Refrigerated Display Cabinets

Progress made and research and development issues

Brunel University

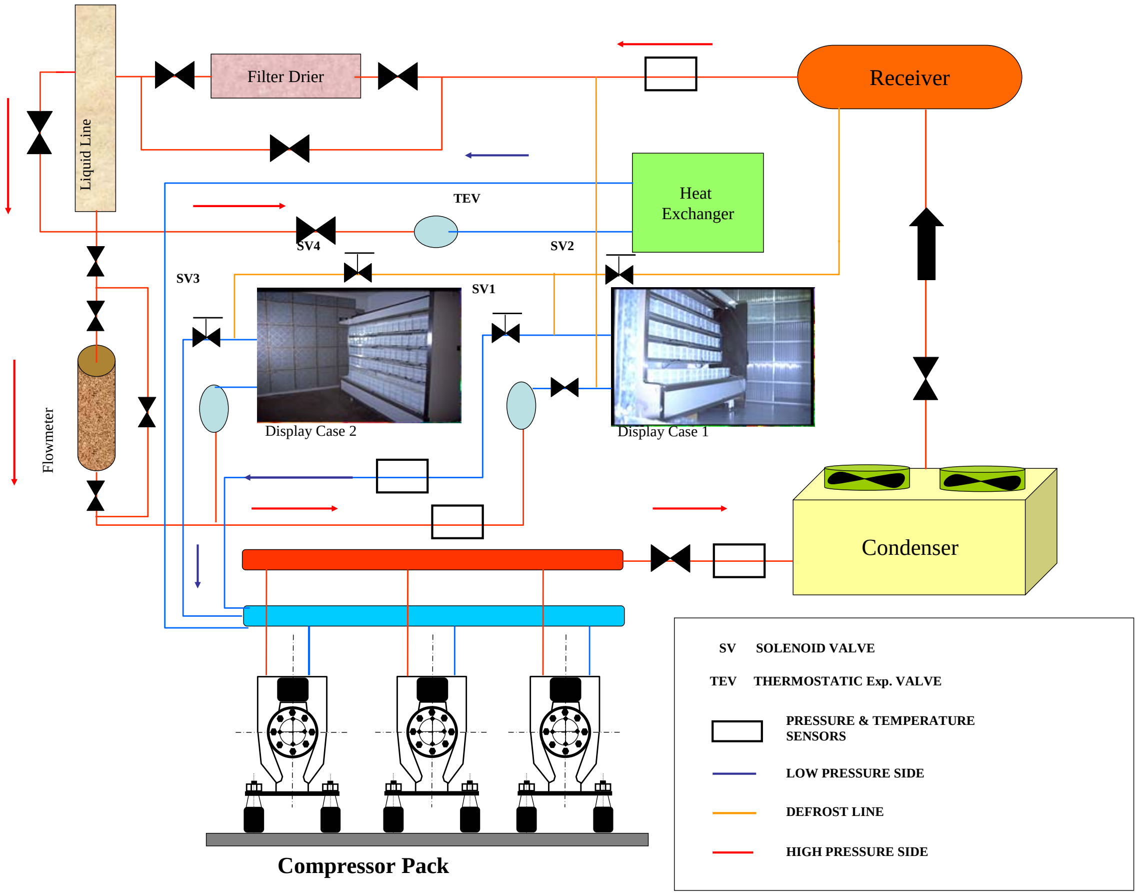
Professor Savvas Tassou

Brief History

1. Work started as a collaboration between Safeway Stores PLC and Brunel University back in 1994. CASE Studentship funded by EPSRC and Safeway– David Stribling
2. Followed by a PhD by Dr Weizhong Xiang
3. A recent PhD by Dr Abas Hadawey
4. A current PhD project by Ahmad Al-Sahhaf
5. Other investigations funded by DEFRA and EPSRC (Drs Deborah Datta, Richard Watkins and Issa Chaer).

Test facilities and Modelling Tools

- Environmental test chamber to be able to test at EN441 conditions.
- Replication of refrigeration pack and typical supermarket control system in the laboratory for research on modelling and control
- CFD simulation – one of the 1st applications of CFD to display cabinet modelling



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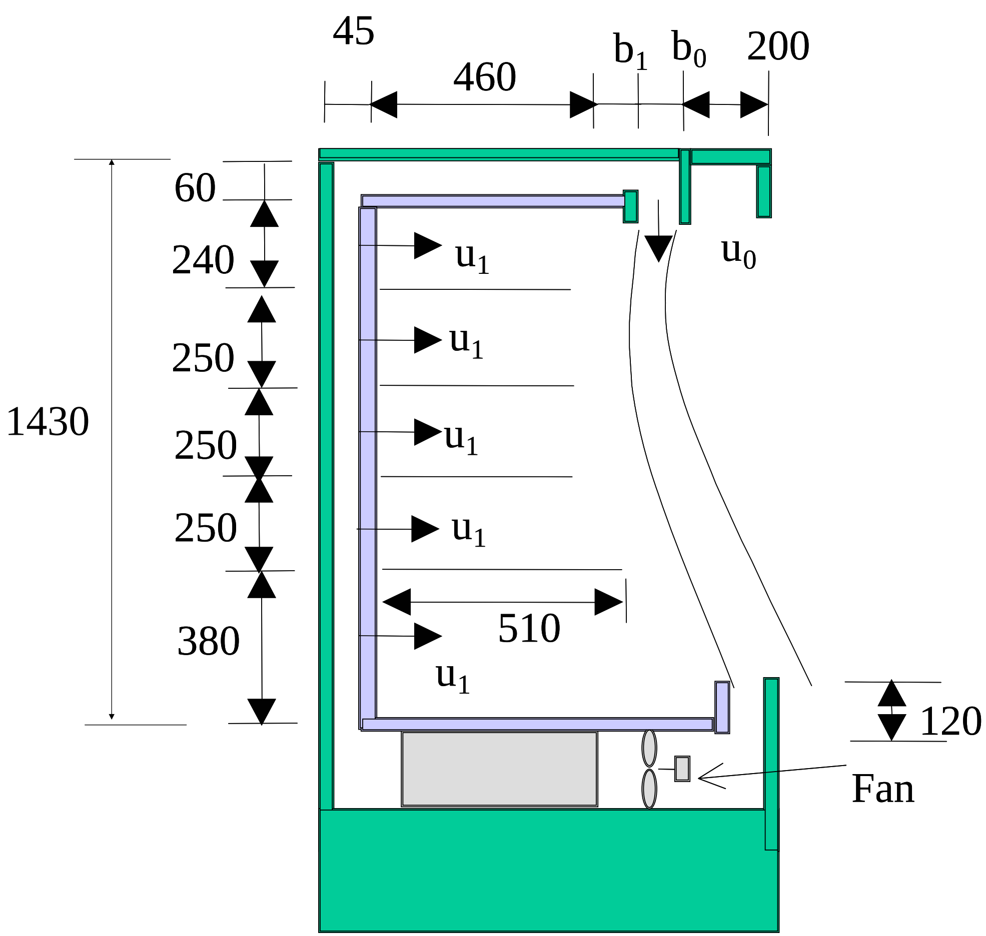
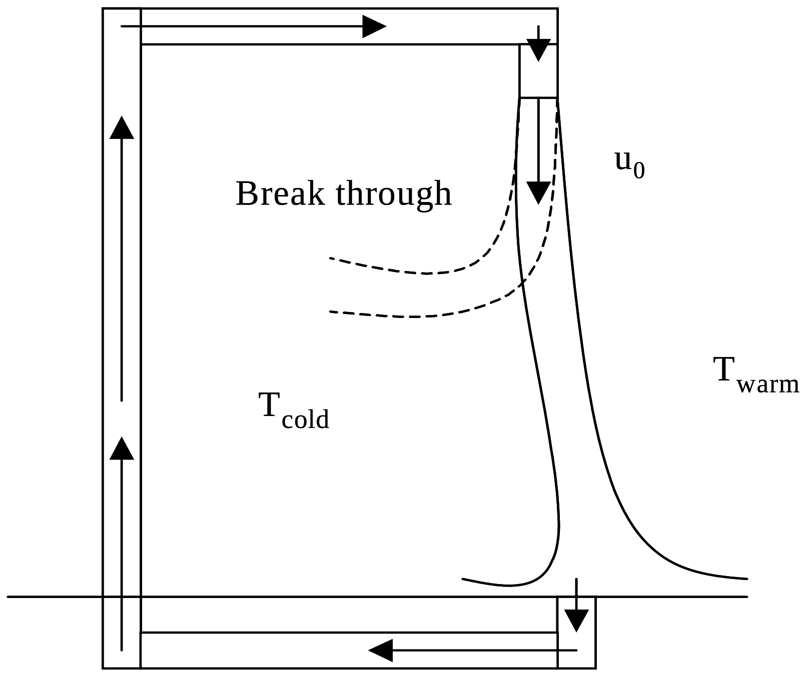
Multi-deck cabinet design issues





$$D_m = \frac{(\rho_0 b_0 u_0{}^2)}{gH^2(\rho_c - \rho_w)}$$

Deflection modulus = 0.14~0.18

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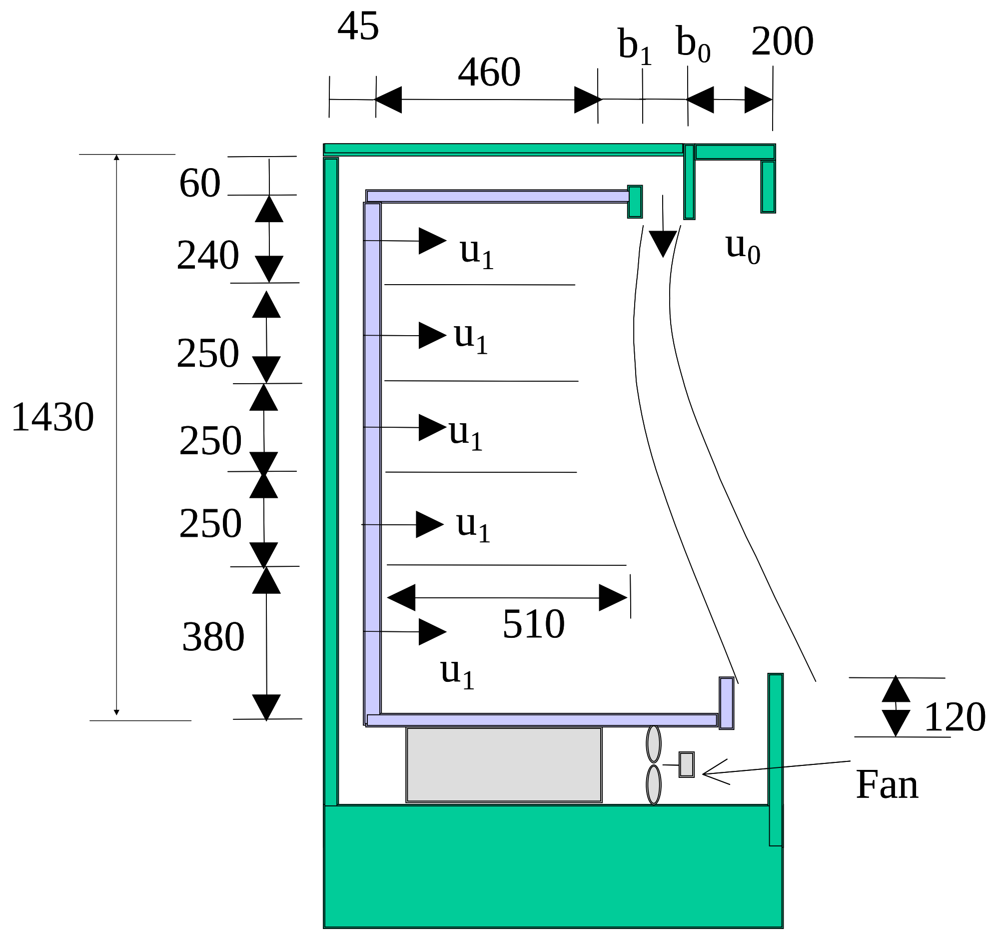
Multi-deck cabinet design issues



H = Opening height
b_o= Air curtain slot width
u_o = air curtain initial velocity
ρ_c = density of cold air in cabinet
ρ_w= density of space air
ρ_o= density of air at air curtain discharge

$$D_m = \frac{(\rho_0 b_0 u_0{}^2)}{gH^2(\rho_c - \rho_w)}$$

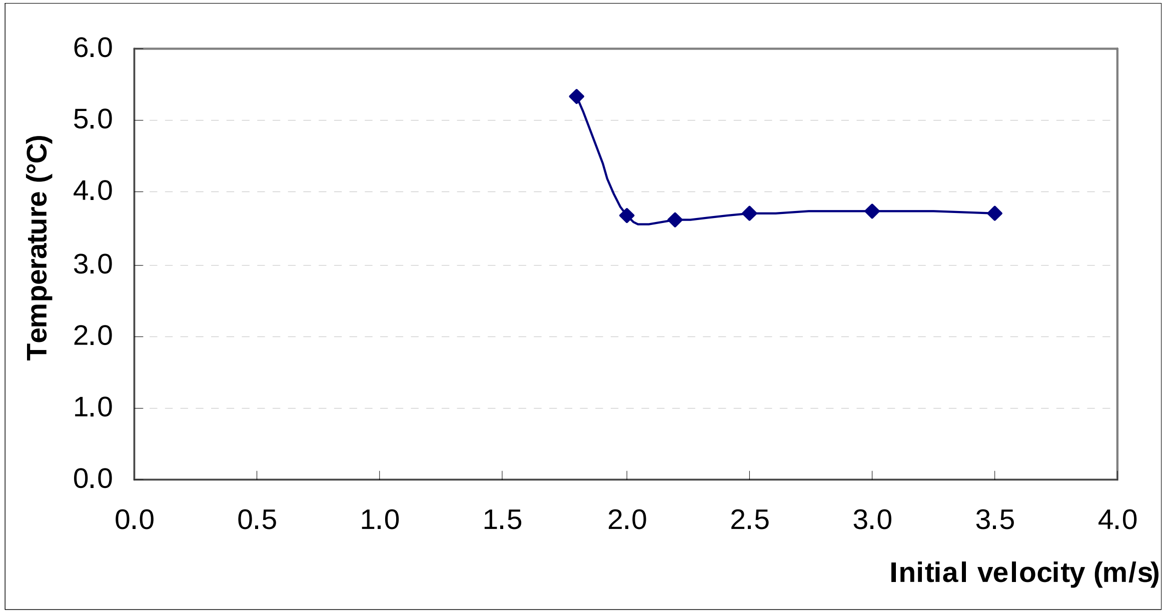
$$D_m = \frac{b_o . u_o^2}{g.H^2\left[\left(\frac{T_o}{T_c} - \frac{T_o}{T_w}\right)\right]}$$

Deflection modulus = 0.14~0.18

Multi-deck cabinet design issues

Minimum initial air curtain velocities for non-isothermal air curtains.
Slot width = 60 mm

Height of opening (m)	Minimum velocity (m/s)	Minimum air flow rate (m^3/s/m)
0.25	0.4	0.023
0.40	0.64	0.038
0.60	0.96	0.057
0.80	1.11	0.089
1.00	1.60	0.096
1.20	1.92	0.115
1.38	2.24	0.134



Multi-deck cabinet design issues

$$u_o^{\ 2} = \frac{0.18.g.H^2\left(\frac{T_o}{T_c} - \frac{T_o}{T_w}\right)}{b_o}$$

- Experiments and simulation have shown that for multi-deck cabinets *H* should be the maximum distance between shelves in the cabinet
- Increasing the slot width should reduce the velocity required to provide good sealing
- A loaded cabinet will require a lower air curtain velocity to provide good sealing
- Back panel flow to the shelves will aid the air curtain particularly when the cabinet is not fully loaded.

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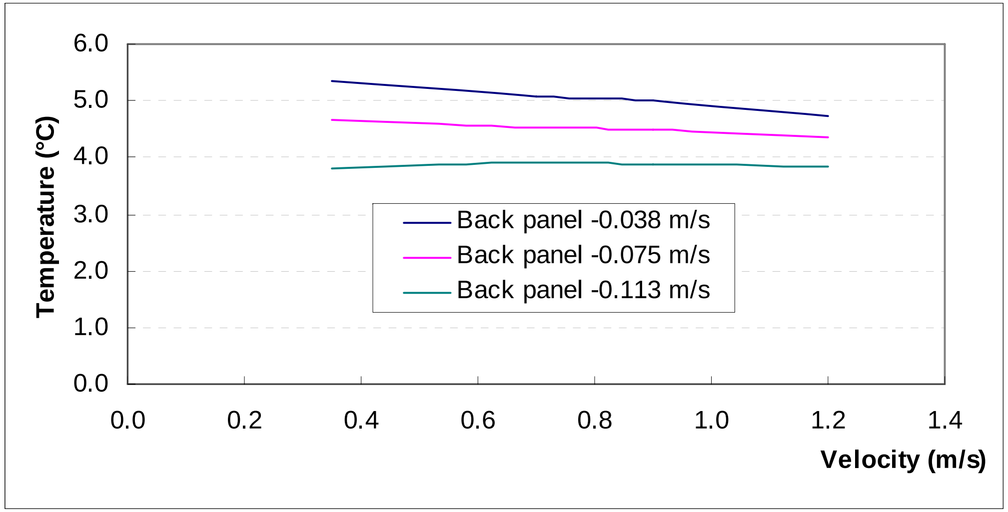
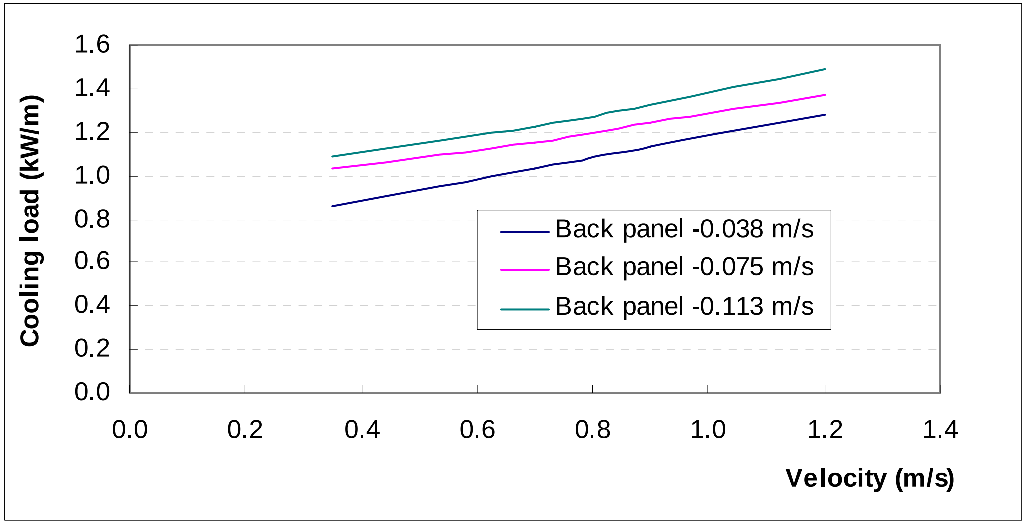
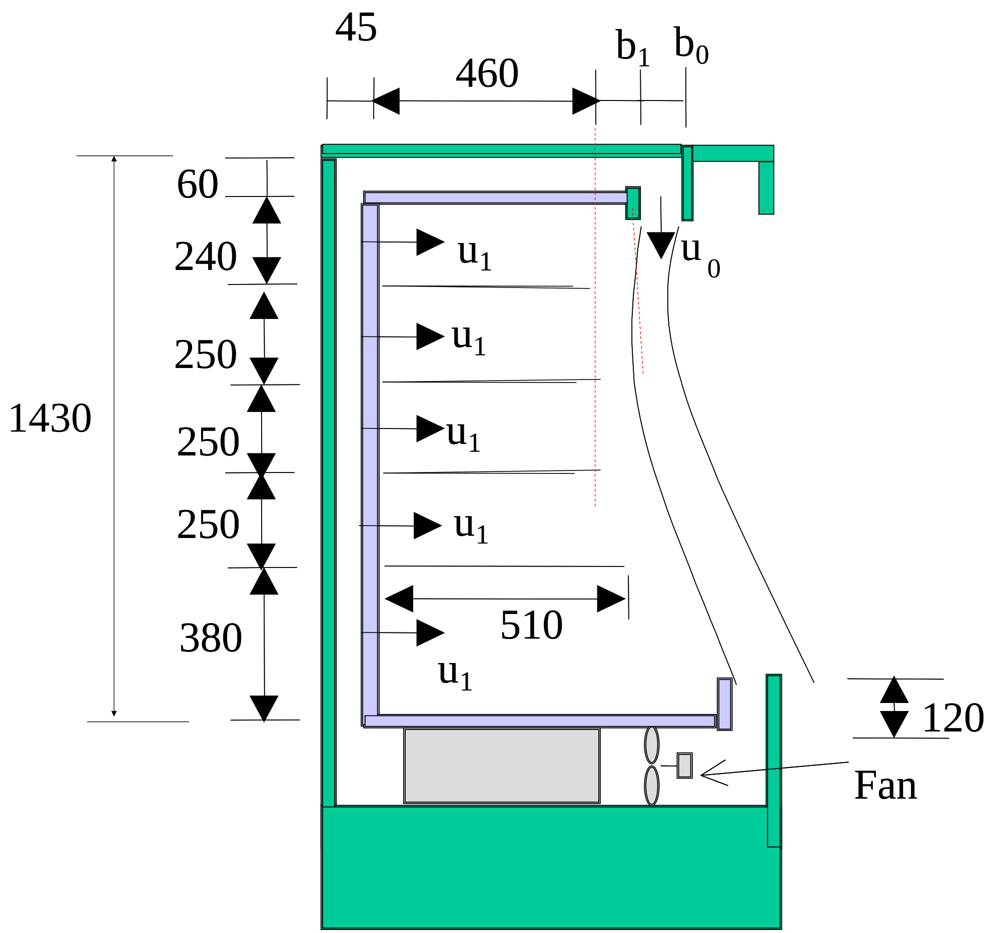
Multi-deck cabinet design issues

- Back panel flow to the shelves can help maintain lower product temperature
- High back panel flow reduces the flow requirement from the air curtain
- Increasing the air curtain flow increases the refrigeration load.





Multi-deck cabinet design issues
Air curtain position



- Position of air curtain discharge in relation to edge of shelve can influence performance.

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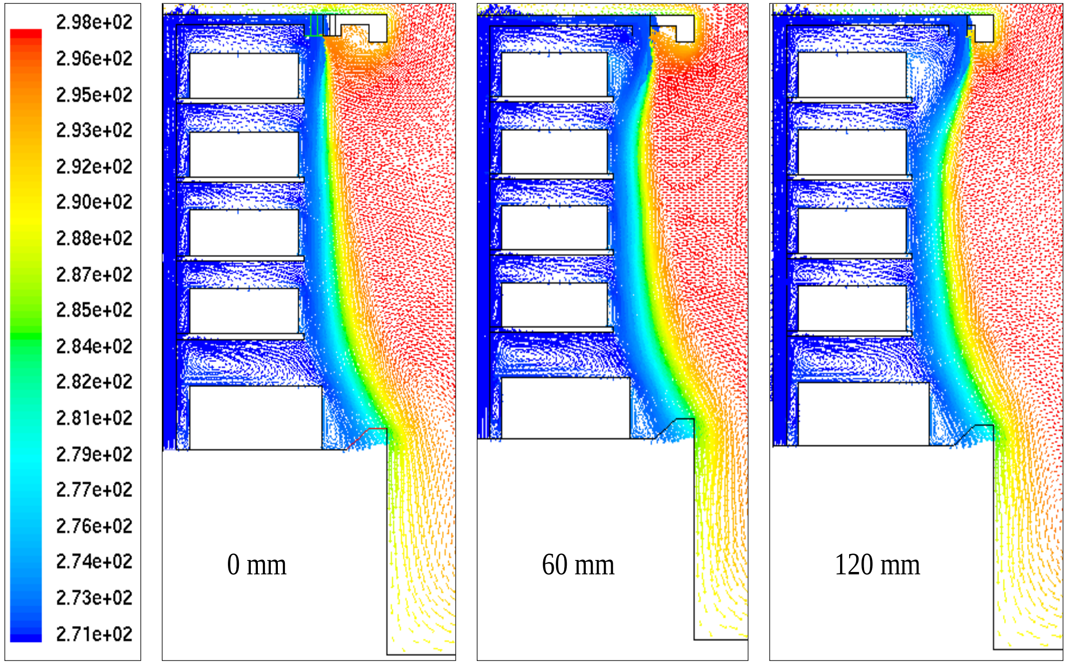
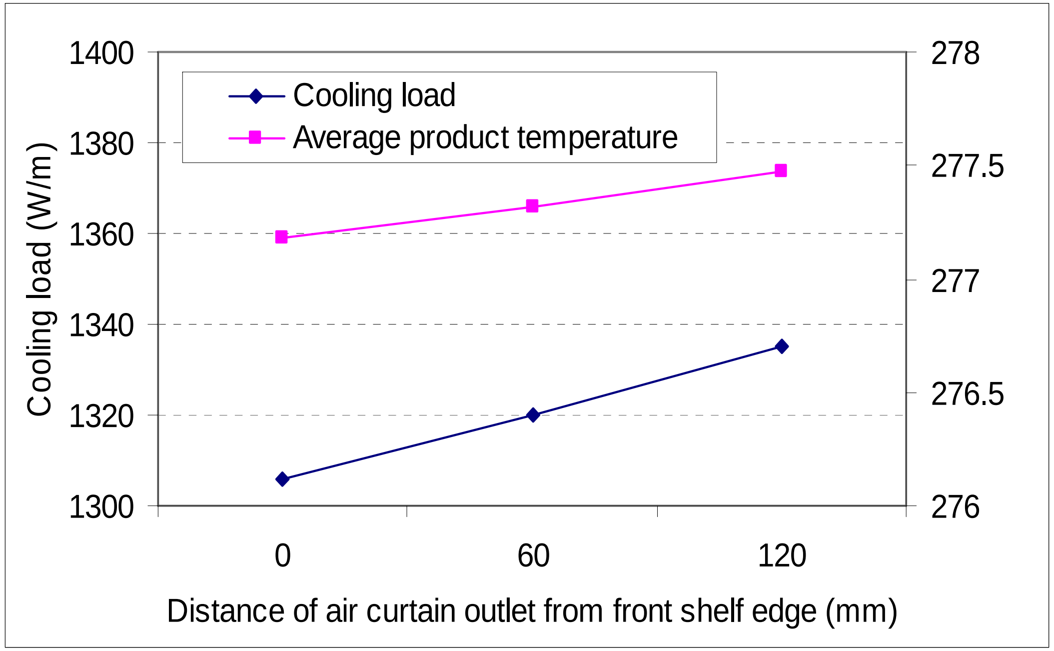
Multi-deck cabinet design issues
Air curtain position





- Best performance achieved when b_1= slightly above 0 mm
- Increasing b_1 increases average product temperature and cooling load

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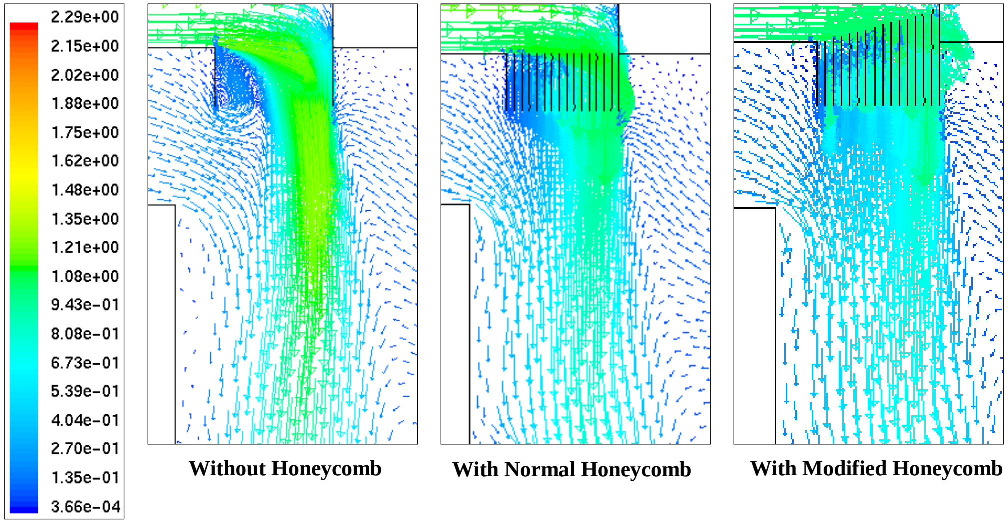
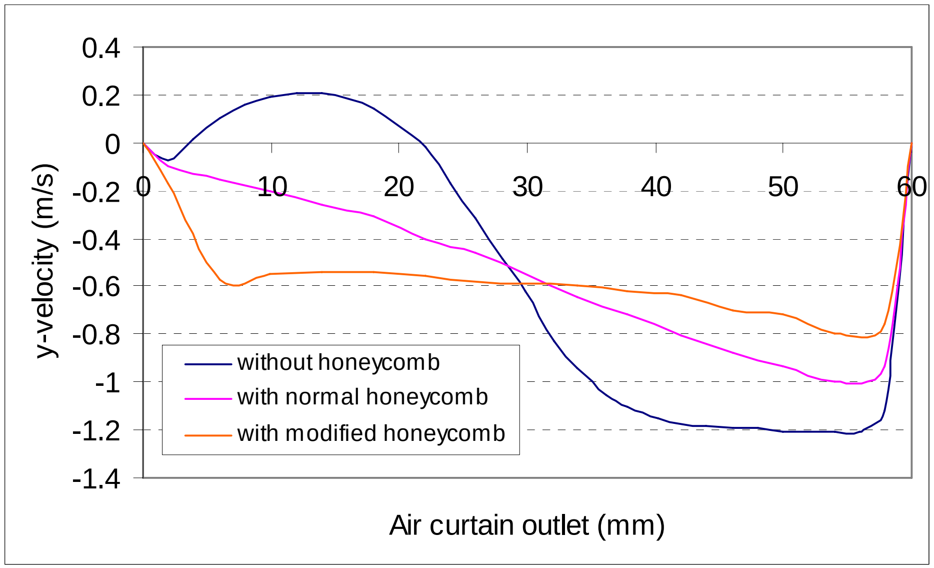
Multi-deck cabinet design issues
Honeycomb and air curtain discharge angle





- Reducing turbulence at discharge air grille reduces mixing and ambient air entrainment
- Use of honeycomb will reduce turbulence and can modify discharge velocity distribution.
- Use of honeycomb can slightly reduce air entrainment and cooling load.
- A small positive air curtain discharge angle (5^o-10^o) can reduce slightly the cooling load

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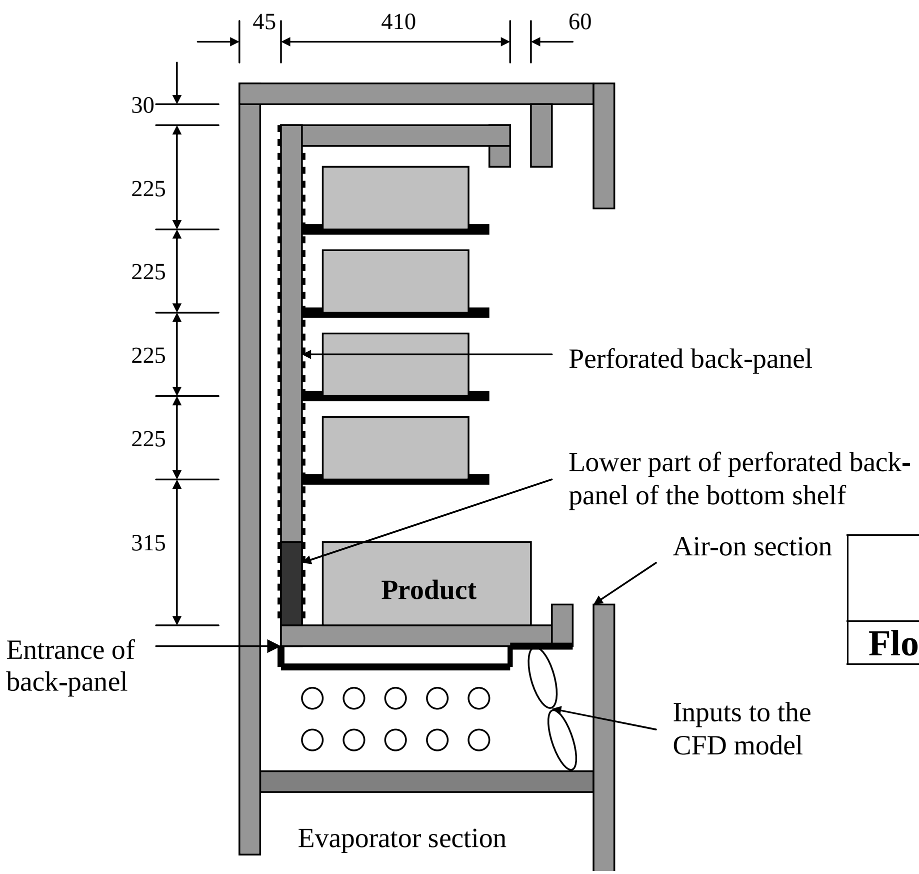
Multi-deck cabinet design issues
Pressure drop and flow distribution



- Pressure drop in flow tunnel (rear and top) discharge grille and perforations in the back panel will influence flow distribution and the performance of the cabinet
- Back panel flow to each shelf can be controlled by back panel perforation rate.

Position	Air curtain	Top shelf	Second shelf	Third shelf	Fourth shelf	Bottom shelf
Flow distribution (%)	30.0	13.0	12.0	12.0	14.0	16.0

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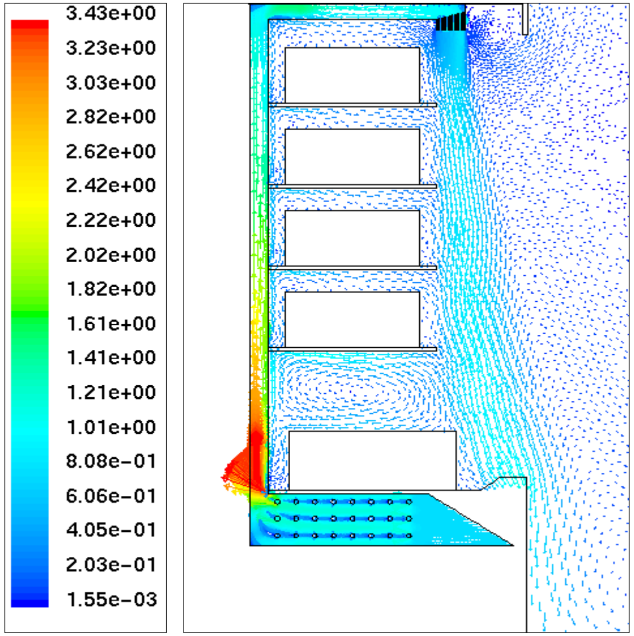
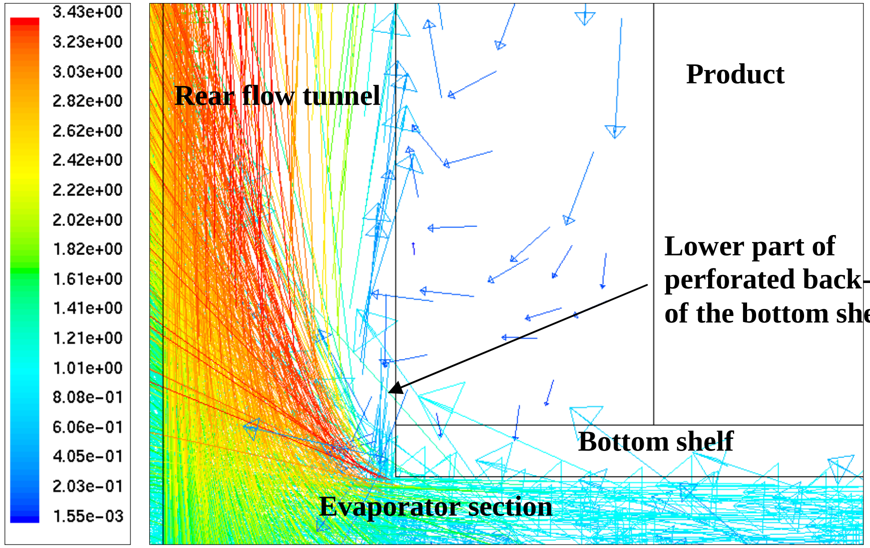
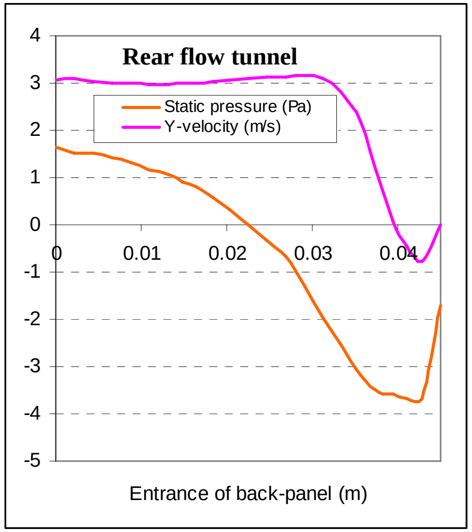
Multi-deck cabinet design issues
Flow to bottom shelf

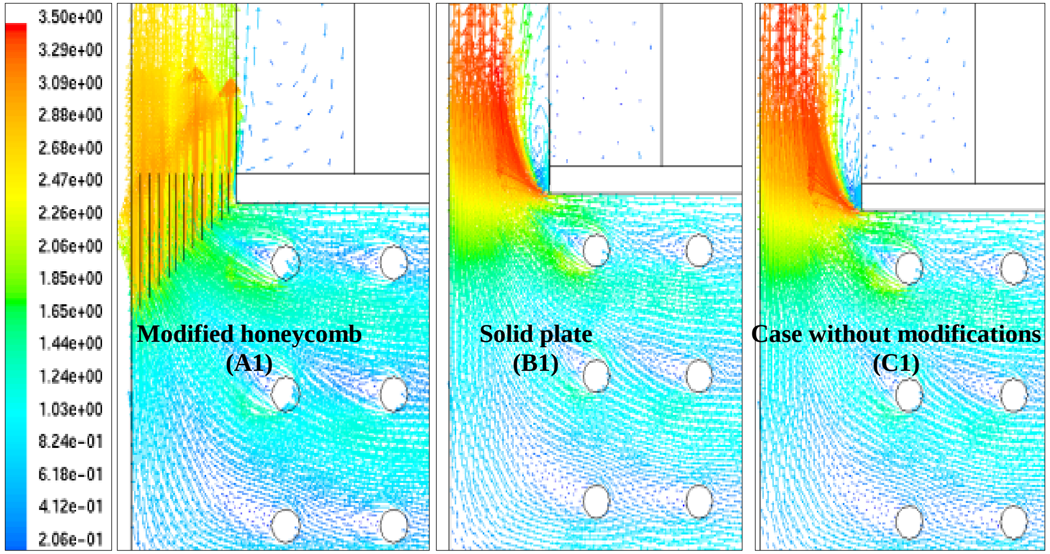


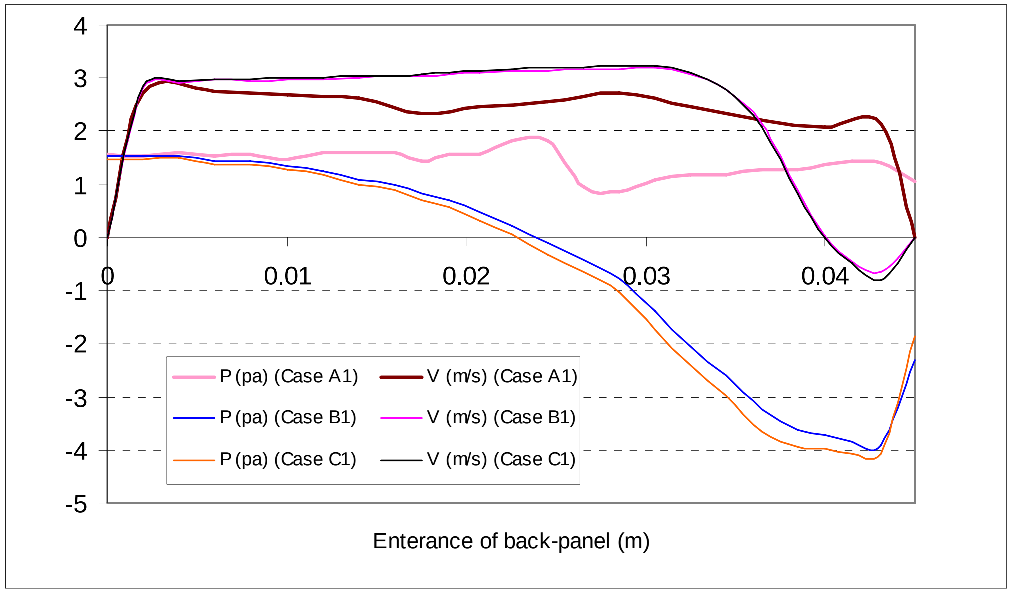




Perforated back-panel

Multi-deck cabinet design issues
Flow to bottom shelf





- Uniform flow distribution in back flow tunnel can be controlled through honeycomb or appropriate flow resistance at inlet to rear flow tunnel

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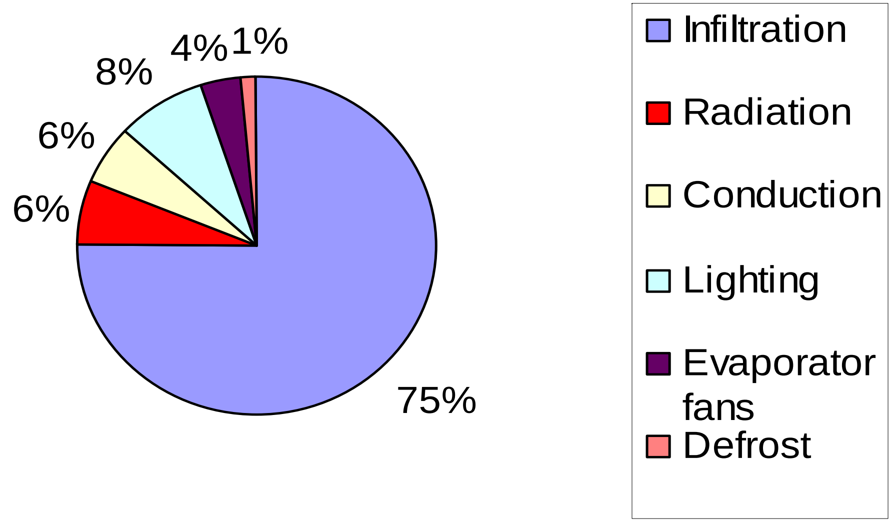
Energy Saving Potetntial



Contributions to load of open vertical multi-deck cabinets

ECM motors 67% more efficient-
Tangential fans -Variable speed?
More efficient coil
More efficient lighting –LEDs – 66% savings

→ Energy savings ~ 30%

Night blinds → Savings ~ 20%

Air curtain → Significant potential

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Environmental impact

•Materials, energy

- Open chilled display cabinet
- Display volume = 500 litres

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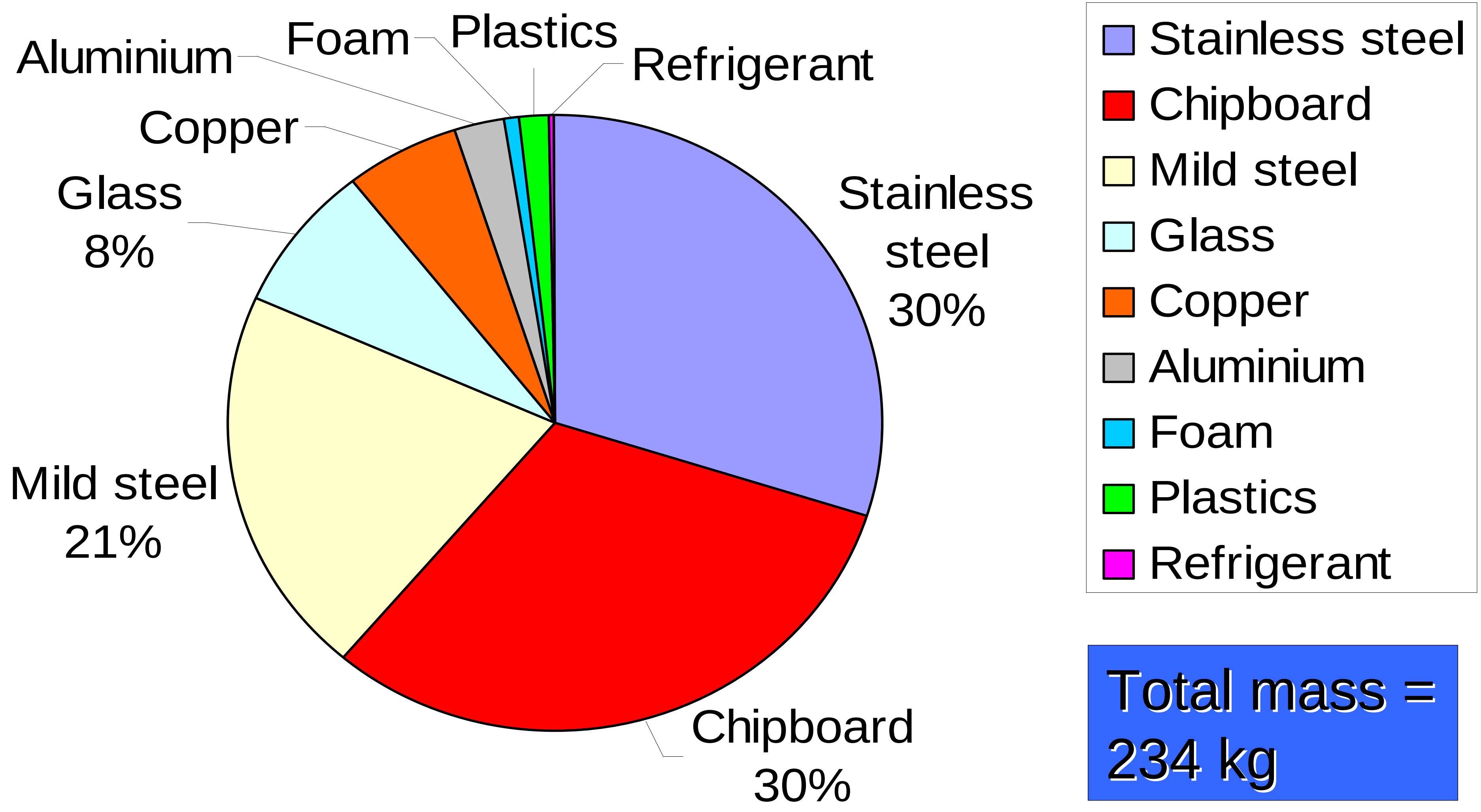
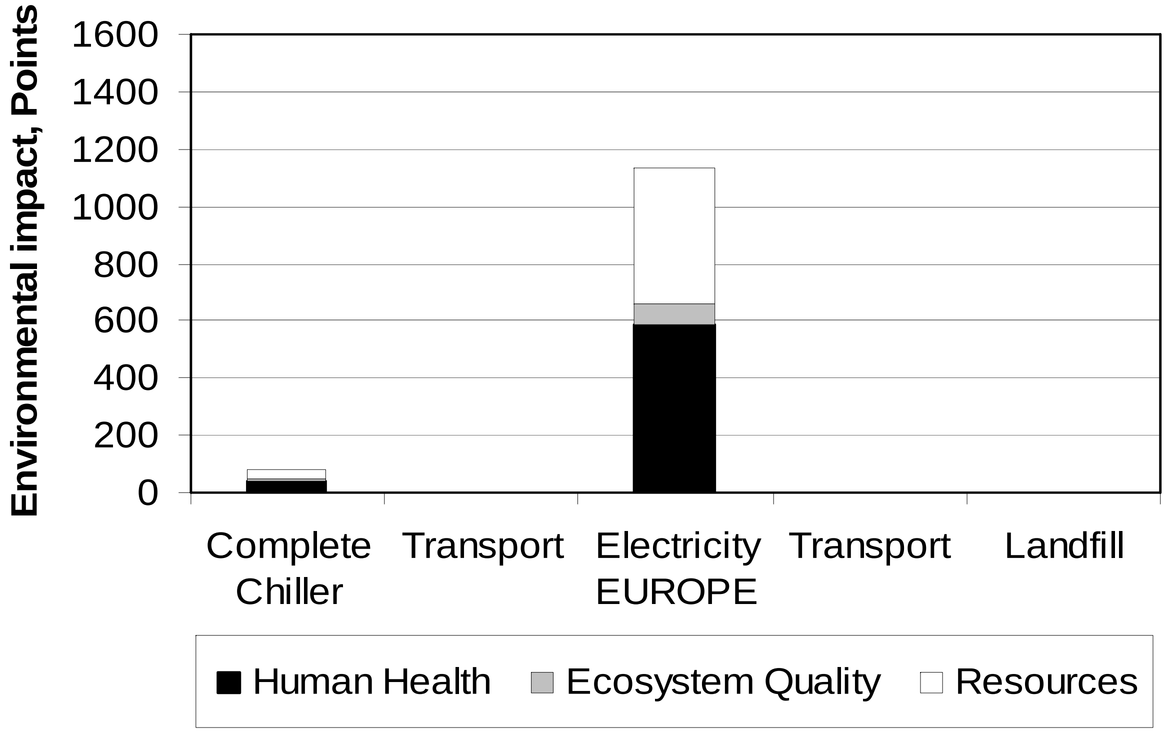
Environmental impact - Inventory



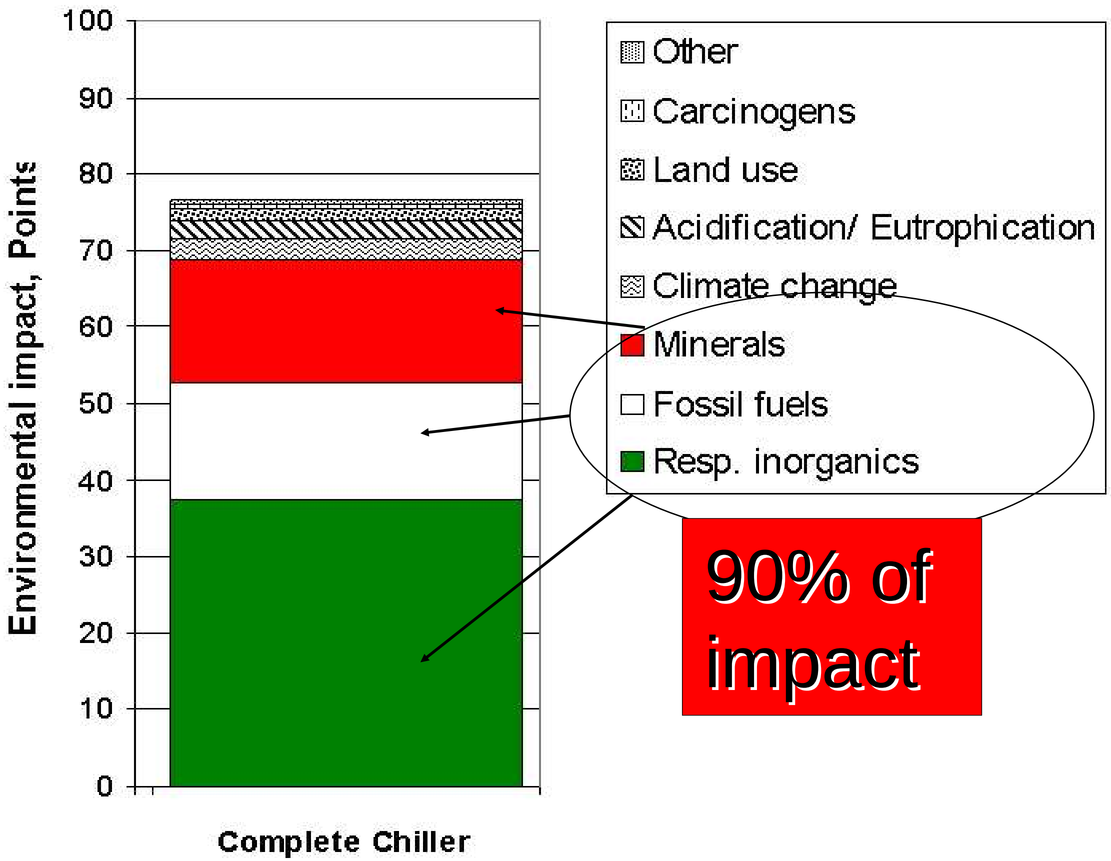
Total mass = 234 kg

Environmental impact – Life cycle



- 8 years, 24 hours a day

Environmental impact – Materials



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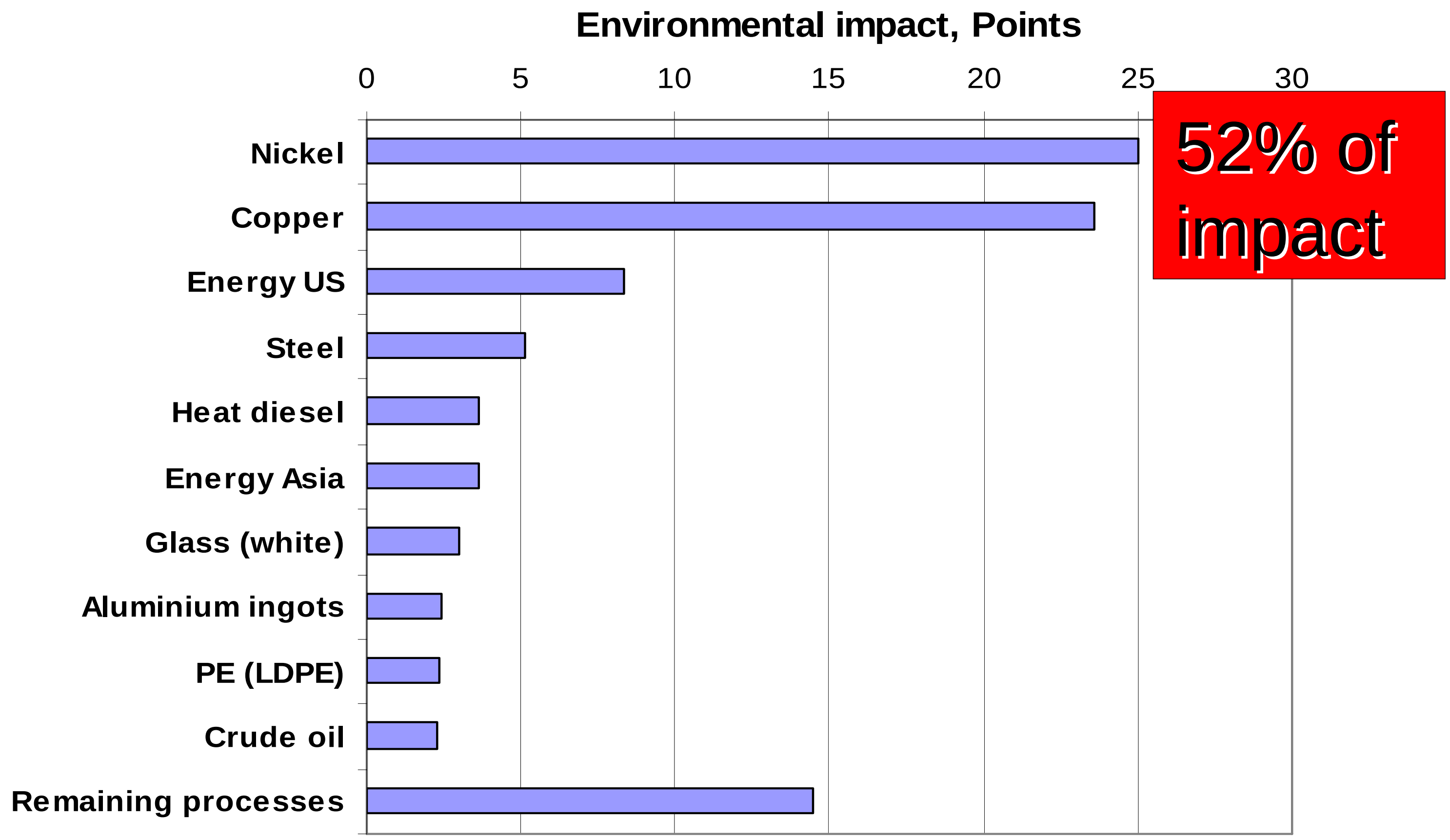
Environmental impact – Materials



Reducing impact – Materials

- Copper and Nickel have similar contributions
- Nickel (in stainless steel) can be avoided by using 430 stainless steel instead of 304
- Reduces the chiller's environmental impact from materials by 30%.

Reducing impact – Components & Fabrication

- At End of life, cabinets are shredded into 2cm size pieces
- What is needed is clean separation

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Reducing impact – Components & Fabrication

GOOD DESIGN FEATURES:

- Minimize number of materials
- Low use of plastics
- Use of wood with low embodied energy
- Flat sheet insulation with minimum bonding
- Key-hole drop-on fixings or screws, rather than rivets or spot-welding
- Electrical distribution & components concentrated in one accessible compartment

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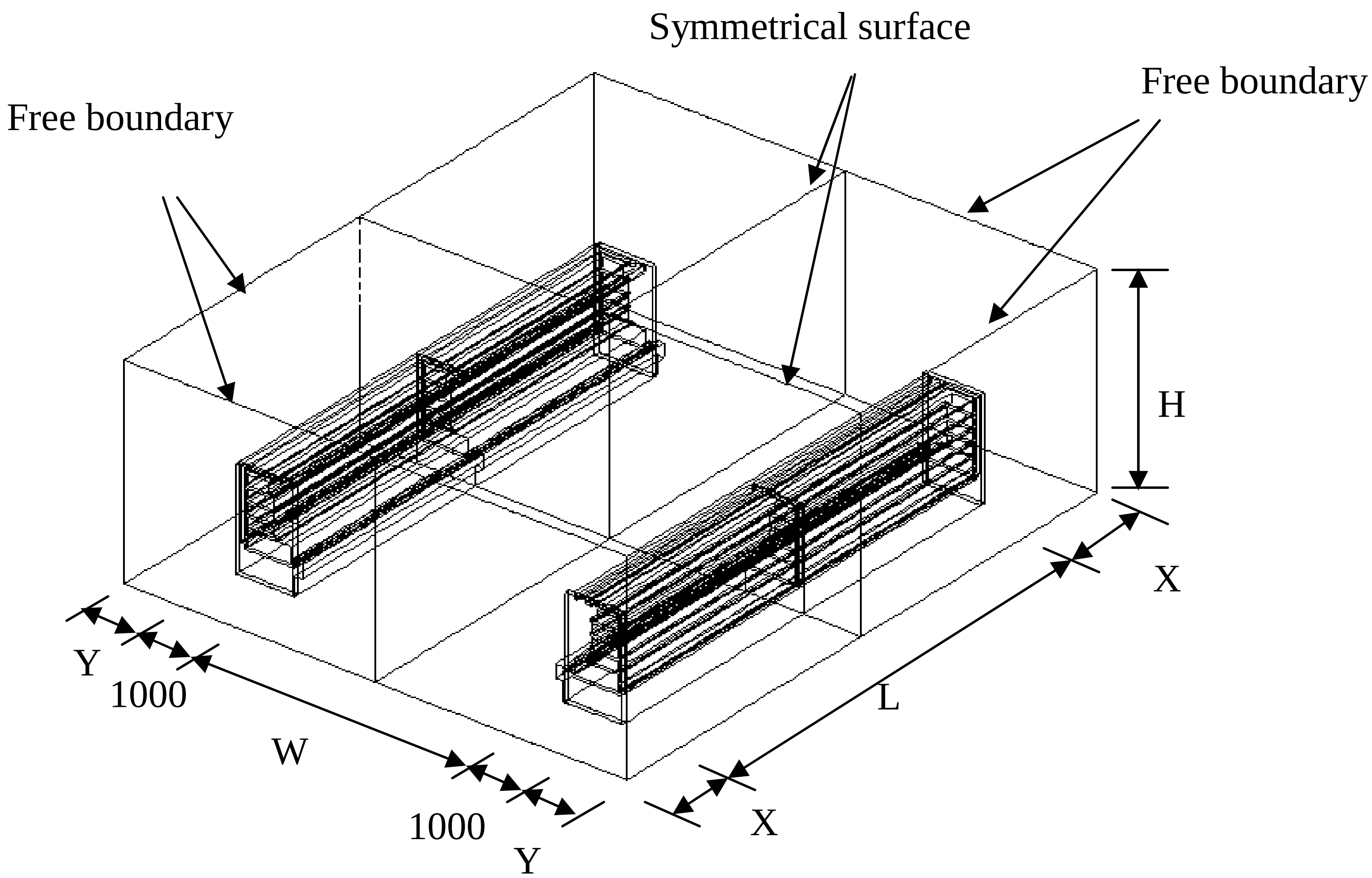
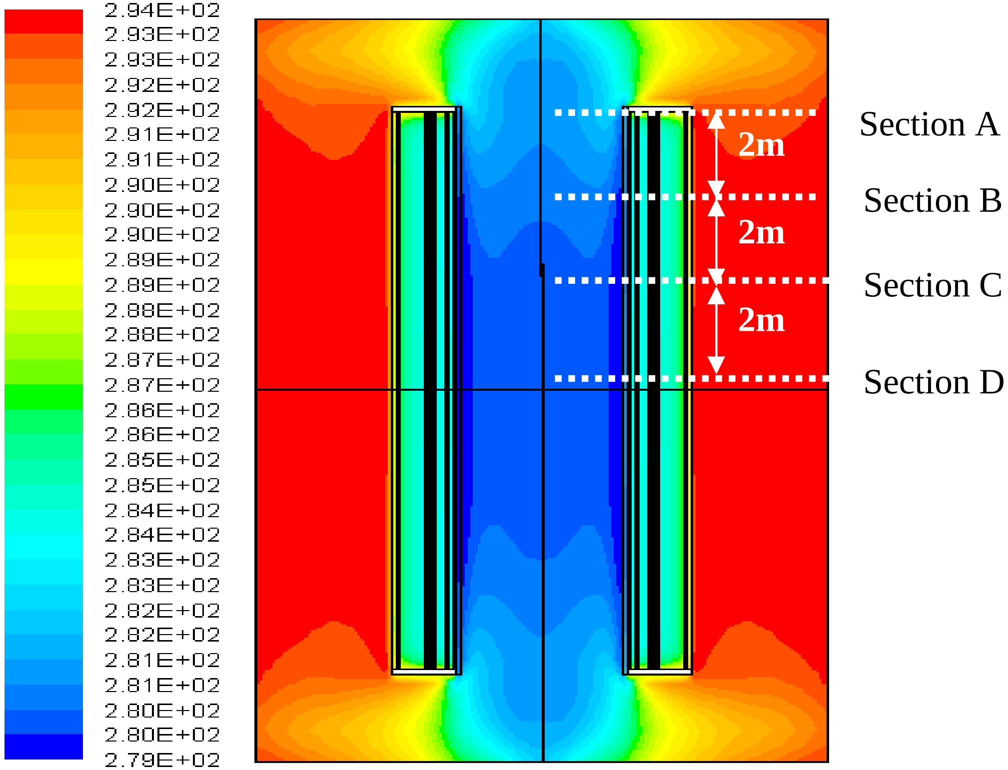
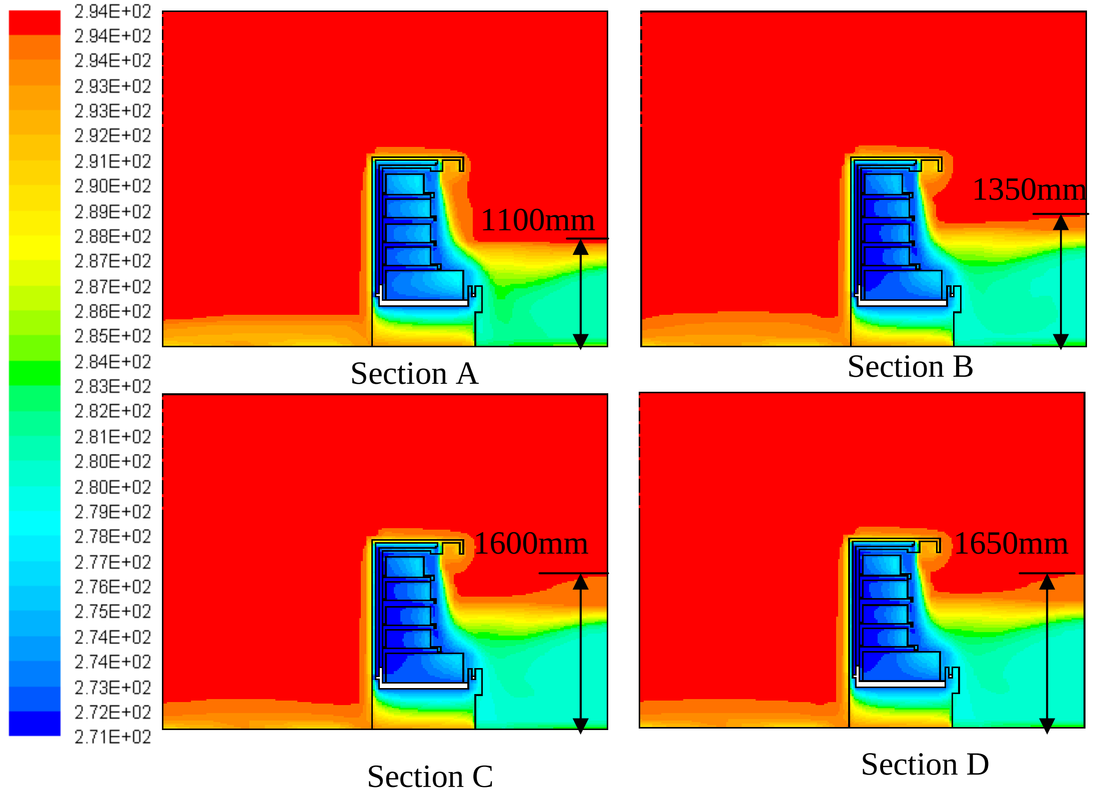
Simulation of supermarket zone - aisle



No heating system in zone





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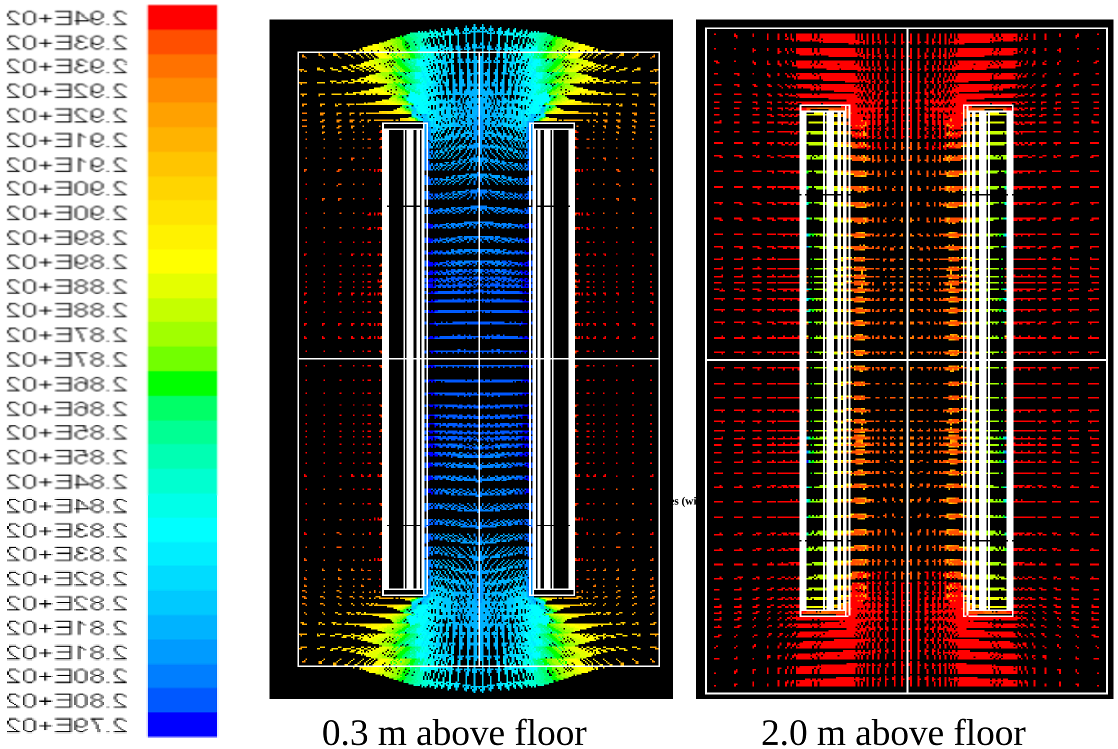
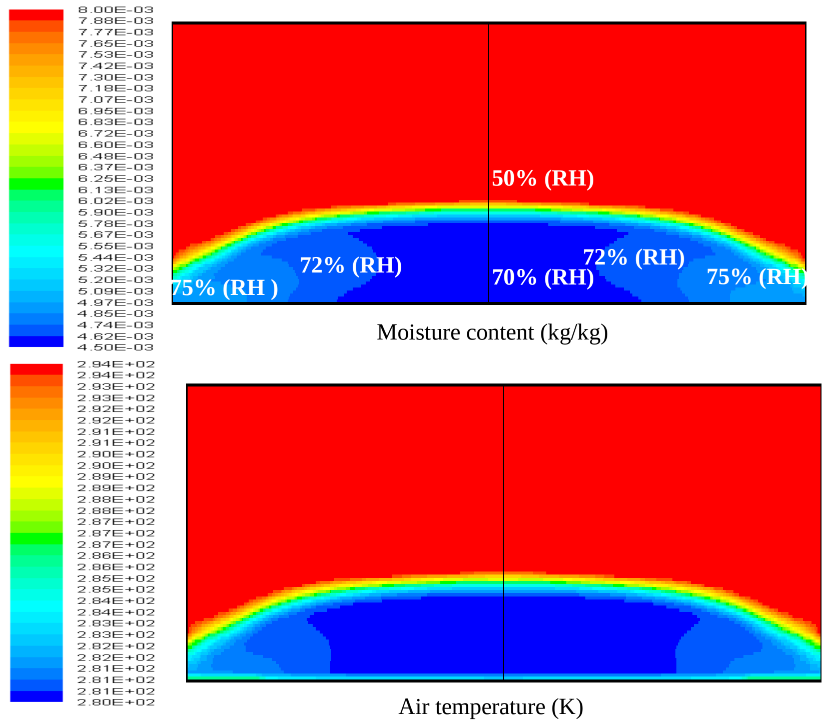
No heating system in zone



Temperature coded velocity vectors (K) on two horizontal planes (without HVAC system)



Variation of temperature and moisture content along the aisle centre line (without HVAC system)

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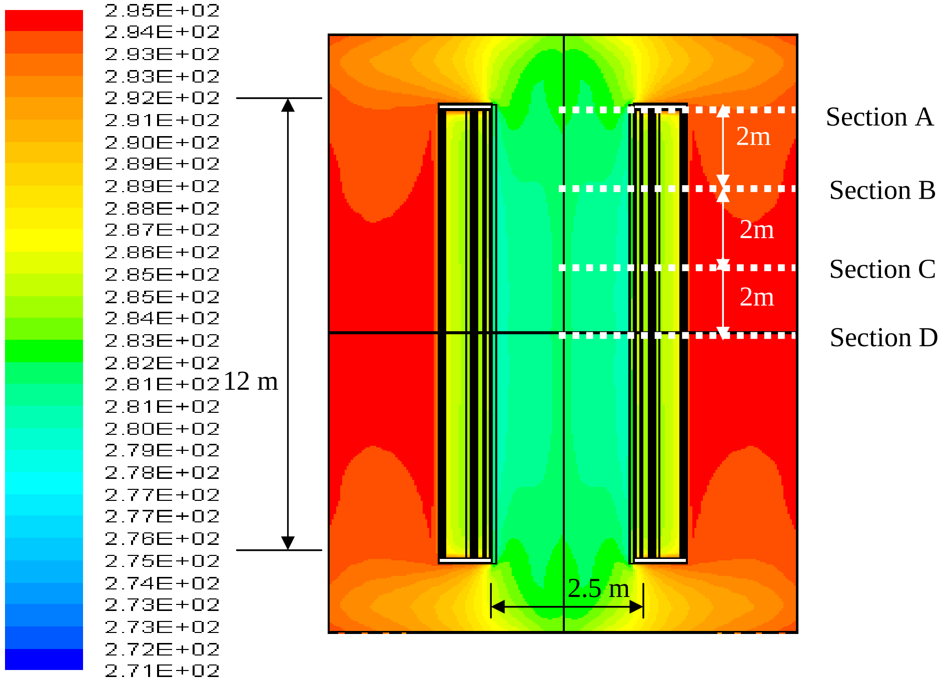
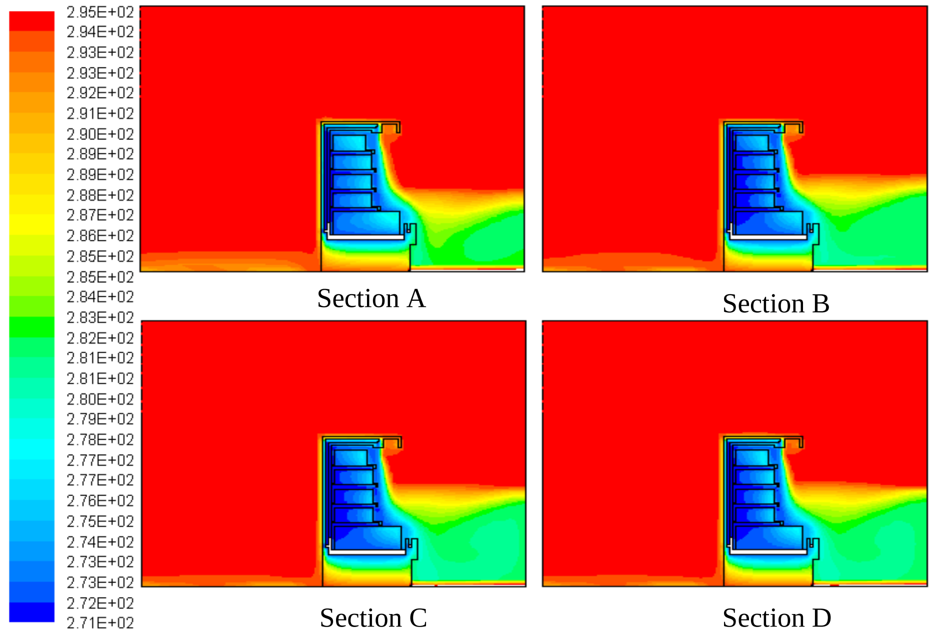
Under floor heating system



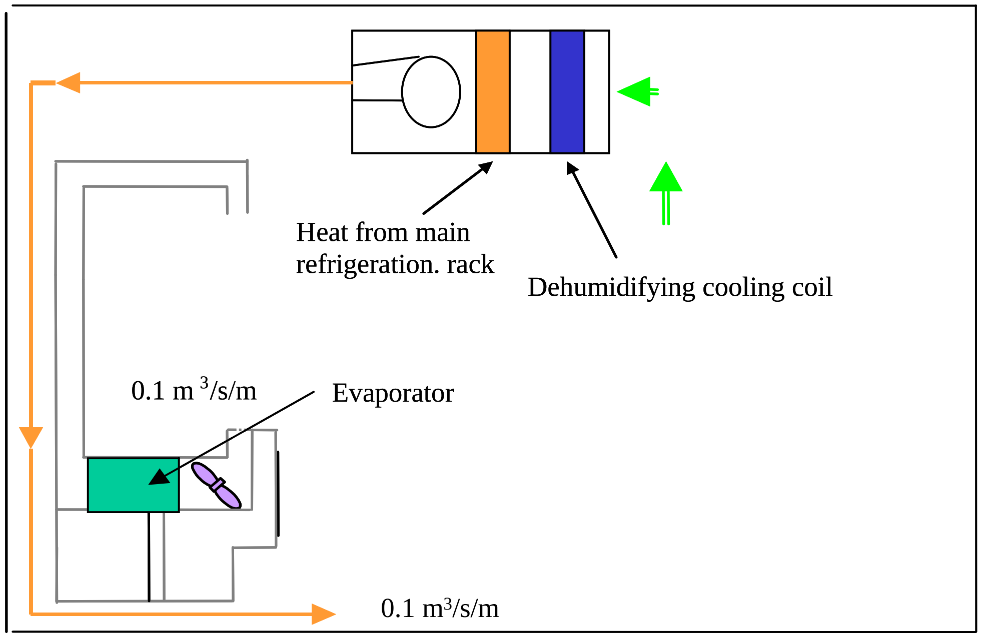
Temperature contours (K) on a horizontal plane 0.3 m above floor level

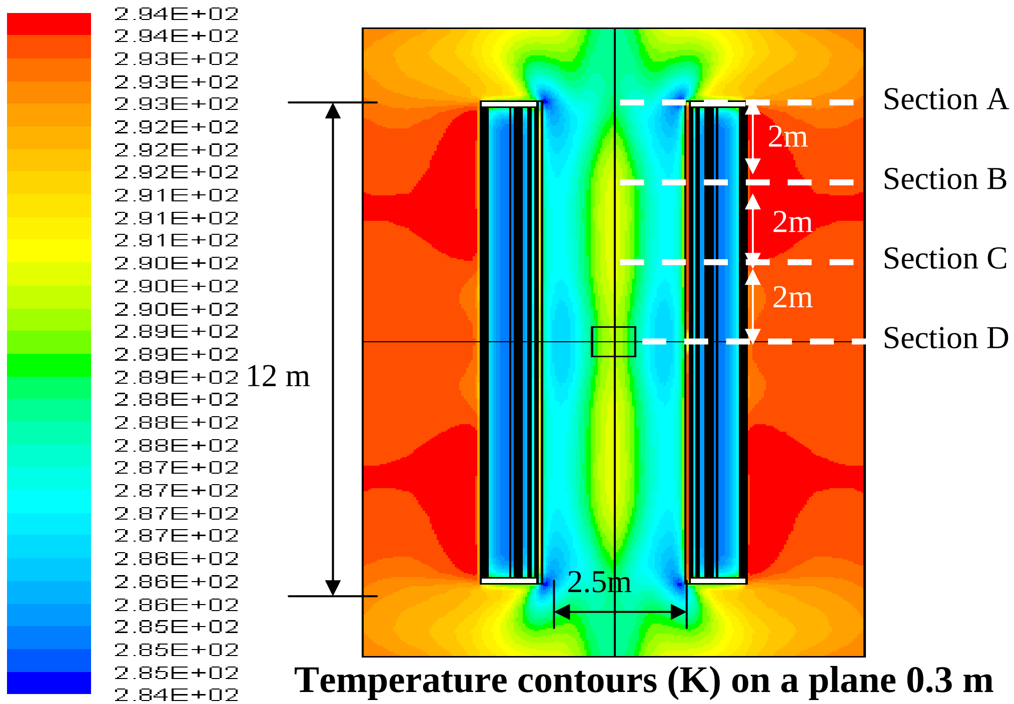


Temperature contours (K) at different sections (floor heating system)

Heating power (W/m^2)	Cooling load (kW/m)	Product temperature (°C)			Minimum temperature in zone (°C)
		Top shelf	3rd shelf	Bottom shelf	
0 (No HVAC)	0.91	3.1	2.1	3.8	7.5
150	0.93	3.7	2.5	4.7	9.0
200	0.96	3.9	2.6	4.9	9.5

Top extract and bottom supply

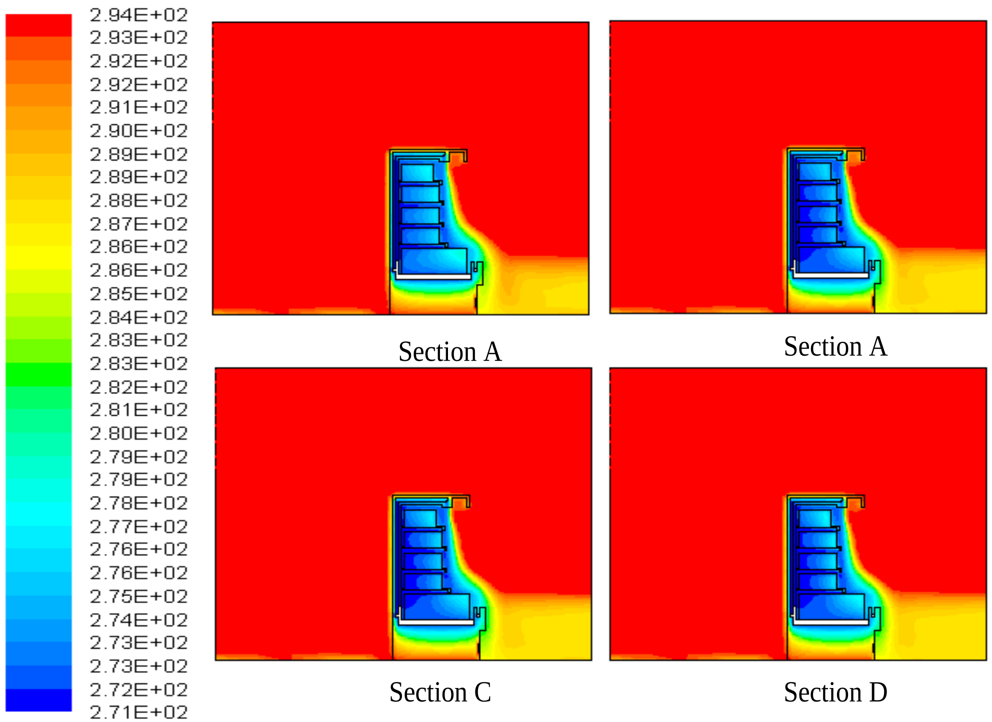




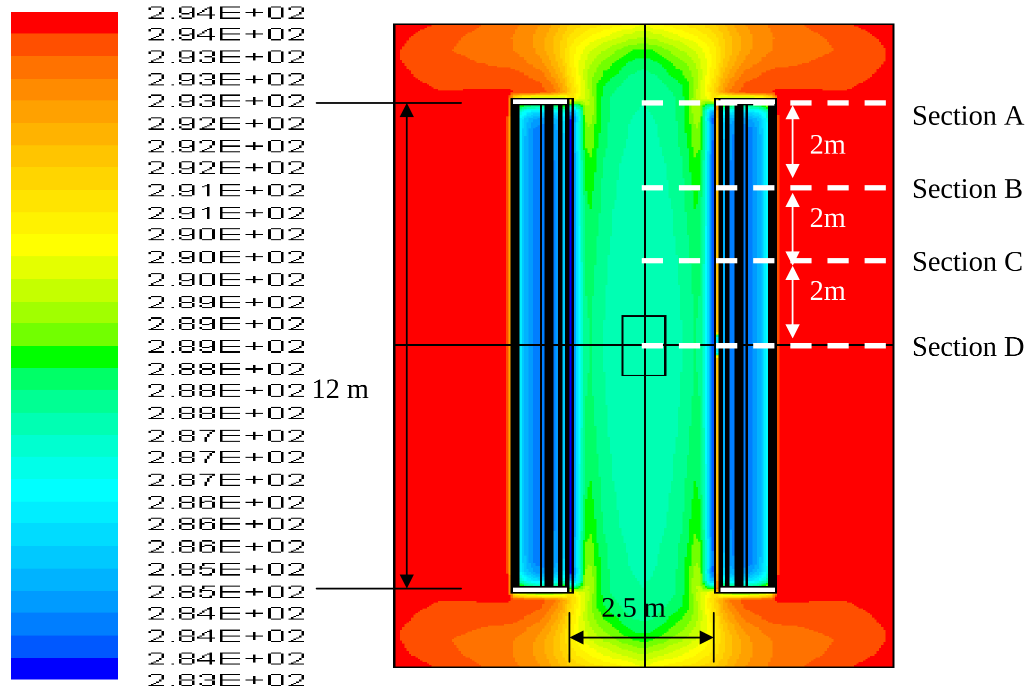
Temperature contours (K) on a plane 0.3 m above floor level (top suction and bottom supply system)

Bottom supply temperature (°C)	Cooling load (kW/m)	Product temperature (°C)			Minimum temperature in zone (°C)
		Top shelf	3rd shelf	Bottom shelf	
No heating system	0.91	3.1	2.1	3.8	7.5
21	0.82	3.3	2.2	4.2	10
25	0.84	3.5	2.4	4.4	11

Bottom extract system – no heating in aisle

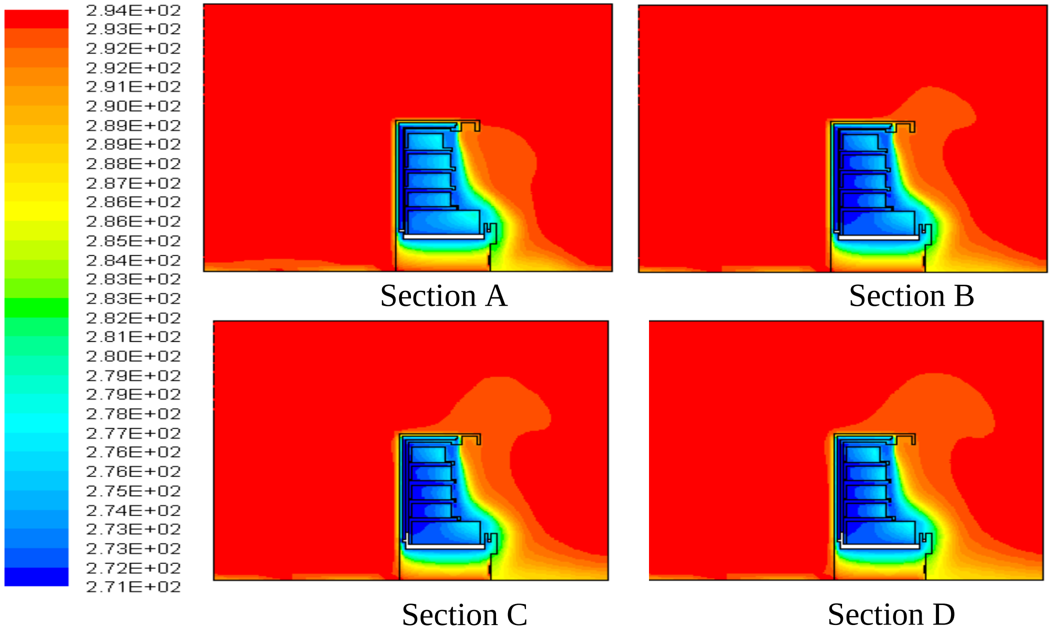


Temperature contours (K) at different sections (bottom extract system

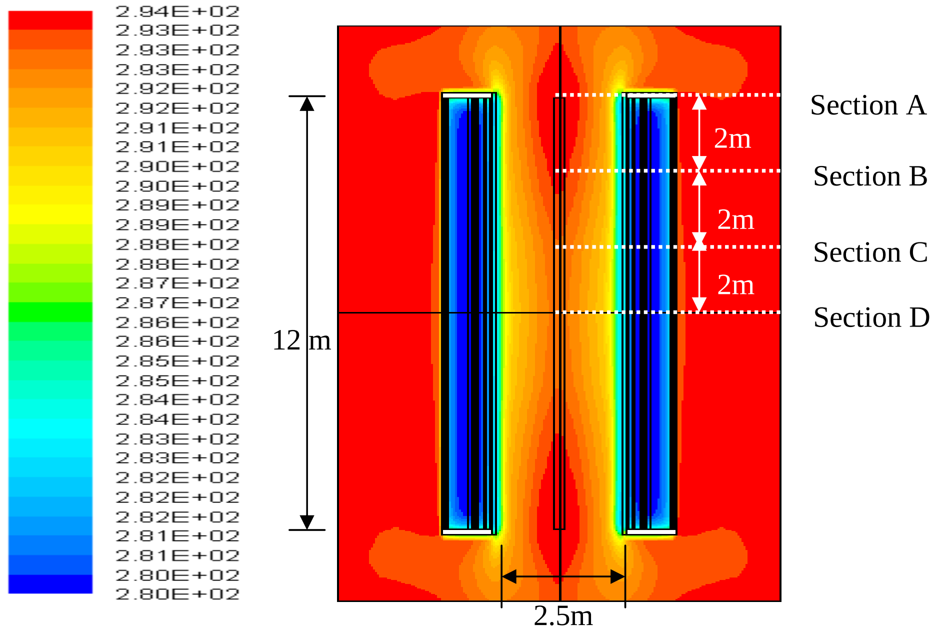


Temperature contours (K) on a horizontal plane 0.3 m above floor level (bottom extract system)

Bottom extract and top supply system

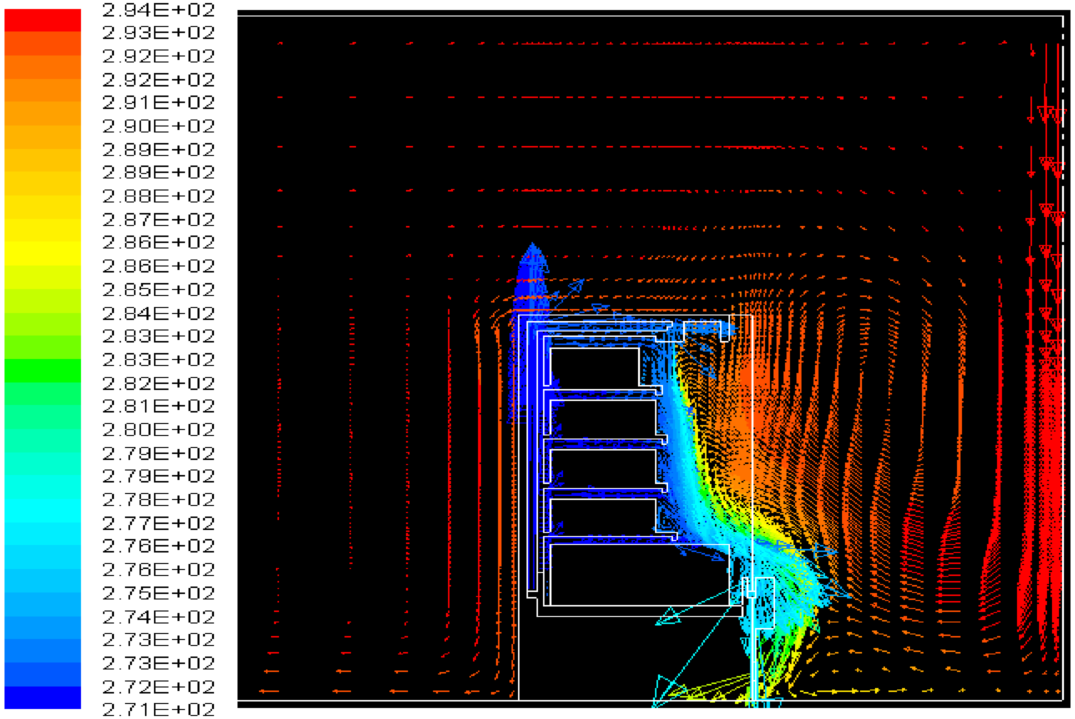


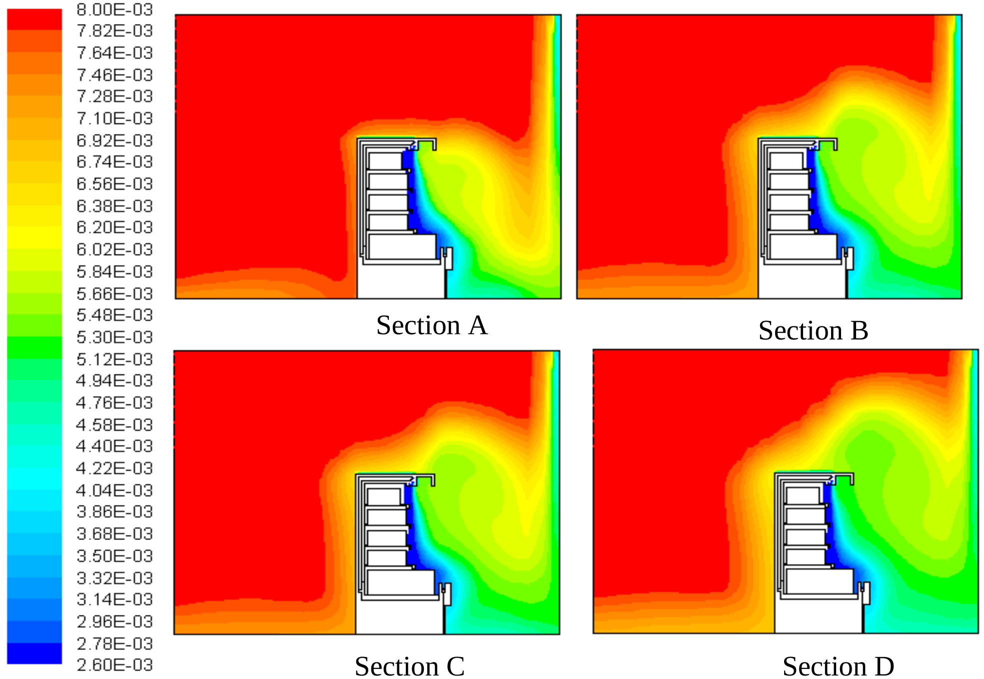
Temperature contours (K) at different sections (bottom extract and top supply system)



Temperature contours (K) on a horizontal plane 0.3 m above floor level (bottom extract and top supply system)

Bottom extract and top supply system





Temperature coded velocity vectors (K) at Section D (bottom extract and top supply system)

Moisture content (kg/kg) at Sections A, B, C, and D (bottom extract and top supply system)

Comparison of different systems

Latent and total cooling load for different systems

Zone type	Latent cooling load (kW/m)	Total cooling load (kW/m)
No HVAC	0.28	0.91
Top extract and bottom supply	0.24	0.82
Bottom extract and top supply	0.16	0.84

Comparison between bottom extract system, bottom extract and top supply systems and no HVAC system

Zone type	Temperature Top shelf (°C)	Temperature 3rd shelf (°C)	Temperature Bottom shelf (°C)	Zone minimum air temperature (°C)
Bottom extract	3.6	2.4	4.7	13
Bottom extract and top supply	3.7	2.4	4.7	17
No HVAC system	3.1	2.1	3.8	7.5

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Summary

- Progress has been made but further work needs to be done to gain an in-depth understanding of the factors influencing the performance of air curtains in display cabinets.
- Becoming more important with the use of higher opening heights.
- Evaluation of performance of ECM fans and LED lighting in field trials.
- Control integration and system optimisation in real time.
- Compact and efficient evaporator/cooling coil designs to minimise material use and frosting/defrosting losses.
- Impact of merchandising approaches on cabinet design, sales and energy use