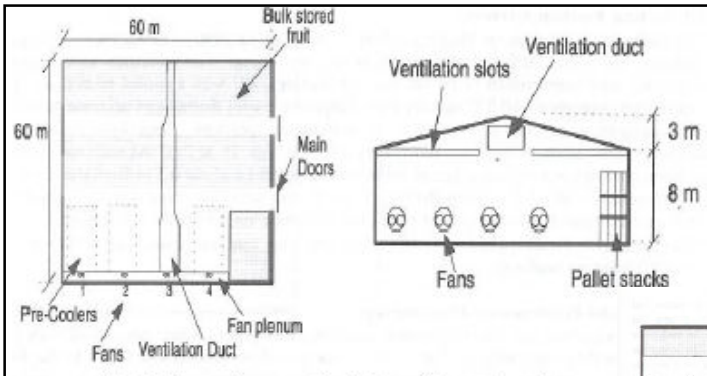


Fig. 1: Plan and cross-sectional views of the apple coolstore

Fig. 2: Store survey measurement positions (*) and stored product positions (shaded), (a) March 12 1990, (b) May 7 1990, (c) May 23 1990, and (d) April 7 to April 9 1992.

Summary of measured air velocity (m/s), for surveys on (A) March 12 1990 (in aisles), and (B) May 7 & May 23, 1990 (among bulk stacked pallets).

	Bottom		Middle		Top	
	A	B	A	B	A	B
Mean[a]	0.69	0.24	0.56	0.29	0.62	0.41
95 % minimum[a]	0.26	0.4	0.26	0.60	0.16	0.7
95 % maximum[a]	1.88	1.14	1.16	1.43	2.40	2.45

[a] Calculated using a log-normal statistical distribution

Mean air and fruit temperatures for survey between April 7 and April 9 1992 (means with the same letter are not significantly different, 95% confidence level)

Position (Fig. 2d)	Air Temperatures (°C)		Fruit Temperatures (°C)	
	Mean	Grouping	Mean	Grouping
1	0.63	a	0.77	a
2	0.31	b	0.53	b
3	0.29	b	0.51	b
4	1.39	c	2.02	c
5	1.08	d	1.40	d
6	0.89	e	3.09	e
7	1.46	c	2.51	f
8	1.34	c	0.78	a

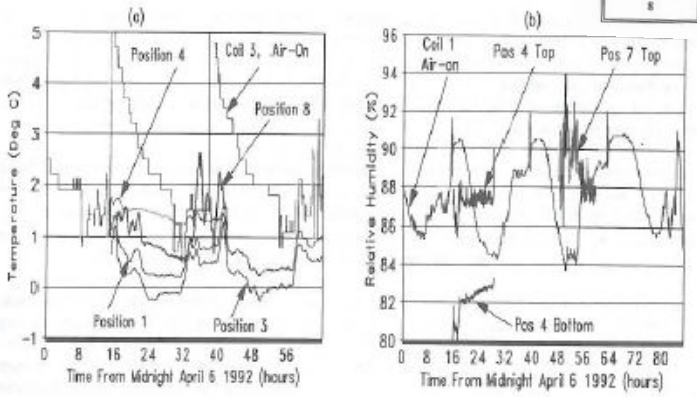


Fig. 3: (a) Measured air temperature, and (b) measured RH, April 7 to April 9 1992.

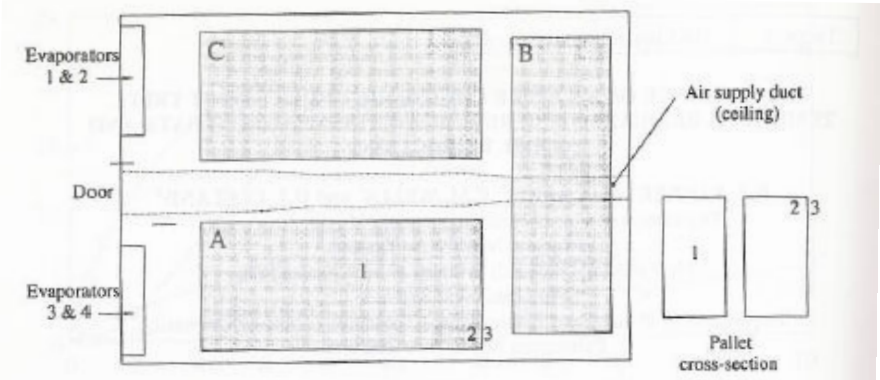
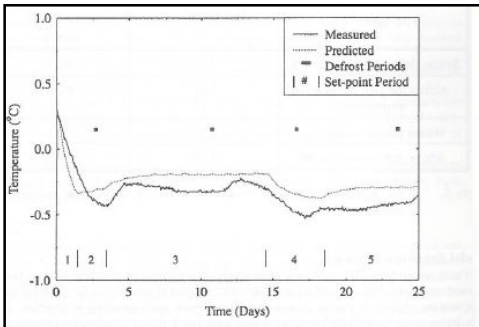


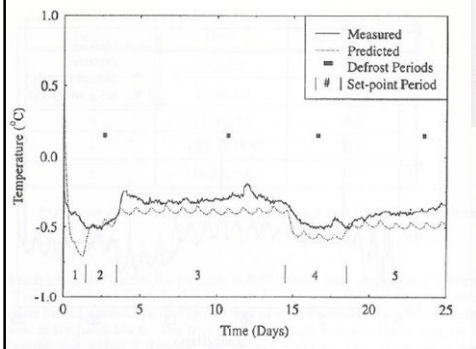
Figure 1. The industrial apple coolstore layout and pallet cross section showing product block and temperature measurement positions (denoted 1, 2 and 3).

Period	Days	Set-point (°C)
1	0 to 1.5	-0.8
2	1.5 to 3.5	-0.7
3	3.5 to 14.5	-0.5
4	14.5 to 18.5	-0.7
5	18.5 to 25	-0.6

Evaporator air-off temperature set-points used during the 25 day ti period.



Comparison of measured and predicted temperature for an apple at the centre of the pallet block (position 1, Figure 1) in the industrial coolstore.



Comparison of measured and predicted temperature for an apple towards the outside of the pallet block (position 2, Figure 1) in the industrial coolstore.

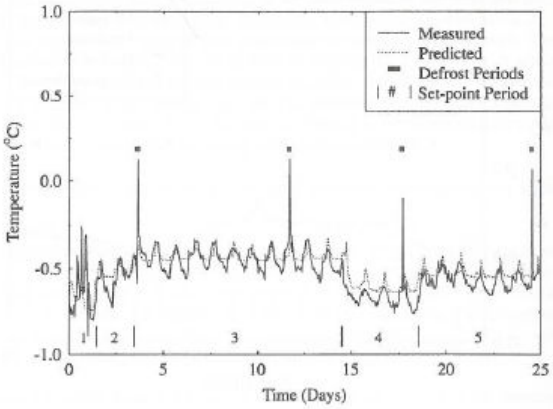
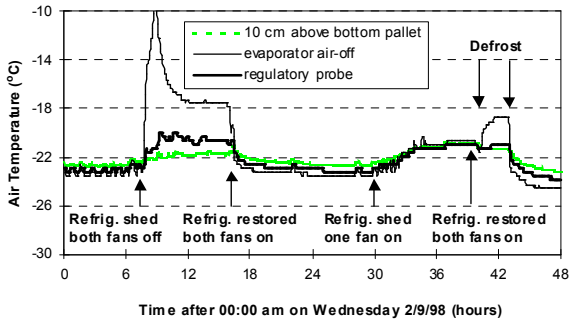
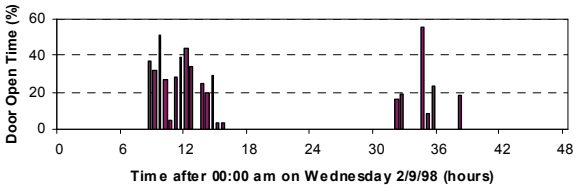


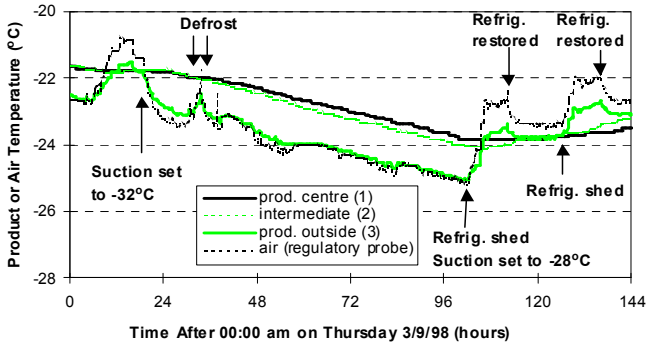
Figure 3. Comparison of measured and predicted air temperature (position 3, Figur in the industrial apple coolstore.

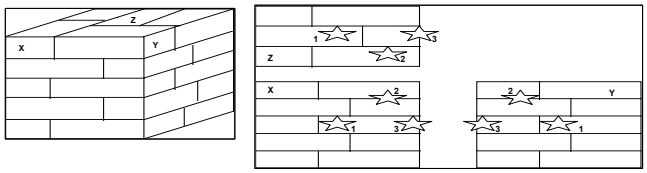
Load Management Potential (Daily Shedding)



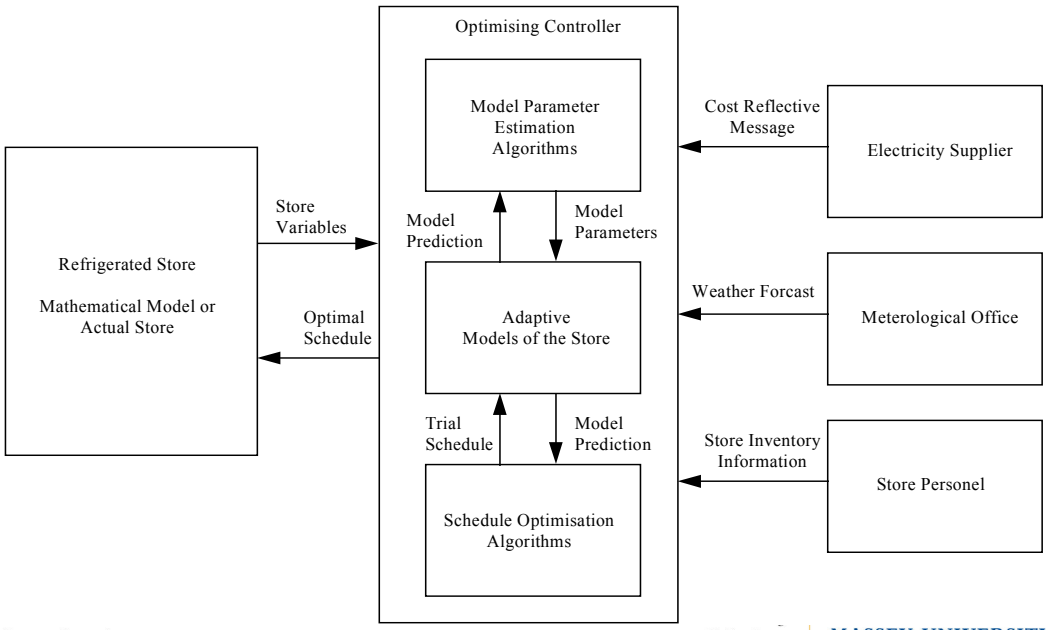


Load Management Potential (weekend precool)

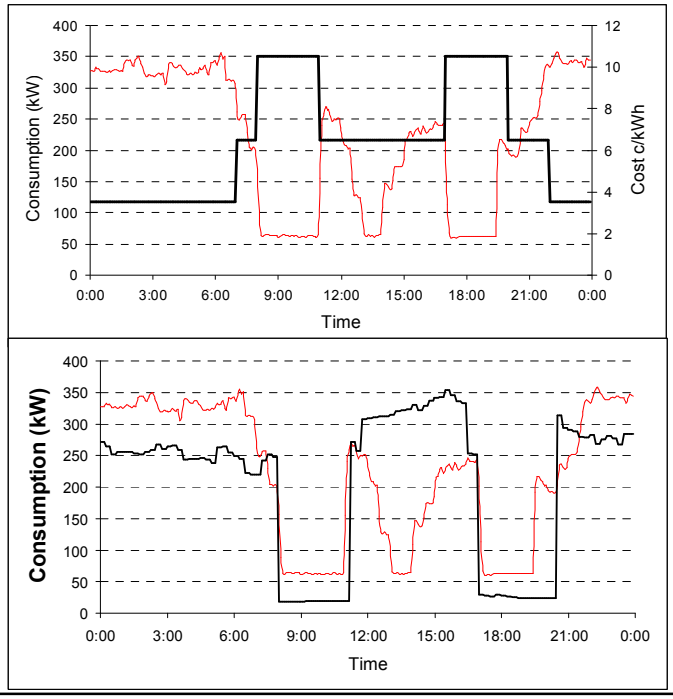




Optimising Controller

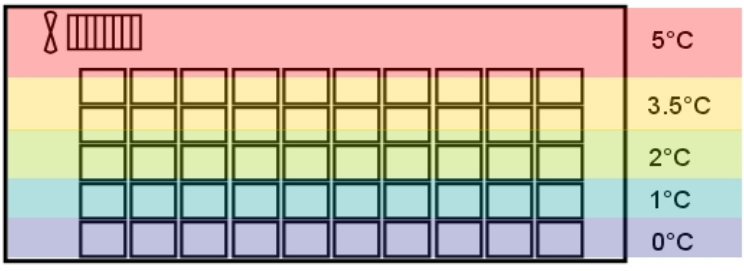


Optimising Controller



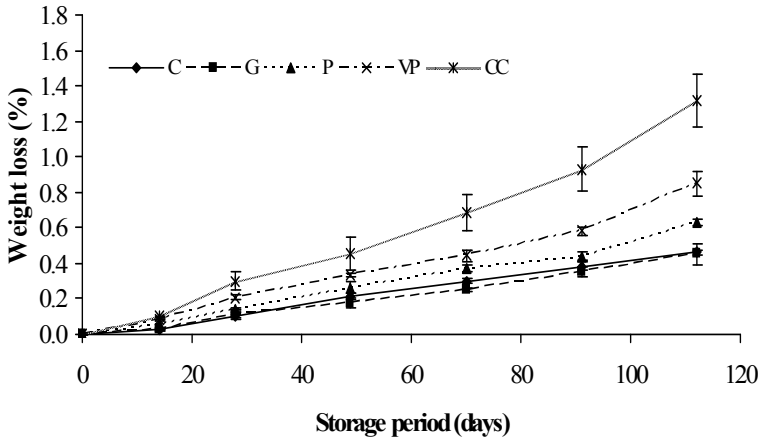
Load Management

- Temperature stratification can result unless cycle fans



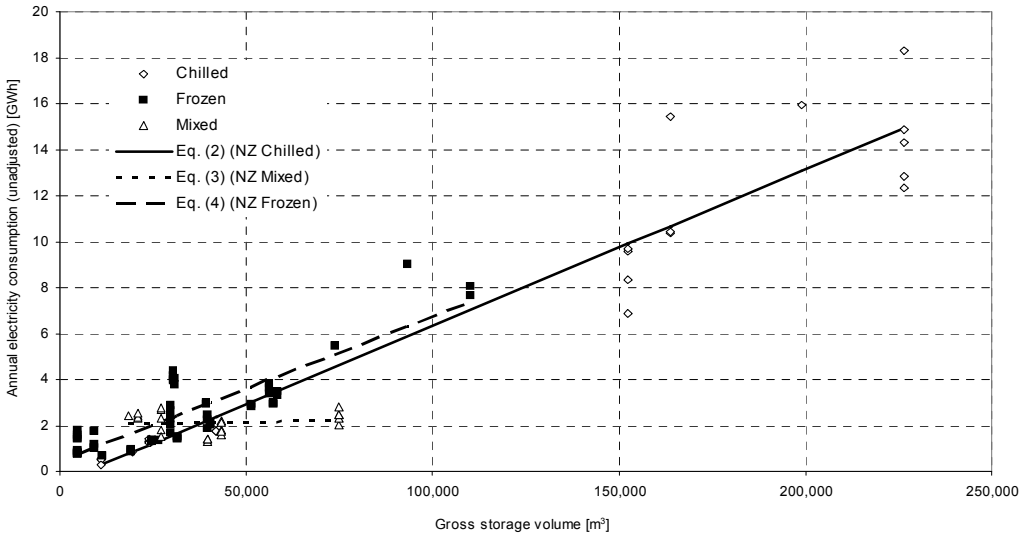
- Only if product down to temperature
- Check product shelf-life sensitivity to temperature fluctuations
- Base on air temperature as product centre lags surface

Effect of Temperature Fluctuations on Frozen Dough

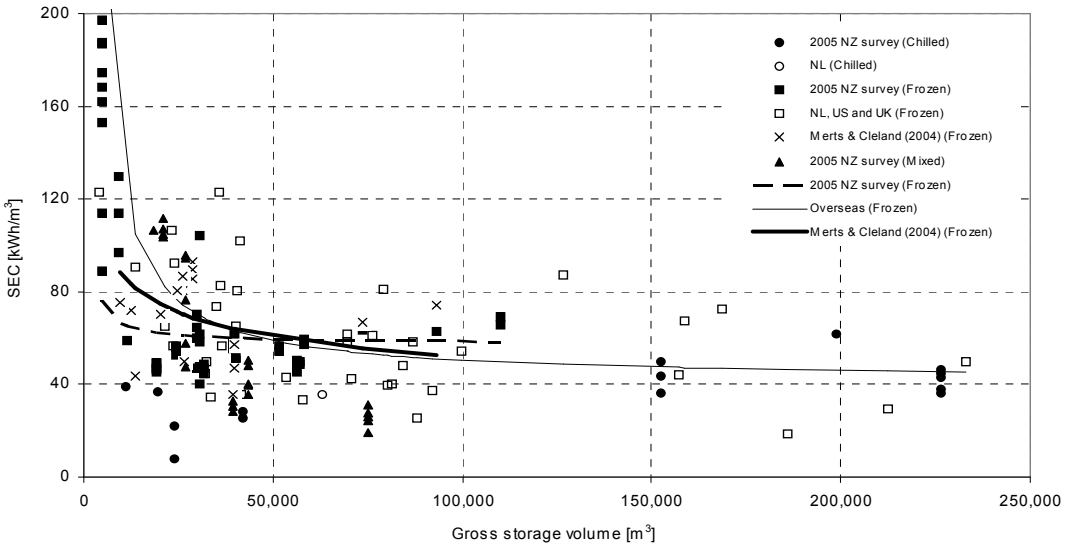


Regime	Set-point
Control (C)	-18±0.1°C
Good Practice (G)	-18±1°C
Poor Practice (P)	-18±3°C
Very Poor Practice (VP)	-18±5°C
Cold Chain (CC)	-18±1°C
	-13±1°C
	-8±1°C

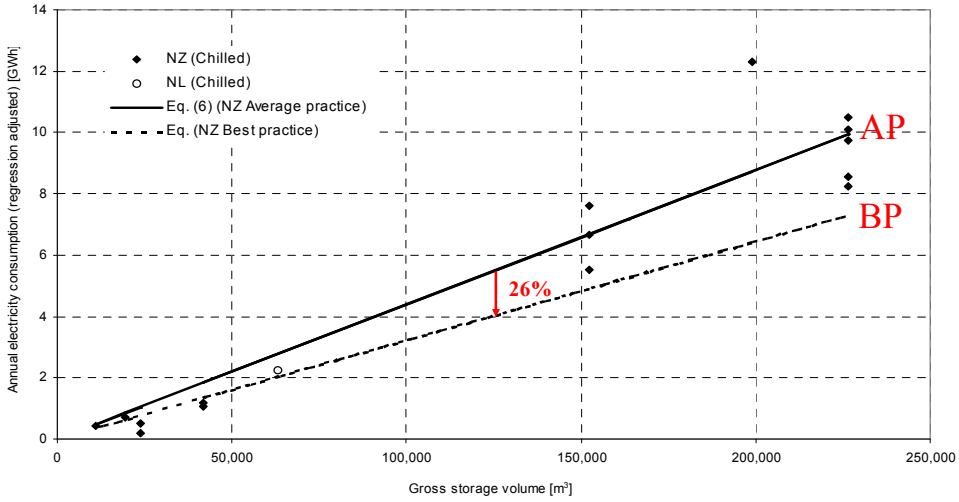
Cold Store Energy Use (GWh pa) (Werner, 2006)



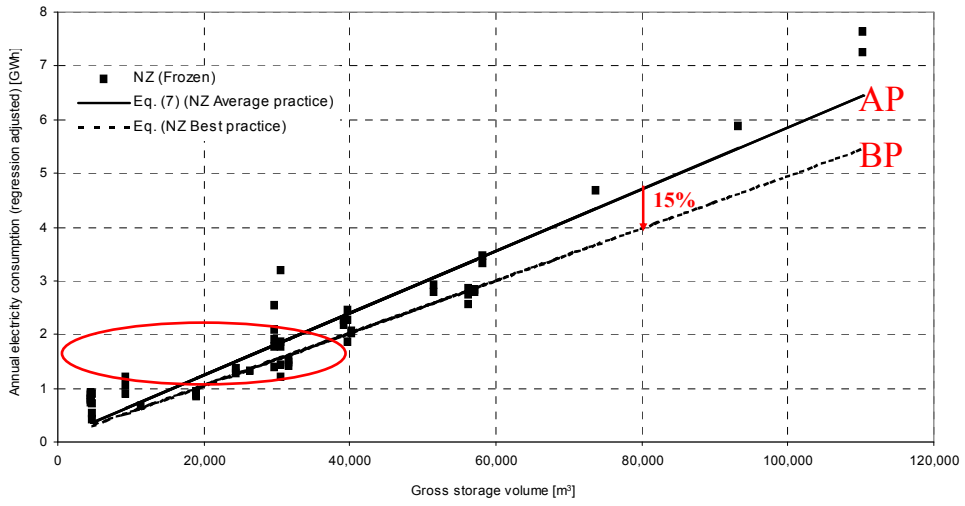
SEC vs Store Volume



Chilled Facilities (GWh pa)



Frozen Facilities (GWh pa)



Energy Efficiency Opportunities

- Every site is different
- 15-25% difference between average and best practice
- Reduce heat loads e.g.
  - evaporator fan speed control
  - door closure and/or protection
  - optimise defrost frequency and duration
  - reduce solar gain
  - prevent product reheat
  - minimise lighting and underfloor heating
- Improve refrigeration efficiency
  - increase suction
  - decrease discharge
  - reduce compressor part-load operation
  - economise or multi-stage

Conclusions

- Temperature variability is highly dependent on
  - airflow distribution
  - temperature control system
  - heat load variability
- Minimum spatial variability set by air split
- Cold store load management has considerable potential if the product is not sensitive to temperature fluctuations
- Many stores have potential for >15% improvement in energy efficiency
- Minimise heat loads before addressing refrigeration system performance

Acknowledgements

- The contributions of Andrew East, Richard Love, John Mawson, Inge Merts, Stephen Werner and Dave Tanner to the ideas presented in this workshop is gratefully acknowledged
- The financial support of the OECD Cooperative Research Programme on Biological Resource Management for Sustainable Agricultural Systems is appreciated

Forever discovering
Te Kunenga ki Pūrehuroa
MASSEY UNIVERSITY

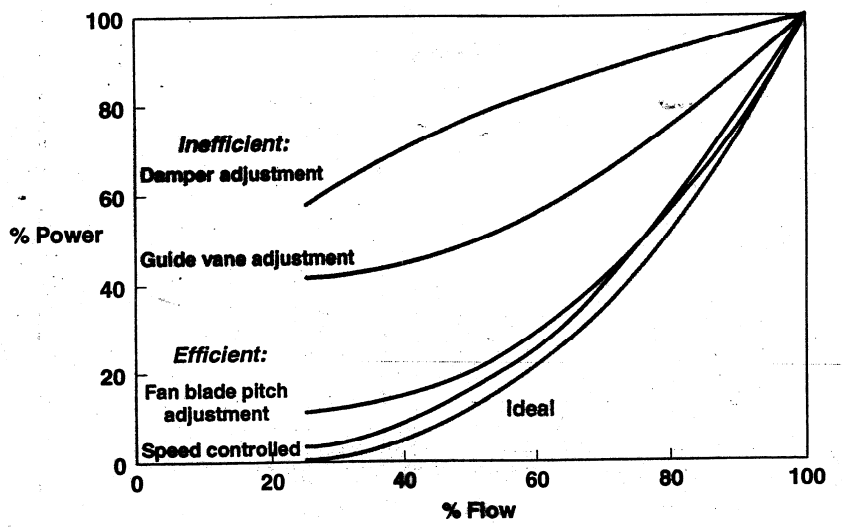
Questions

Fan Controls

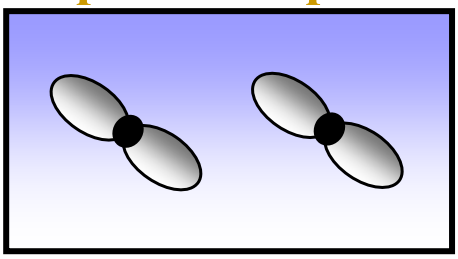
- On/Off
  - simple and cheap
  - non uniform
  - reduced power savings vs speed control
- Damper
  - relatively simple and cheap but little energy savings
- Multi-speed
  - higher capital
  - limited speed options
- VSD
  - highest cost but greatest benefit
  - ease of control across full range
  - slight efficiency overhead at full speed

Fan Speed Control

Power usage for various methods of reducing air flow



Multiple Two-Speed Fans



Fan 1	Fan 2	Capacity	Power
High	High	100 %	100 %
High	Low	75 %	59 %
~~High~~	~~Off~~	~~55 %~~	~~50 %~~
Low	Low	50 %	18 %
Low	Off	30 %	9 %
Off	Off	10 %	0 %