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Supermarket refrigeration research at Food Refrigeration and Process Engineering Research Centre (FRPERC)

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Food Refrigeration & Process Engineering Research Centre

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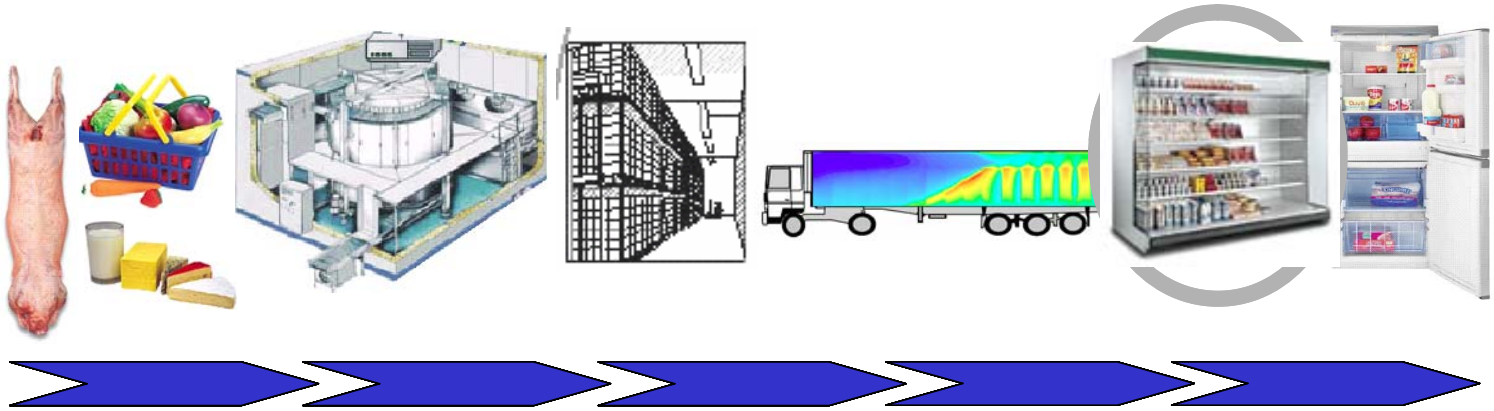

Whole cold chain:

Primary Chilling - Freezing, thawing & tempering - Secondary chilling - Chilled & frozen storage - Transport & distribution - **Retail** - Domestic handling

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Retail display

Ideally:

360° access

Customer able to interact with product, no barriers (i.e. doors)

All product on view

All at same temperature

Flexibility

Reality:

2D view of food

Food increasingly packaged

Product visibility often low

Large variations in temperature

Little flexibility

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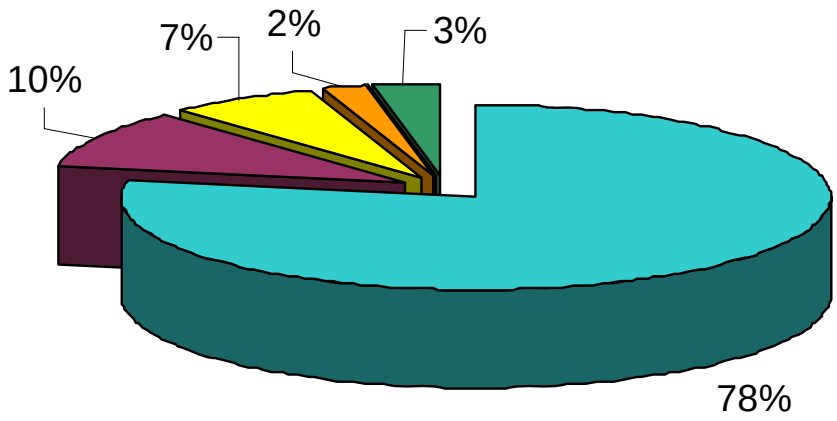
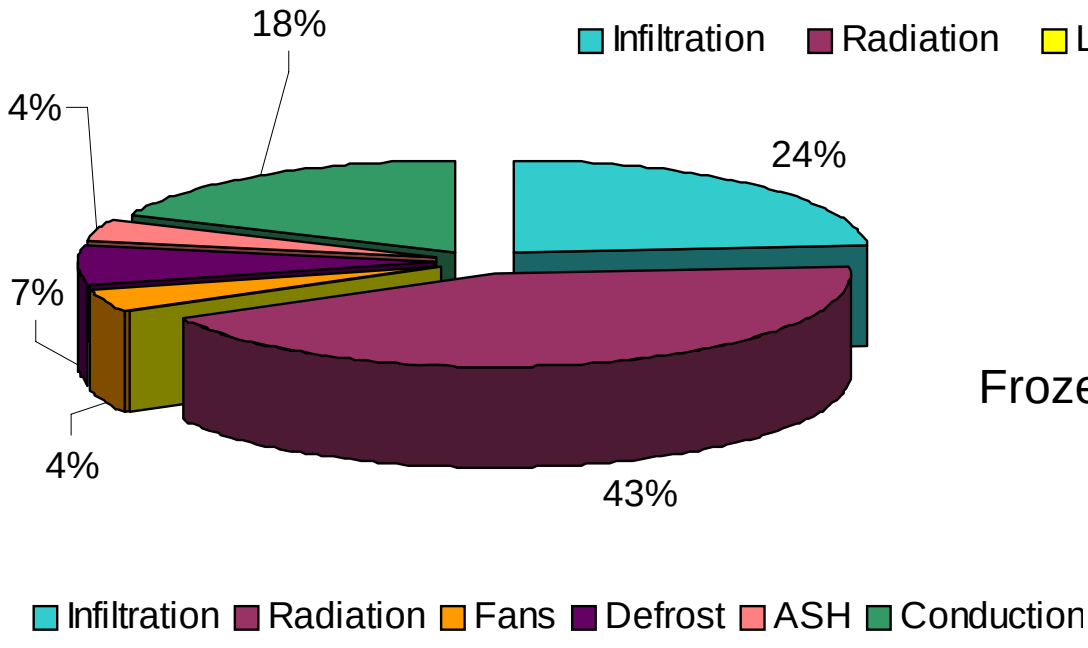
The problem

Chilled multi-deck





Frozen well

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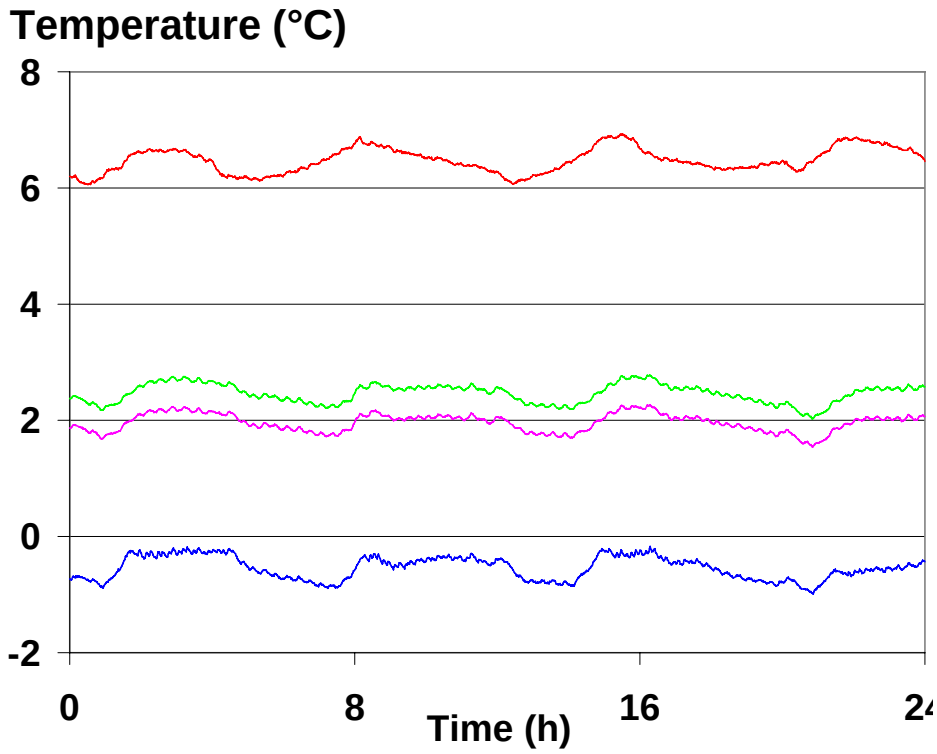
Data: Ashrae

The problem

- Weakest link in cold chain
- High energy consumption
- Range in temperature
  - Rear-front
  - Side-side
- Standards encourage temperature range
  - -1 to 5°C (M1)
  - -1 to 7°C (M2)
  - -1 or 1 to 10°C (H)
  - <-15, < -18°C (L1)
- Are these temperature ideal for food quality?



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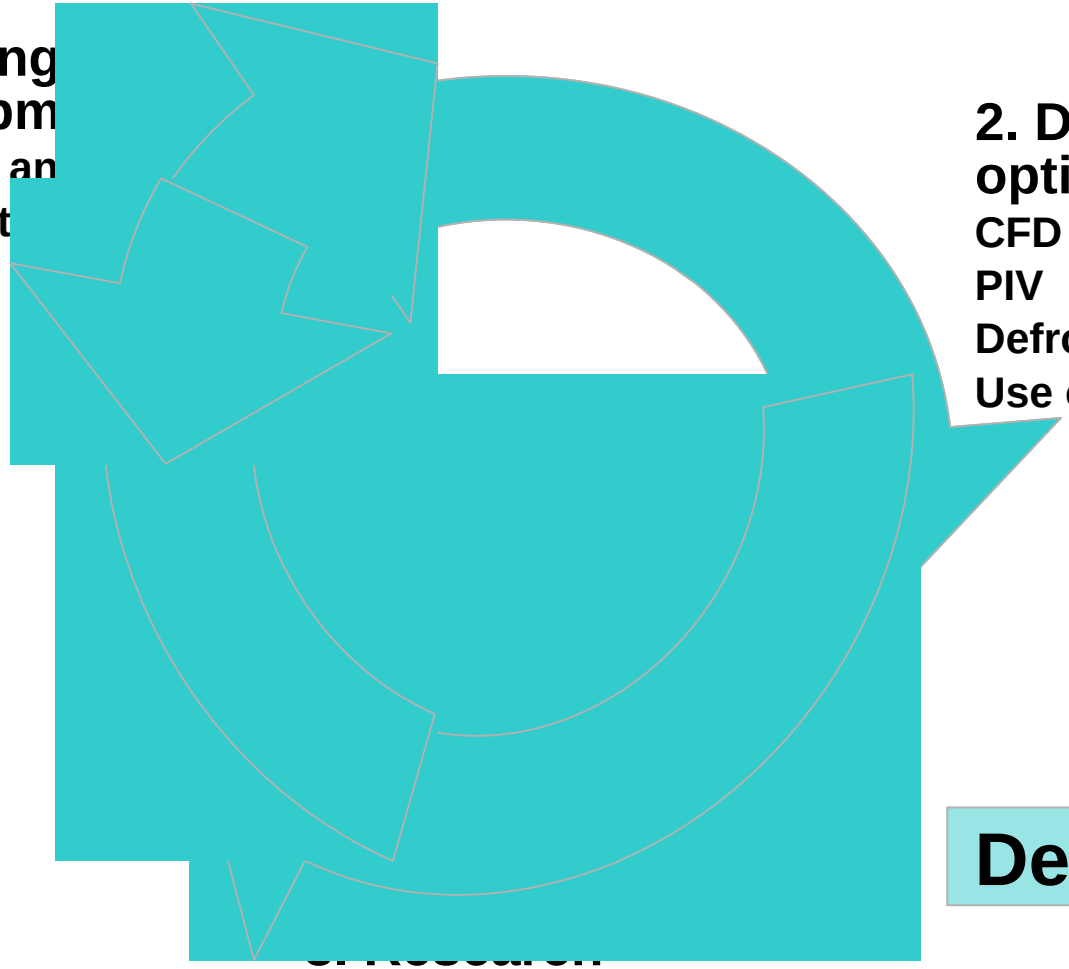
FRPERC areas of experience

1. Testing
developm
Standard an
bespoke t



2. Design and optimisation
CFD
PIV
Defrost optimisation
Use of hydrocarbons

Design rules

Air cycle
Supermarket comfort ('cold feet')
Humidification
Novel refrigerator design

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1. Testing and development

- **Tested over 500 cabinets**
- **Remote and integral cabinets**
- **Standard and bespoke tests**
- **Cabinet optimisation and development**
- **Information on the operation of a large number of cabinets**
- **Common design faults**

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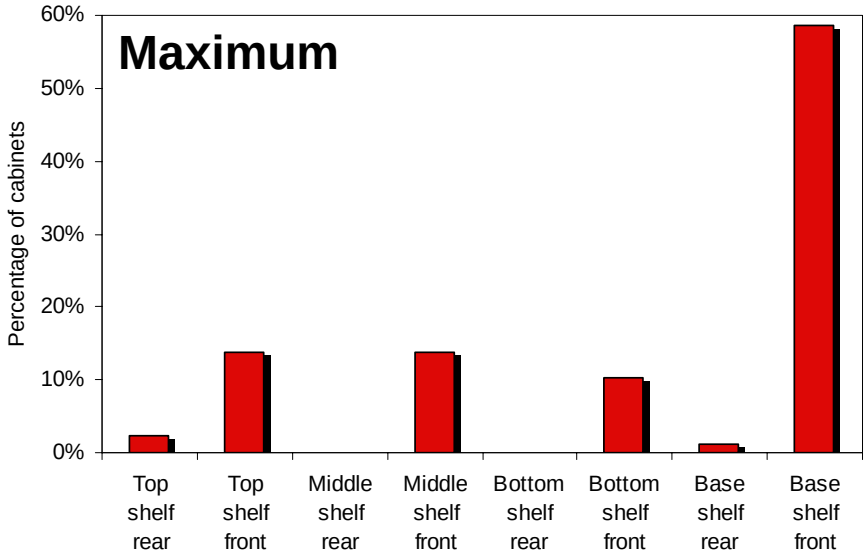
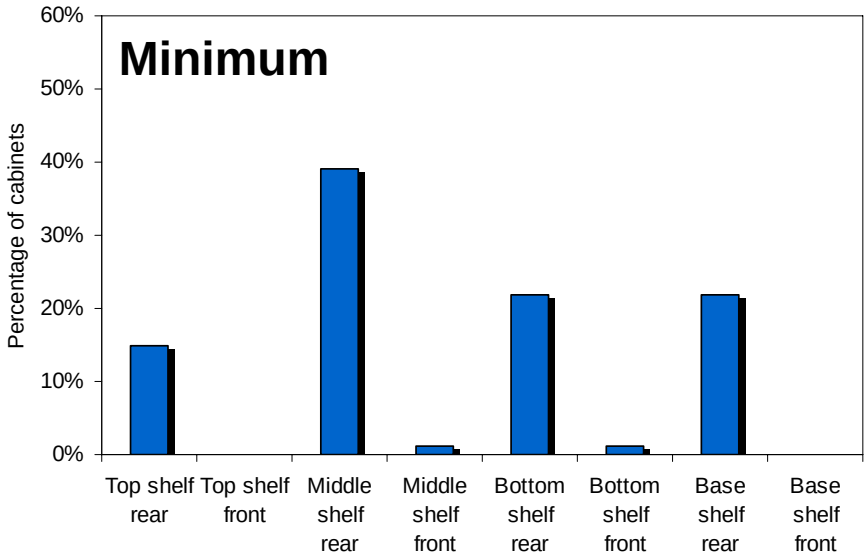
1. Testing and development





Multi-deck

Similarities in position of minimum and maximum temperatures in specific cabinet types

Evans J A, Scarcelli S, Swain M V L. Temperature and energy performance of refrigerated retail display and commercial catering cabinets under test conditions. International Journal of Refrigeration xx (2006) 1-12.

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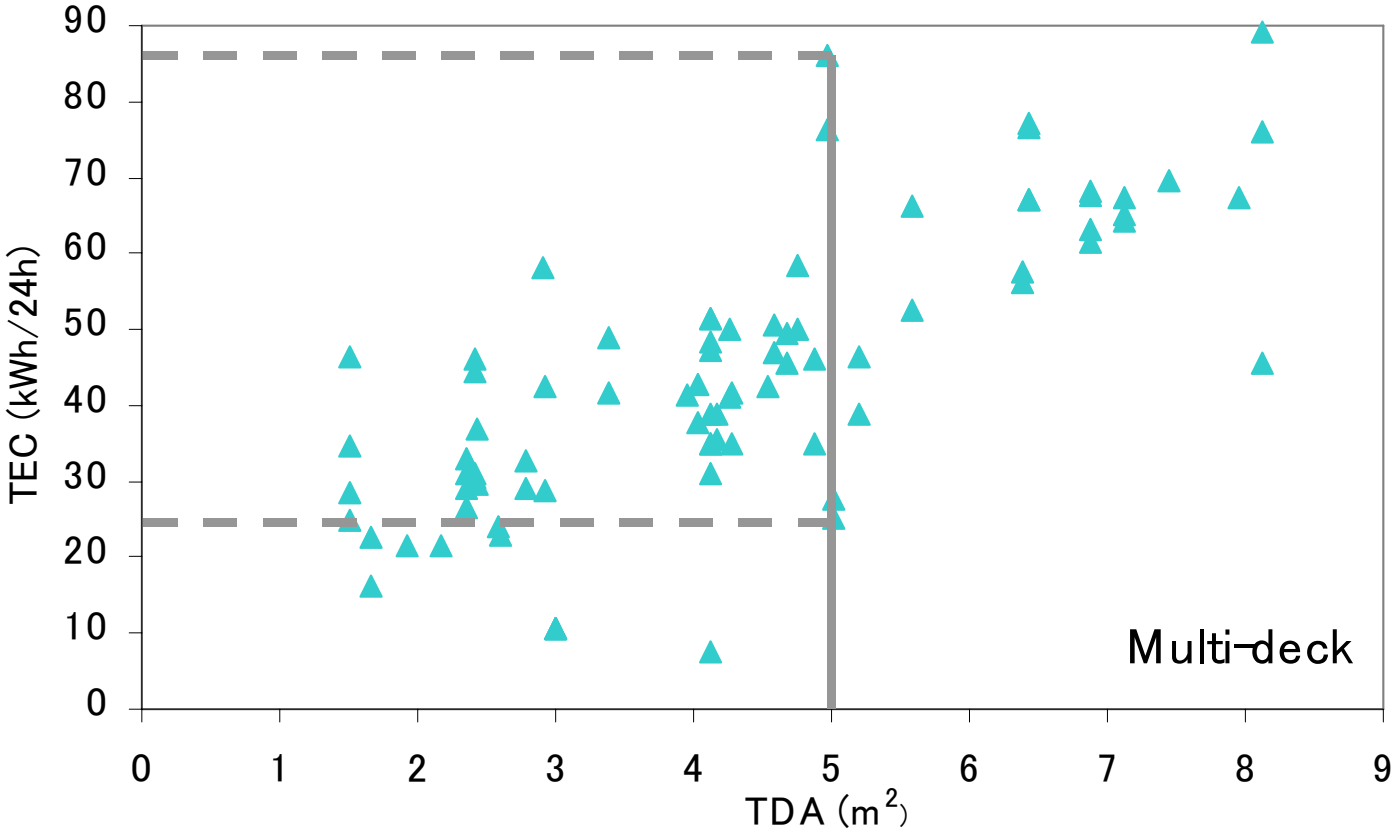
1. Testing and development



Large range in performance for cabinets that have similar functionality

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2. Design and optimisation

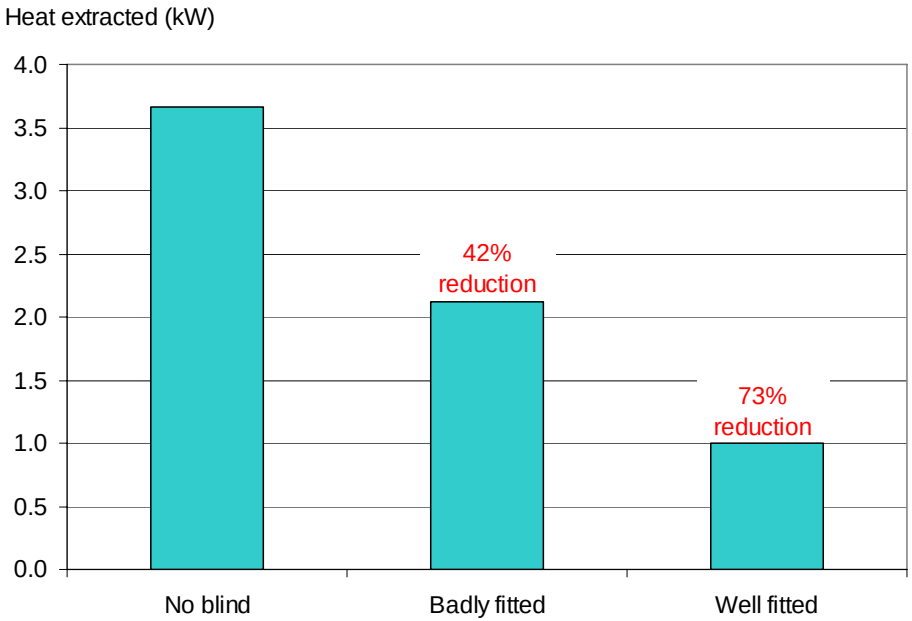
- General:
  - Design of pipe work, TEV etc often makes cabinet temperatures uneven
  - Cabinets sensitive to external interference
  - Designs often allow air to by-pass evaporator
  - Base plate should be insulated
- FGD/HGD cabinets:
  - Control system (defrost, EEVs, trim heaters)

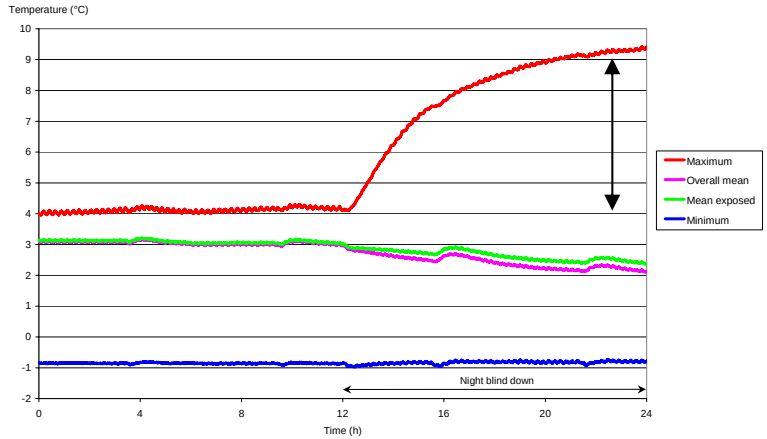
2. Design and optimisation

- Multi-decks:
  - Air flow uneven over shelves (some shelves temperatures lower)
  - Chute shelves largely unsuccessful (need optimisation?)
  - Rear evaporator design very difficult to optimise
  - Area of low pressure at 90° turn at rear base of cabinet
  - Design of rear grille important for even temperature distribution
  - Reduce distance DAG to RAG reduces energy and improves temperatures (risers) ≈ 8% saving in energy
  - Design of DAG very important
  - Curtain turbulence, 10%T to 3%T will reduce infiltration by 8%
  - Shelf front guides
  - 5% reduction in RH 5% reduction in total store energy
  - Double/triple air curtains

2. Design and optimisation – infiltration

- Infiltration (multi-decks):
  - Night blinds - should save majority of load due to infiltration
  - Not always fitted well
  - Localised increases in temperature





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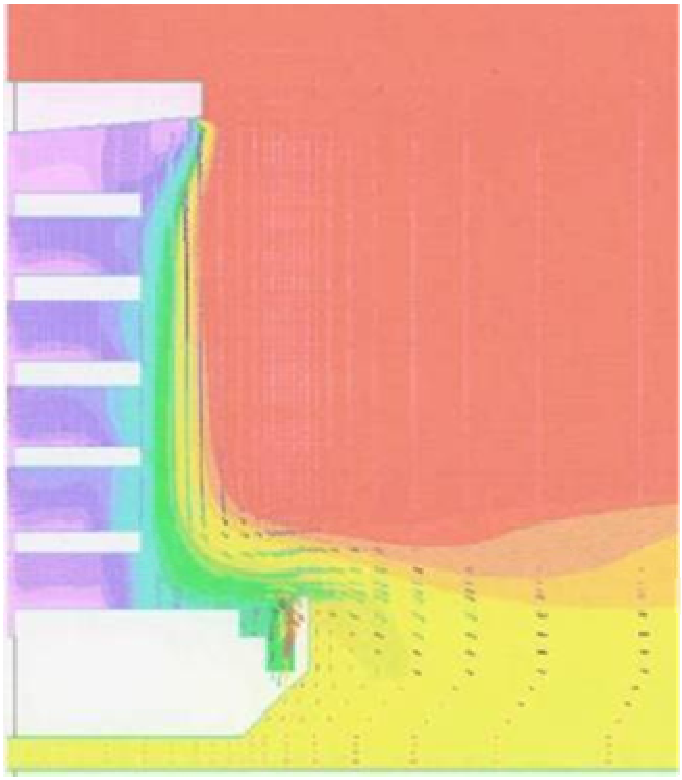
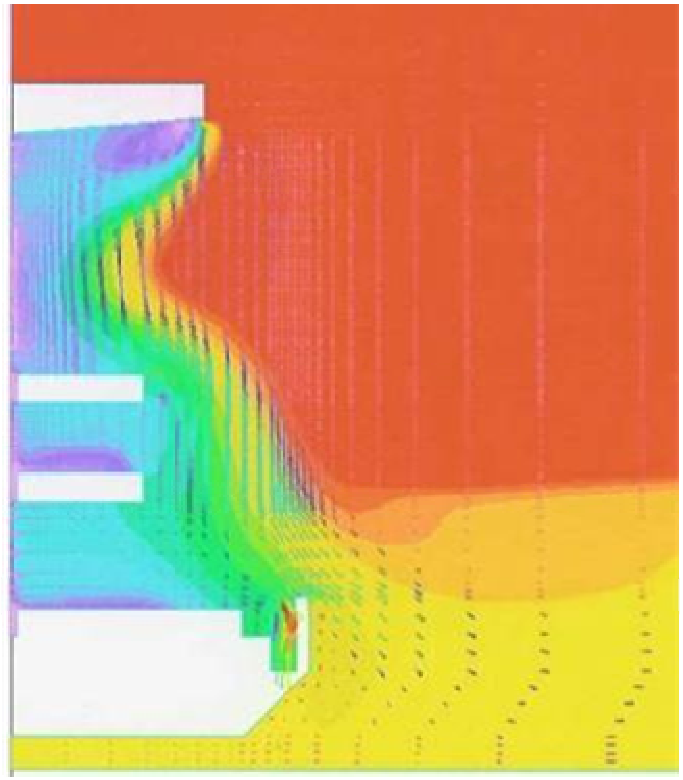
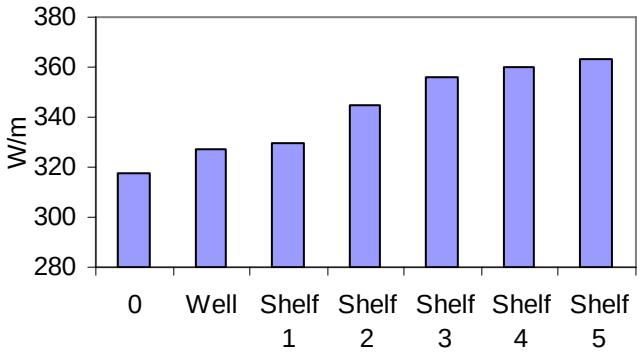
2. Design and optimisation – infiltration







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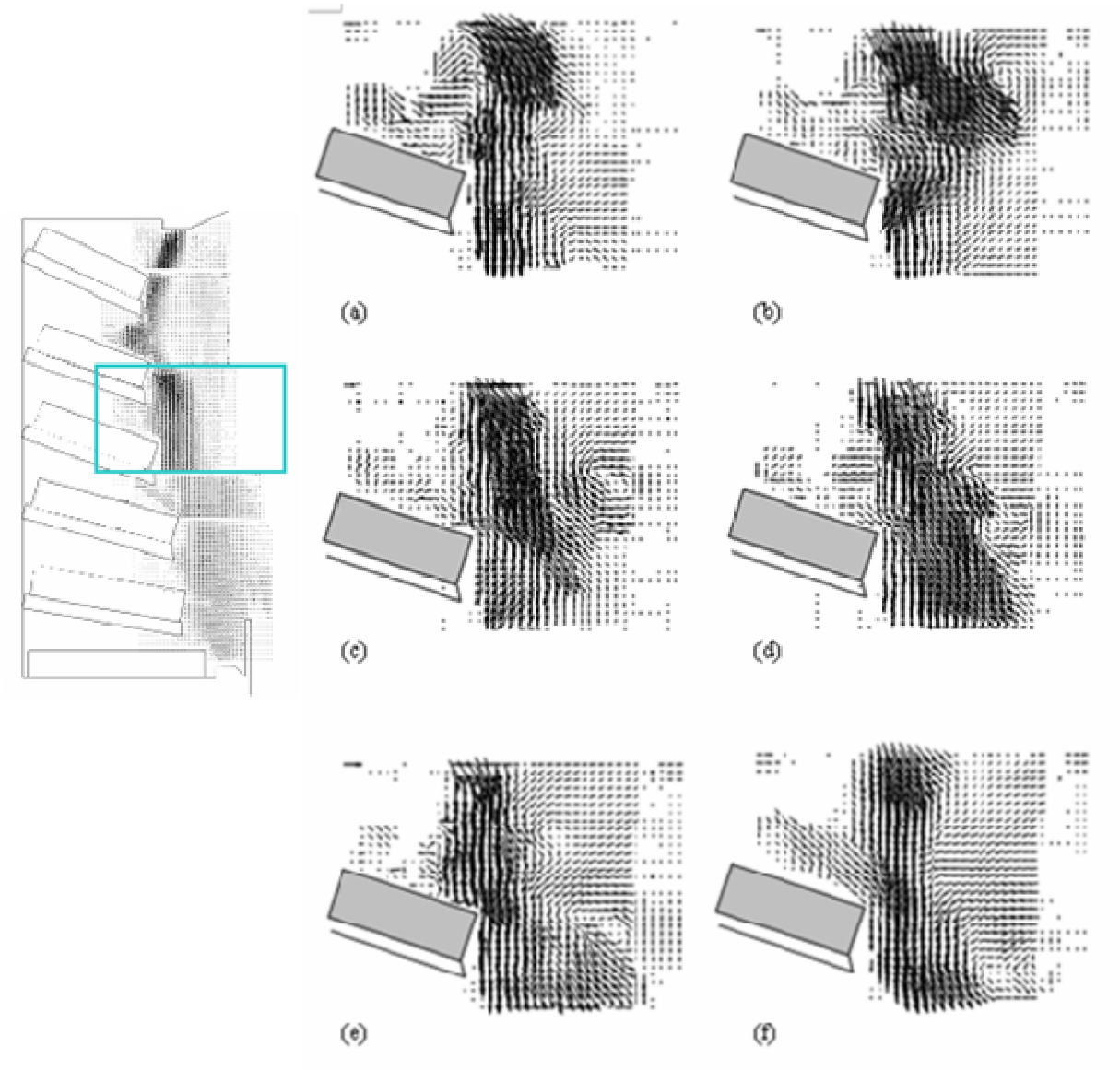
2. PIV



Velocity vectors from instantaneous PIV measurement

Time interval between each reading in the sequence (a) to (f) = 0.25 s.

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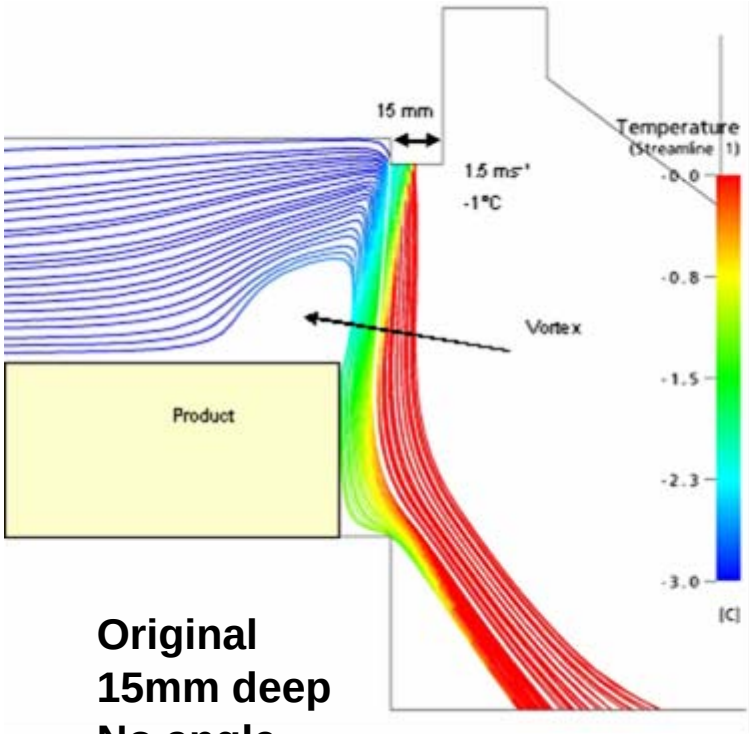
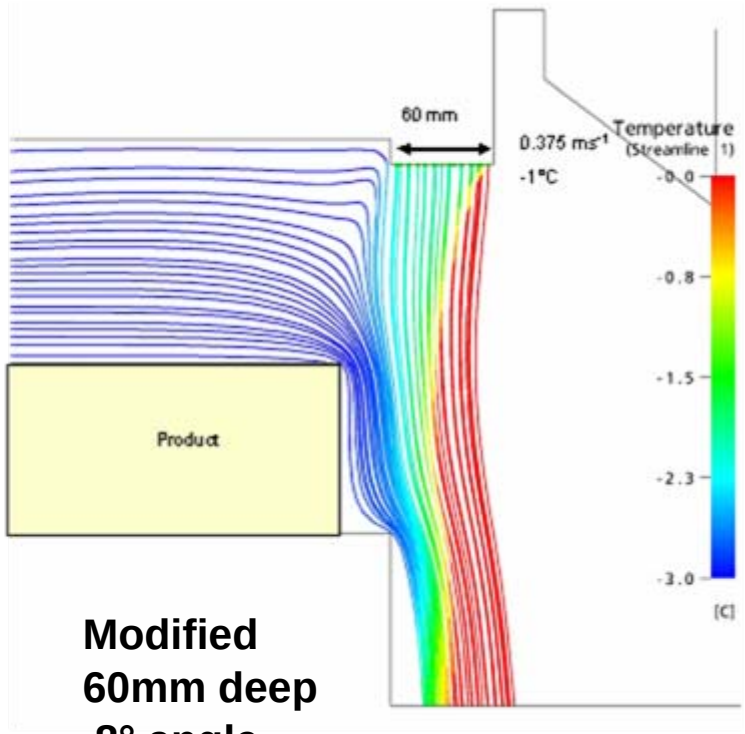
2. Design and optimisation – multi-decks - DAG



Original
15mm deep
No angle
1.5m/s, -1°C



Modified
60mm deep
8° angle
Same volume flow rate and temperature

Reduced temperature from M2 (-1 to 7°C) to M0 (-1 to 4°C) whilst maintaining the energy consumption

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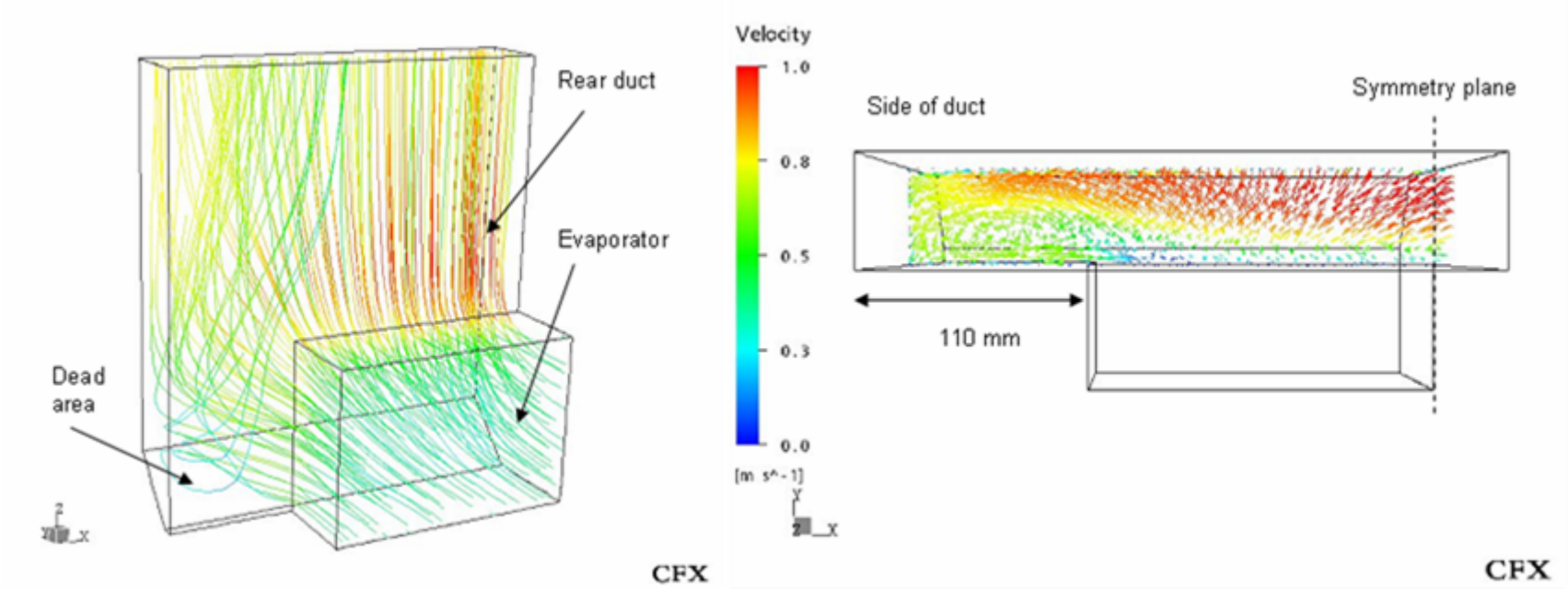
2. Design and optimisation– air flow

- ‘Dead’ area at edges of cabinet
- Caused spiral of air – tended to cause vortices as air entered cabinet from rear duct



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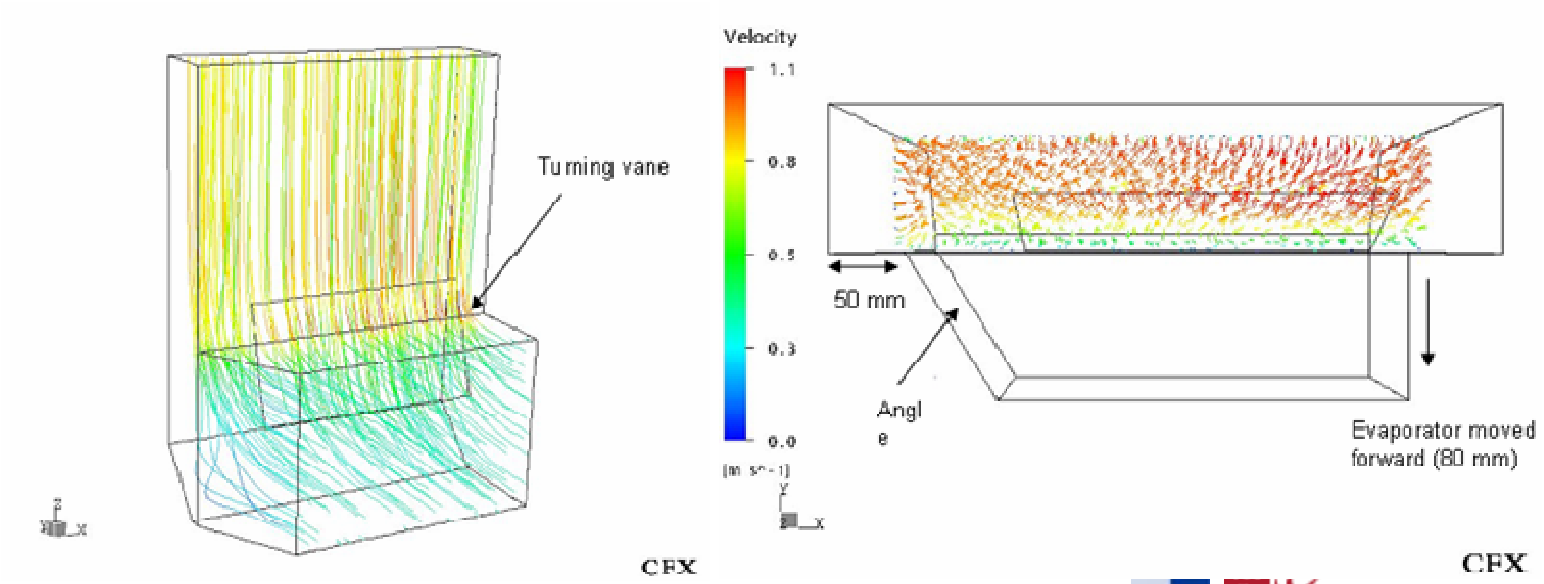
2. Design and optimisation– air flow

- CFD modifications:
  - Lengthen evaporator (reduce dead space)
  - Move evaporator towards front of cabinet and create an angled diffuser to allow the air to expand to the edge of the duct
  - Insert an angled plate at the bottom of the duct to increase the pressure and even out the flow



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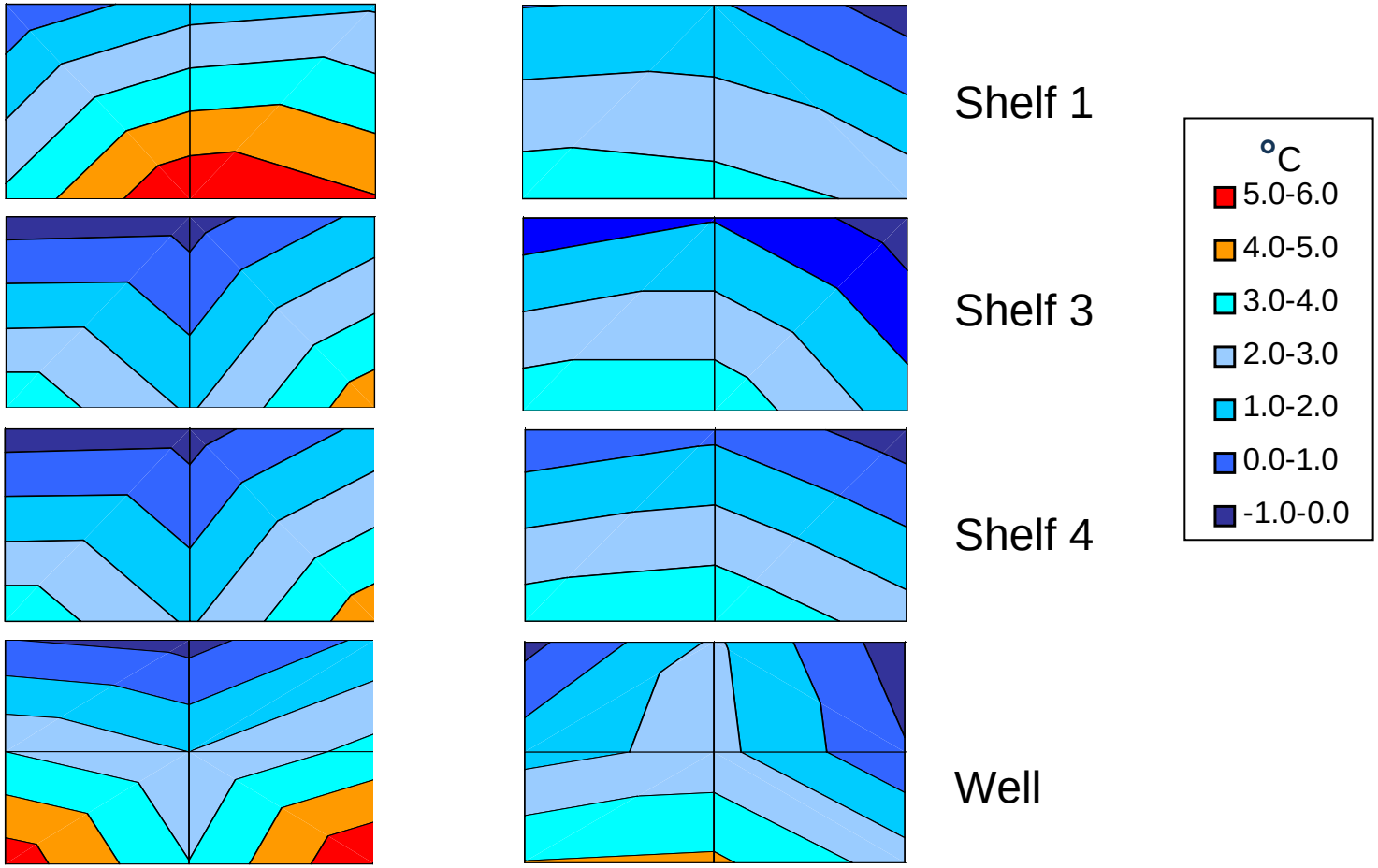
2. After modification



Before:
Maximum temperature = 6.9°C
Minimum temperature = -1°C
Average power = 1.37 kW

After:
Maximum temperature = 4.4°C
Minimum temperature = -1°C
Average power = 1.29 kW

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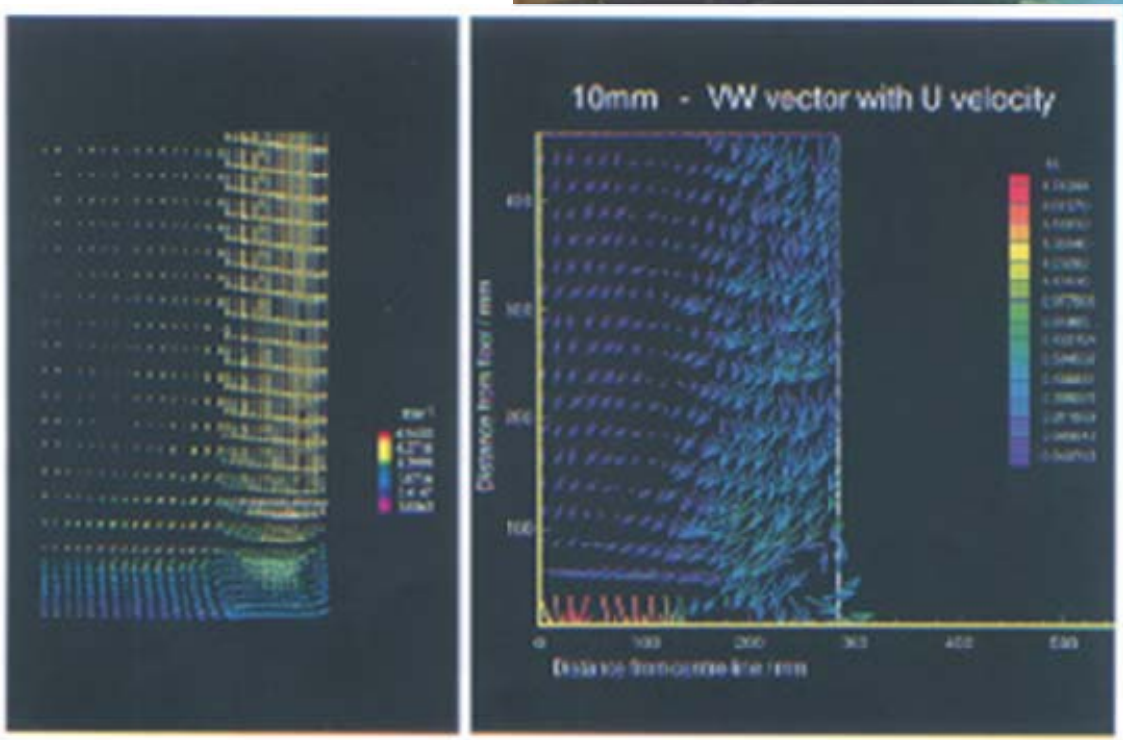
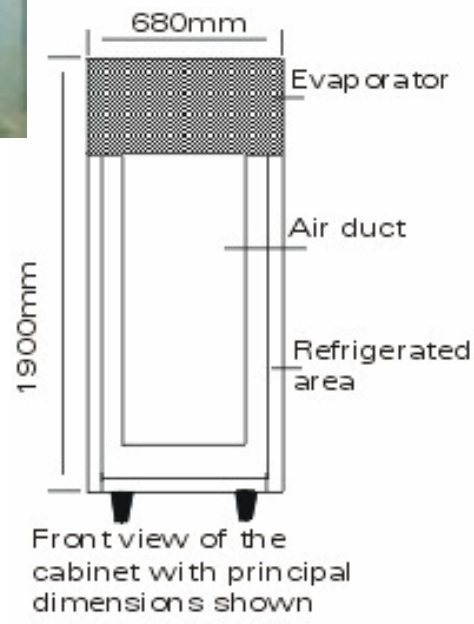
2. LDA/CFD





Front view of the cabinet with principal dimensions shown

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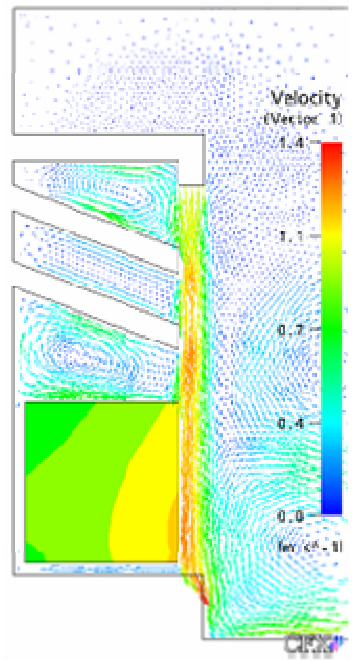
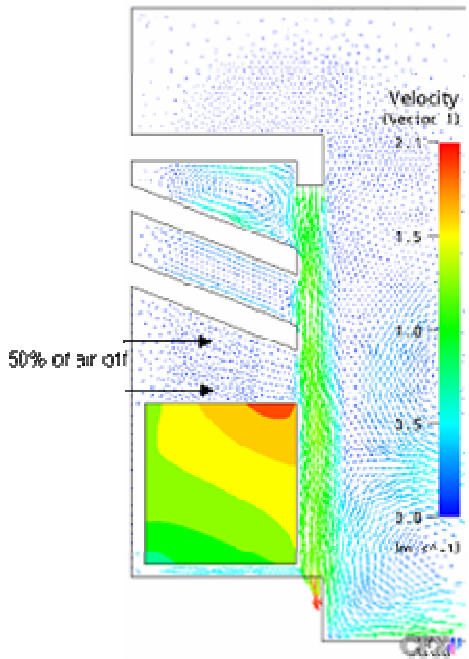
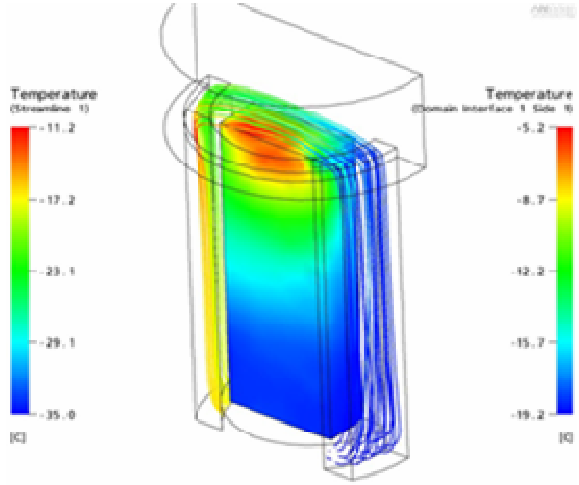
2. Radiation

- Radiation
  - Reflective packaging - reduce by 50%
  - Mirrored ceilings (above well), 2ºC drop in product temp







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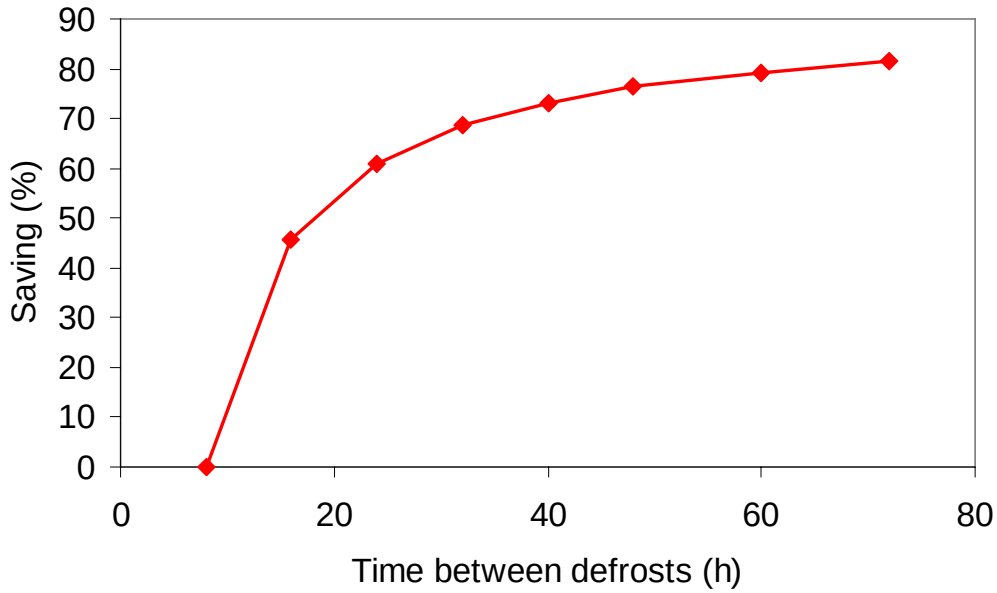
2. Lighting and fans

- Up to 45% electrical saving (claimed) DC fans
- 63% electrical savings (claimed) by better lighting of store and inverter (4% total)
- LED lights (almost no heat generated), long life (50,000 hours)

2. Defrosts

- Defrost optimisation (frozen well)
- Defrost energy = actual energy + overhead (85%)
- Supermarket with 40 cabinets, 56,880 kWh/yr (saving of 24.5 tonnes of CO_2)



- Pulse electro-thermal de-icing (PETD)
- Multi evaporator defrosting

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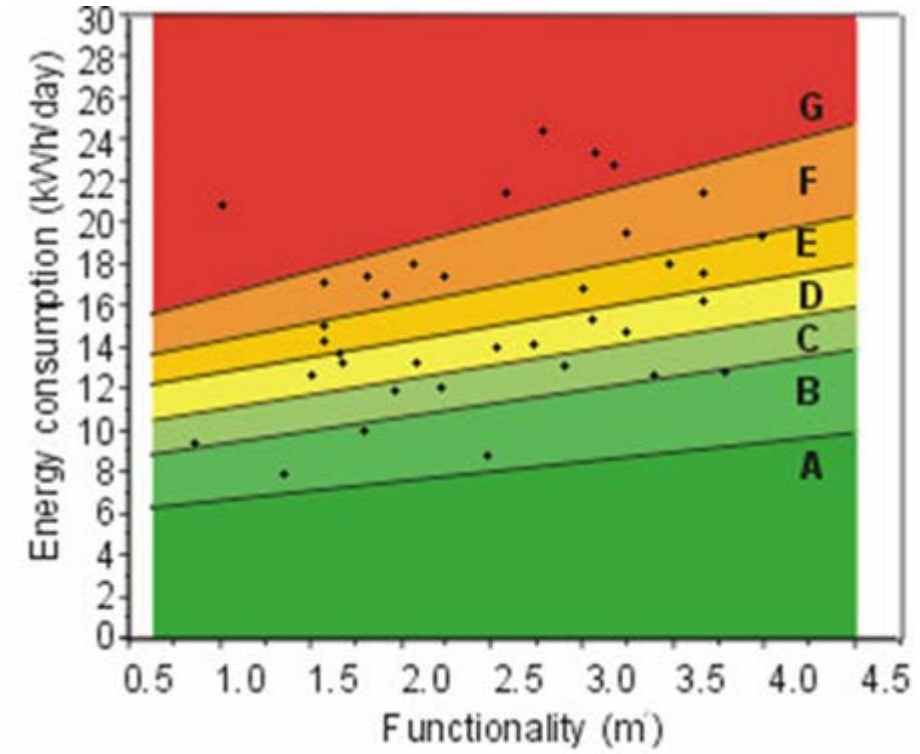
2. Refrigeration system

- Evaporate at higher temperatures
  - Multi-evaporator defrost - reduce T by up to 8ºC
  - High efficiency heat exchangers - increase htc by 60 to 93%
- Inverter compressors - especially integrals
- Localised cooling
- Conversion to hydrocarbons (integral refrigerators and production lines)

3. Energy labelling

- EU SAVE
- Simple method to identify energy efficient models
- Proven that rank order in terms of efficiency of cabinets does not change when using an actual refrigeration plant instead of standard plant
- Introduced basic ‘representative’ cabinet
- Concept developed into UK ECA scheme



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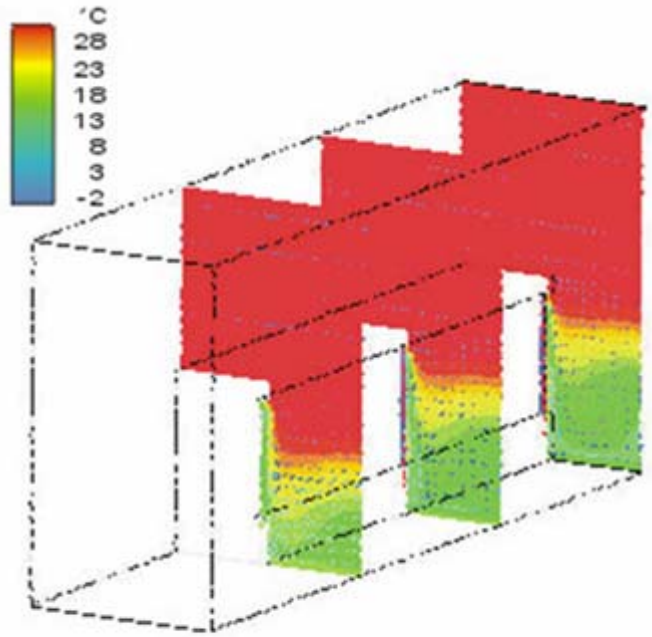
3. Ventilation and containment

- Removing the ‘cold feet effect’ from supermarket stores
- LINK project (1999)
- Asda Stores, Safeway Stores,
  J Sainsbury
- Strategies:
  - Supermarket A - heated floors
  - Supermarket B - fans in the kick plates
  - Supermarket C - diffusers in the ceiling
- CFD to reduce stratification



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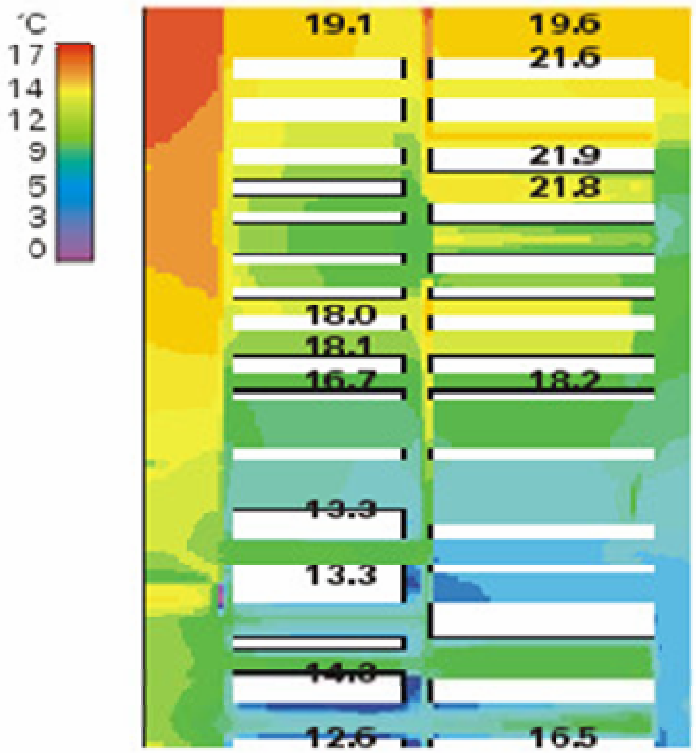
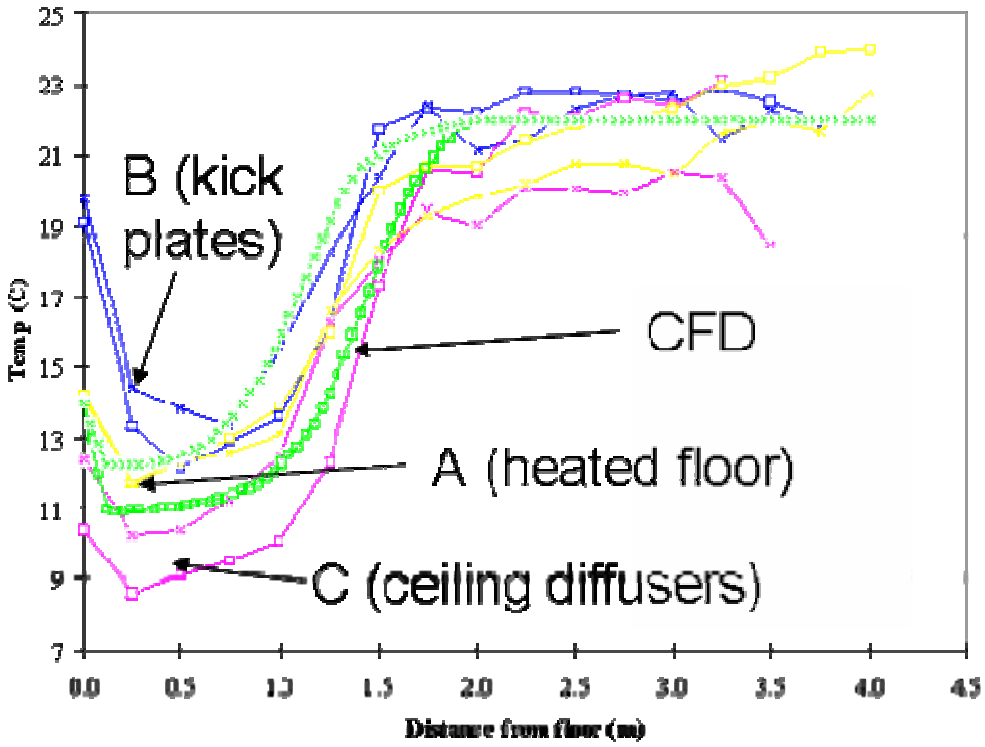
3. Ventilation and containment





Supermarket A., plan view 0.25m height, CFD prediction, measured temperatures superimposed

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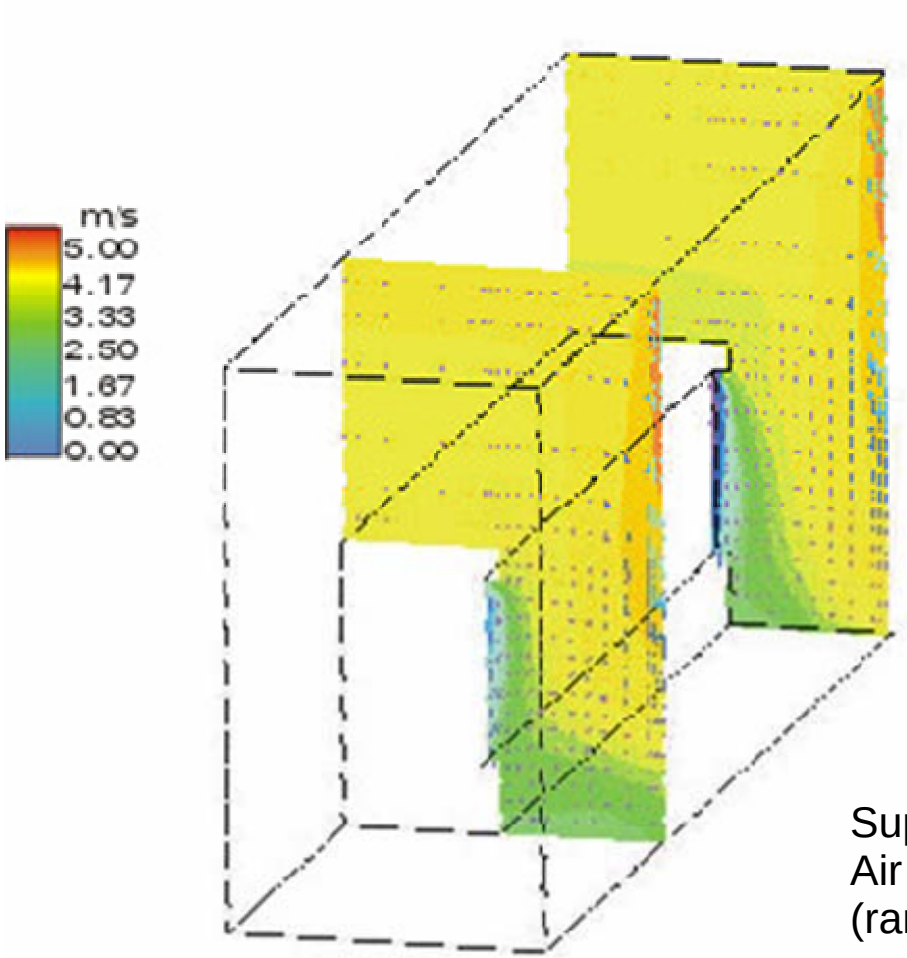
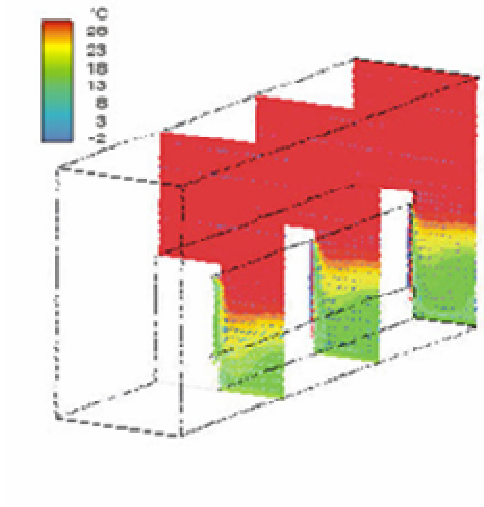
3. Ventilation and containment





Supermarket C
Air exit diffuser at 5 rather than 1 m/s
(range –2 to 29° C)

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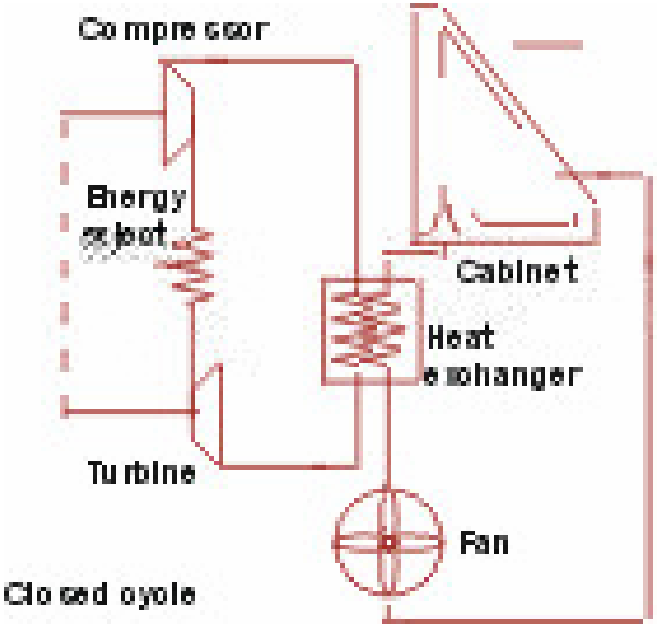
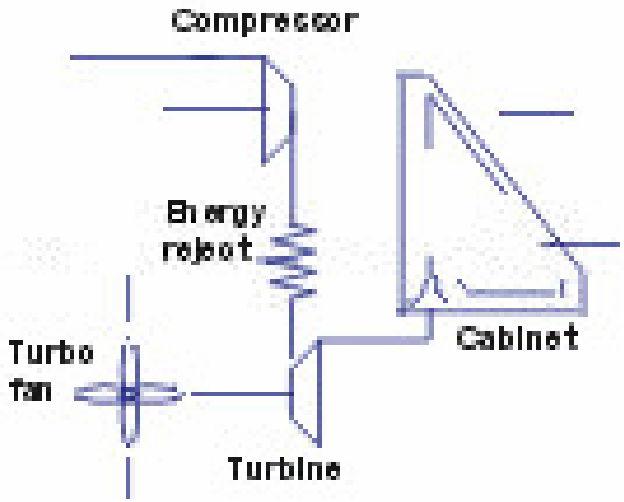
3. Air Cycle

- LINK (1998)
- Air as a refrigerant – environmentally benign
- High losses of refrigerant from supermarkets (15-30% /yr)
- Chilled multi-deck, frozen well
- ‘Turbofan’ (compressed air expanded in turbine, connected to fan)
- Open or closed cycle, open used (novel ejector to recycle air)





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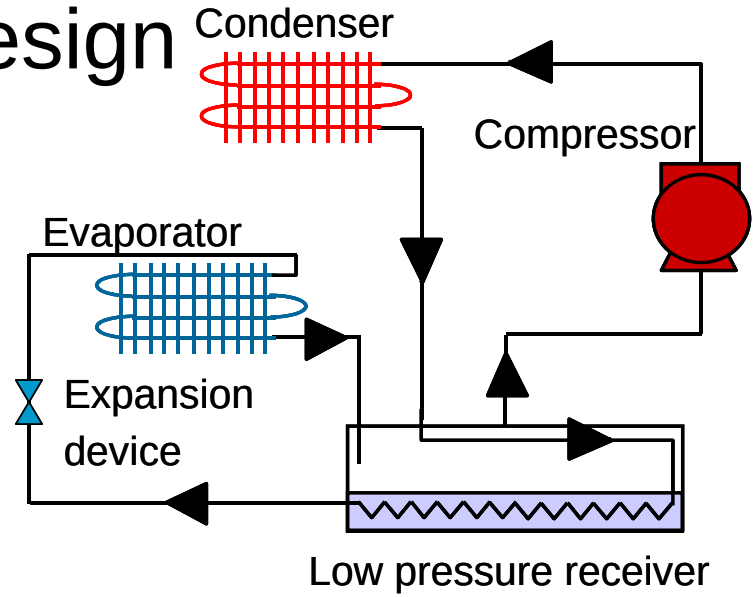
3. Novel refrigerator design

- Independently variable temperature (-20 to +15°C)
- Multi-capillary system with low pressure receiver
  - Low cost
  - Reliable
  - Overfeed evaporator
  - Evaporator surface fully utilised
  - Improved thermodynamic efficiency
  - Superheat control not necessary
  - Greater reliability
- No air exchange on opening
- Easy access to contents
- No cross contamination



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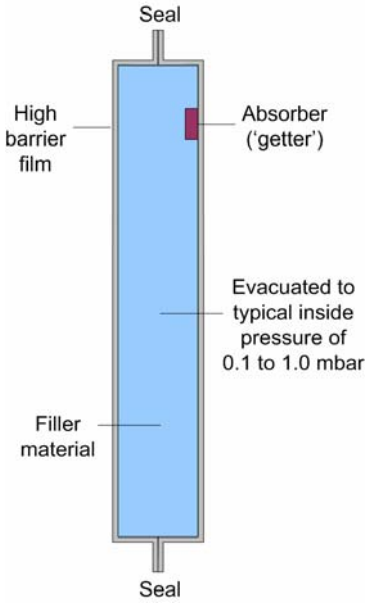
3. VIPs (Vacuum Insulated Panels)

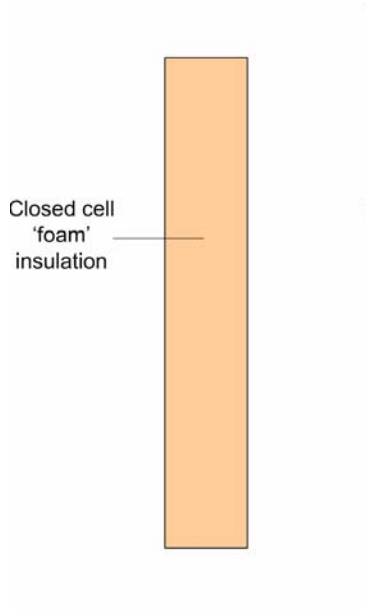
VIP

Conductivity less than 0.005Wm^{-1}K^{-1}



PU

Conductivity typically 0.025Wm^{-1}K^{-1}



- **Highly efficient insulation materials**
- **Conductivities up to 5 times lower than typical current insulation such as polyurethane (PU)**
- **Made by evacuating the air from a micro-porous filler material enclosed in a high barrier film**

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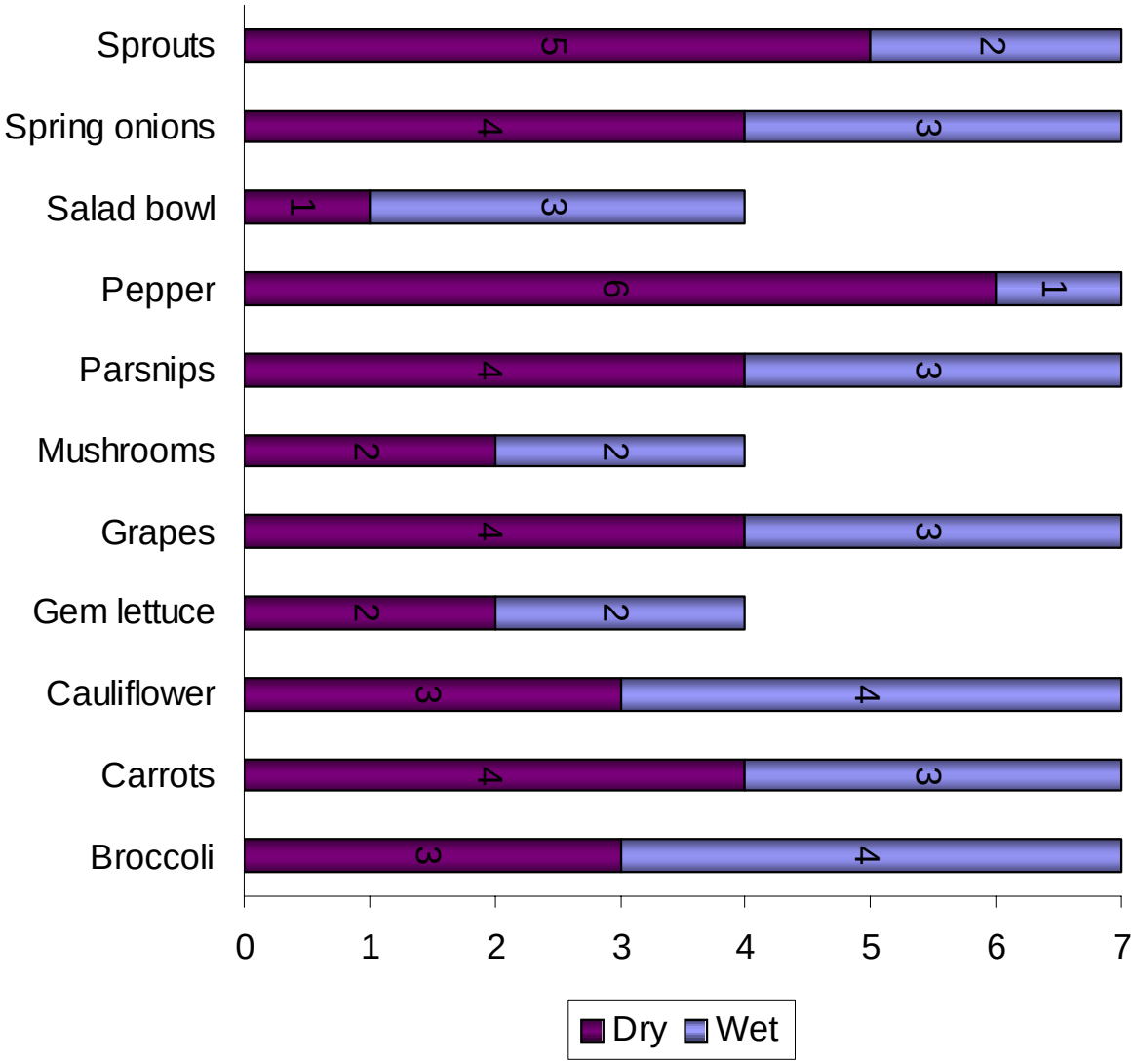
3. Humidification of retail display cabinets

- Use of ultrasonic humidification in display cabinets for unwrapped meats and vegetable produce
- Benefits:
  - Reduced evaporative weight losses
  - Increased display life (and thereby reduced waste)
  - Up to 50% increase in shelf life
  - No adverse microbial effect
  - Minimal effect on cabinet performance
  - No *Legionella* sp. in humidification water

3. Humidification - produce



Extension in shelf life

due to humidification

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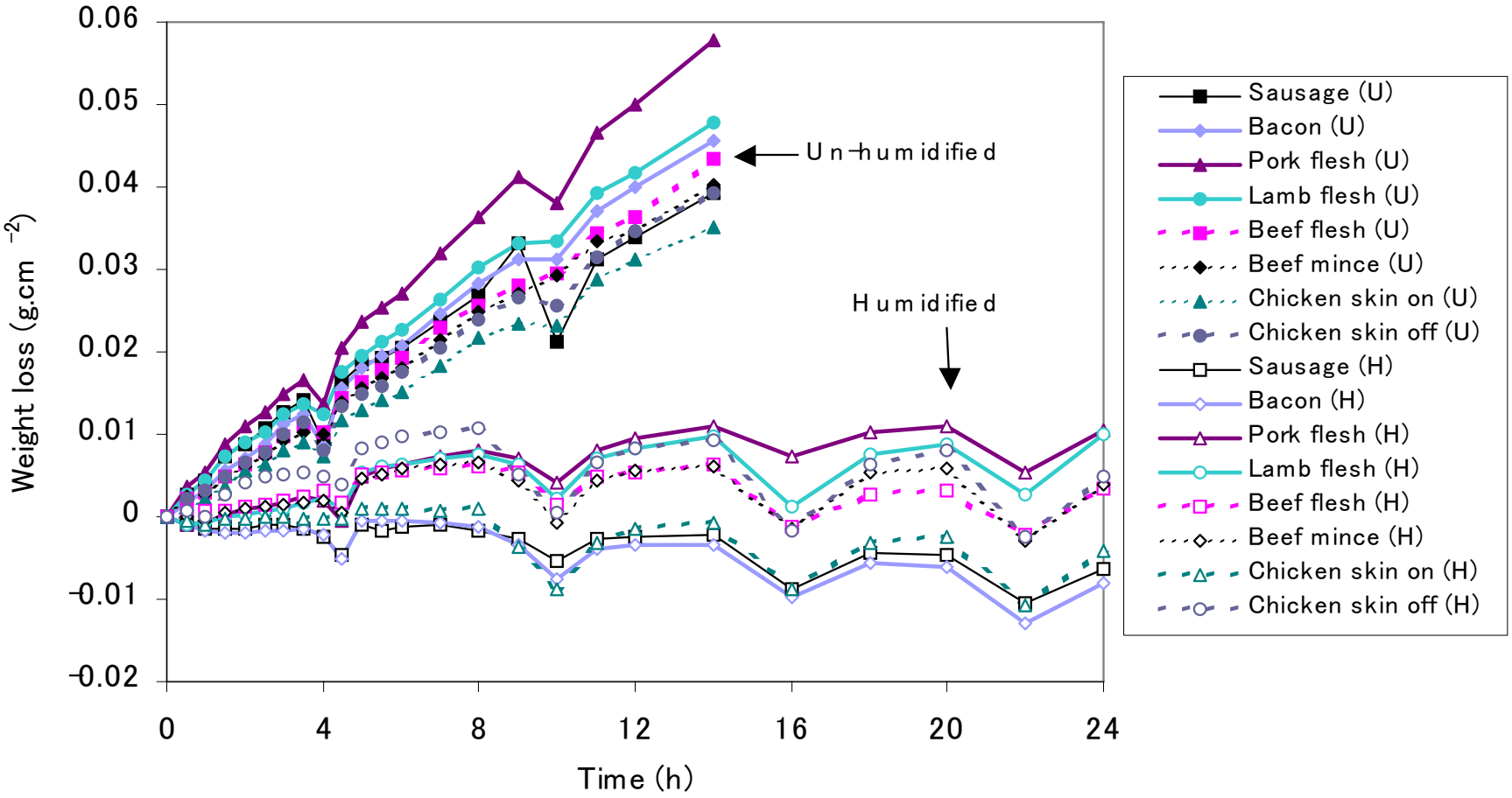
3. Humidification - meat



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Rules learnt from work

- Large differences between cabinets currently on market
  - Cabinets often not fully optimised (air flow, TEV, controls etc)
- A lot of cabinets have the same design faults
- Some of these are real challenges to solve
- Ambient conditions have a large effect of performance
- Balance between food quality value and energy consumption costs
- Novel designs often not developed due to:
  - Timescales
  - Practicality in fitting into preset supermarket configuration
  - Cost
  - Supermarket/food producer constraints
  - Expectations (consumer+supermarket)

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Further information:

www.frperc.bris.ac.uk

With thanks to:

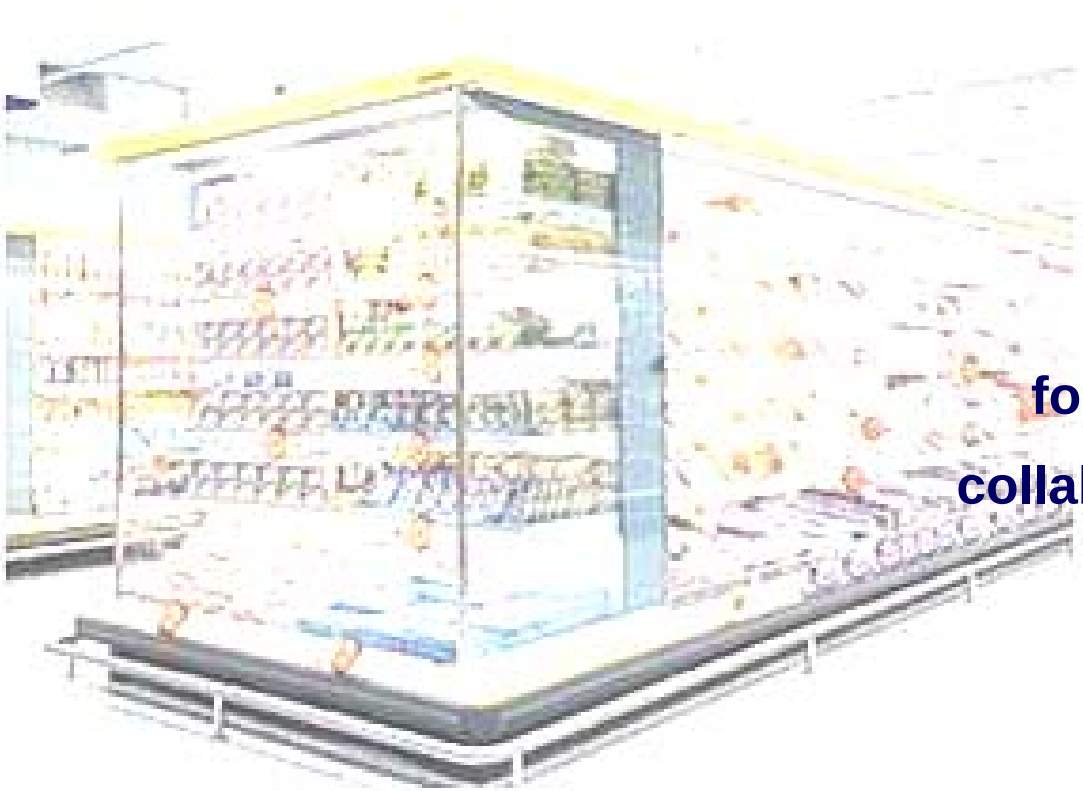
Adande Refrigeration

Dantec Dynamics

JTL

Pastorfrigor

for allowing us to publish collaborative research work



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