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Energy Savings in Refrigerated Transport

defra
Department for Environment Food and Rural Affairs

University of BRISTOL
Food Refrigeration & Process Engineering Research Centre

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Transport Refrigeration
Some facts and figures

- Food transport (motive power and refrigeration) responsible for 1.8 % of total UK greenhouse gas emissions [UKCERK. Catering policy]
- 650,000 refrigerated road vehicles in the EU
- European road freight – 1800 mio t.km – 3rd is refrigerated, around 600 mio t.km
- UK responsible for 8% of EU refrigerated road traffic, 48 mio t.km [CRT]

Transport Refrigeration
Legislation and temperature control

- Temperature control requirements during storage and transport – Chilled and frozen food products - EC 852/2004
- Transport of food products across borders in EU (except fruit and vegetables) covered by ATP agreement. Agreement also covers equipment

Bodies:

- Normally insulated (IN) k= 0.7 W/m^{2}K
- Heavily insulated (IR) k= 0.4 W/m^{2}K
- Temperature control -20˚C; -10˚C; 0˚C; +12˚C
- Most common certification is for all temperature classes (FRC – mechanically refrigerated and Heavy insulation)

Transport Refrigeration

Legislation and temperature control

- External dimensions for a semi-trailer rigid box
  - 13.56 m length (fixed); 2.6 m width (fixed); 2.75 height
- Internal dimensions:
  - 13.35 m length; 2.46 m width; 2.5 m height
- Width is designed to accommodate 2 europallets side by side (size of pallet 1.0 m deep; 1.2 m wide)
- Insulation material deteriorates with time by 3% to 5% per year. Significant impact on energy consumption
- Capacity of refrigeration system for new equipment (1.35 x heat transfer through the body and 1.75 x heat transfer if unit tested outside vehicle)
- ATP certificate valid for 6 years
- 1500 certificates in UK per year

Refrigeration Units

- independent diesel engine with direct drive to compressor and fans – **chosen by majority of trailer transporters**
- independent diesel engine driving generator to electrically power compressor and fans – **majority of truck transporters**
- Vehicle diesel engine driving generator / alternator to electrically power compressor and fans **– small truck and van transporters**
- Cryogenic refrigerant held under pressure and released as required (CO2 or Nitrogen for example)
- Eutectic systems charged at bay/RDC
- Hybrid systems

Refrigeration Units

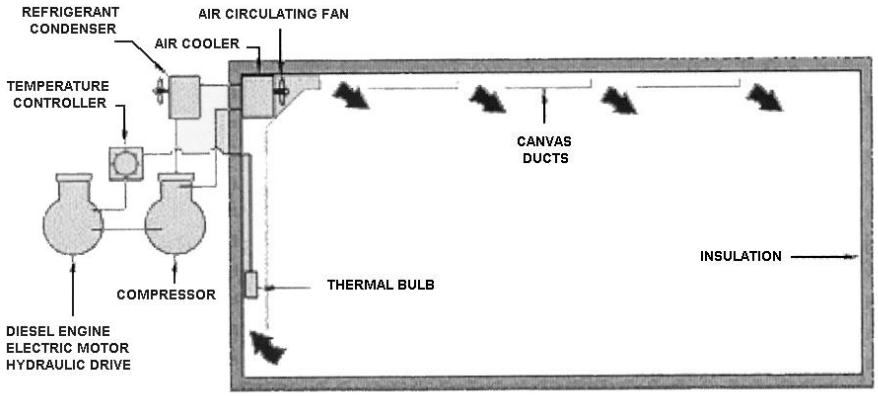
Approximate Drive Ranges (-20°C/+30°C)

	Body Volume (m^3)	Refrigeration Duty (W)	Equipment Weight (kg)
Vehicle Alternator Unit	<3	<400	<80
Direct Drive Unit	5 - 30	250 - 2,500	50 - 150
Auxiliary Alternator Unit	30 - 90+	2,000 - 14,000	100 - 500
Auxiliary Diesel Unit	30 - 90+	2,500 - 10,000	350 – 900*

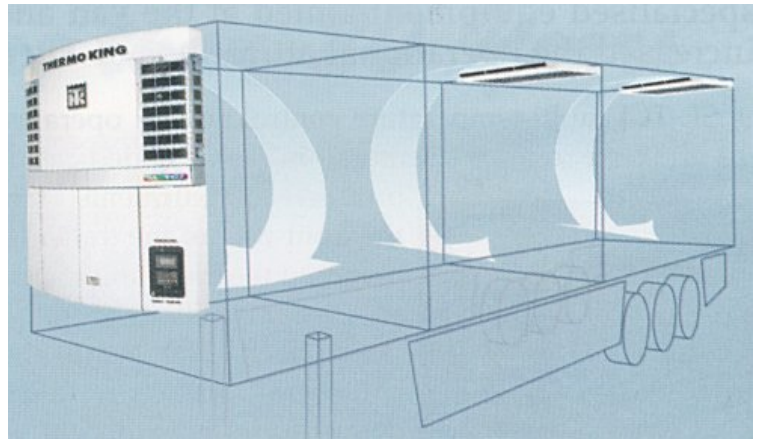
* Includes electric standby

COP = 0.5 ~ 1.5

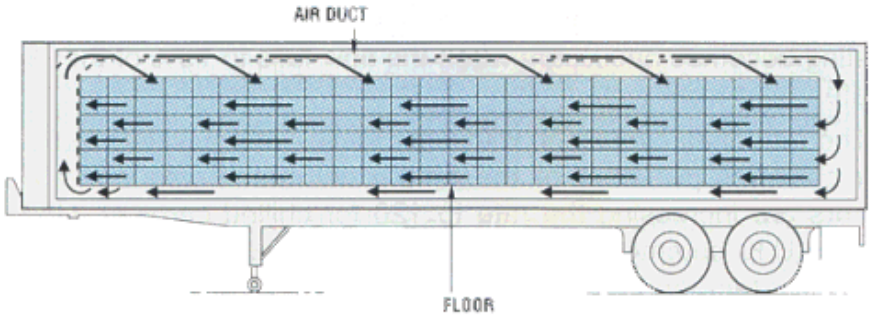
Air Delivery Systems



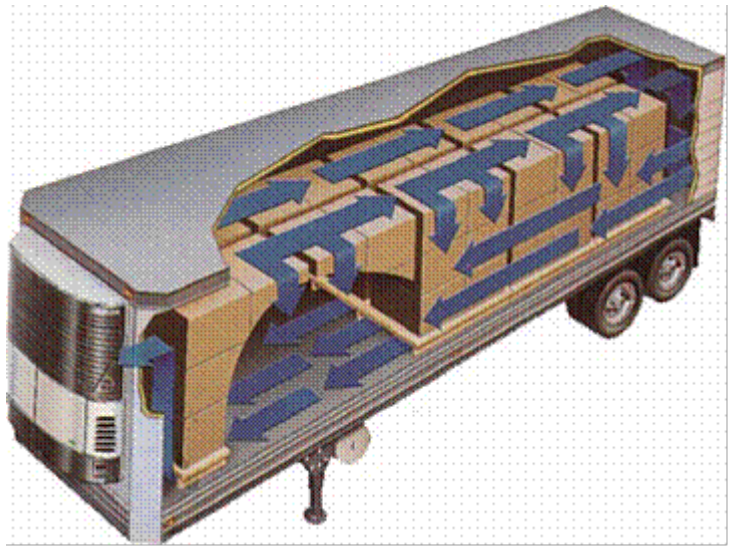
Refrigeration system arrangement



Multi-compartment system



Air circulation



Other commercial systems

Eutectics

Sizing table

Box internal Volume	Drops per hour	Approximate Holdover Capacity (@-33°C)	Approximate Mass
$4m^3$	4 drops/hr	6 kWh	80 to 100kg
$20m^3$	4 drops/hr	25 kWh	450 to 500kg

Cryogenic (total loss systems)

- Liquefied carbon dioxide (CO_2) in an open system (Thermoking)
- Liquid CO_2 evaporates to provide cooling & is then vented to atmosphere
- Heat mode extension of engine coolant system
- System powered by vehicle battery (12 or 24V) when ignition on
- Electric standby (option)

Characteristics of CO_2 cryogenic systems

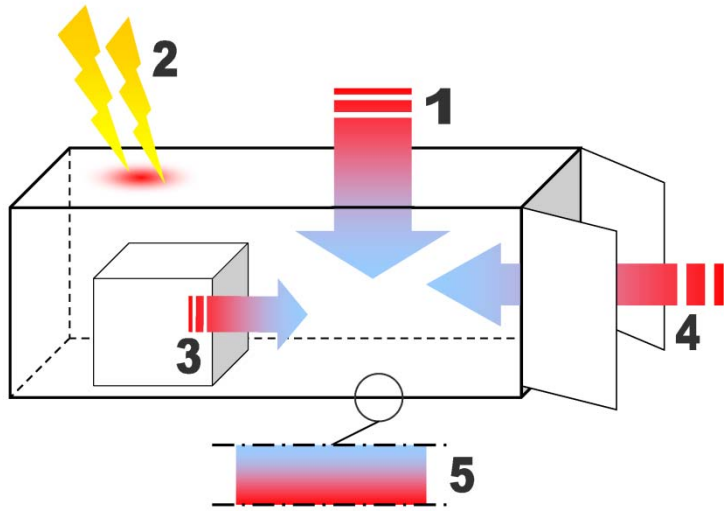
- It is feasible to use cryogenic liquid carbon dioxide for food transport refrigeration for both rigid vehicles and articulated lorries
- Operating costs of the conventional and CO_2 systems will largely depend on the relative cost of diesel fuel and liquid CO_2
- The cost of CO_2 and the infrastructure required will reduce as the number of vehicles using cryogenic systems increases

Advantages of CO_2 cryogenic systems

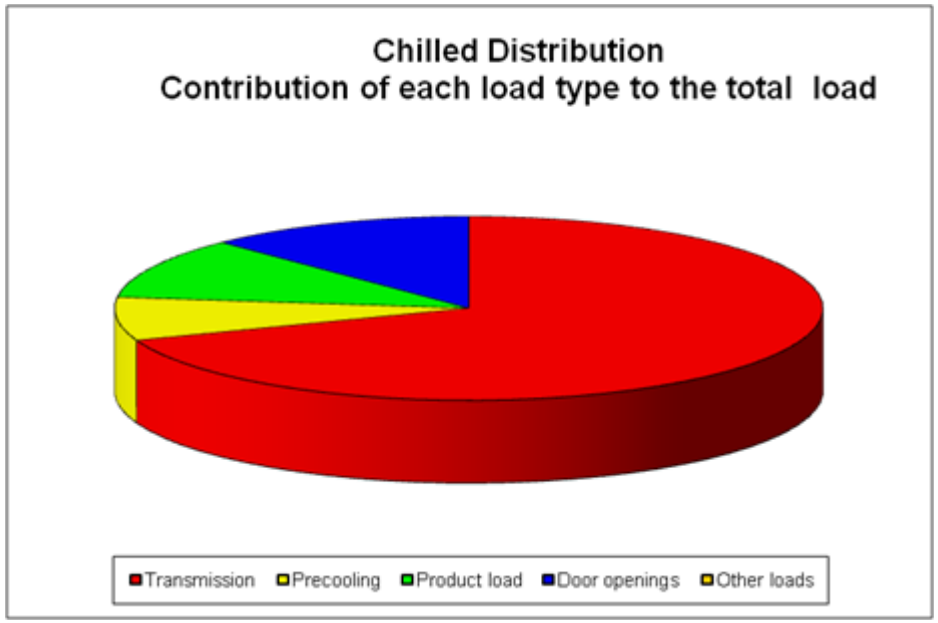
- Silent operation
- Lower maintenance compared to vapour compression systems
- Rapid load pull-down and vey good temperature control
- Potentially zero GHG emissions if CO_2 is recovered from industrial processes (fertiliser manufacture)

Thermal Load

1. Transmission load
2. Solar radiation load. In the analysis the solar radiation load - this can be integrated with the transmission load using an external temperature adjustment
3. Product load
4. Infiltration air load (door openings)
5. Pre-cooling vehicle load



Examples of Thermal Loads



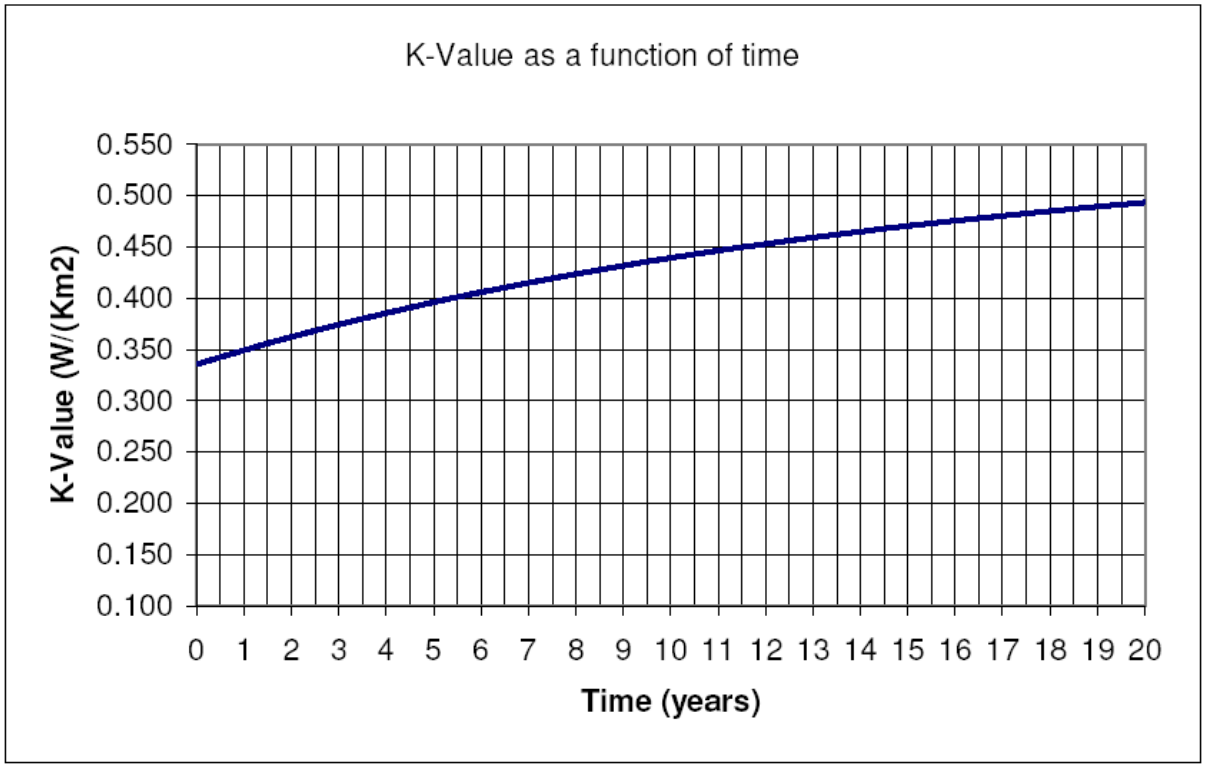
Chilled distribution 43 kWh

Load	*Contribution*
Transmission	**56%**
Precooling	**7.%**
Product load	**20%**
Door openings	**17%**
Other loads	**0%**

Frozen distribution 80 kWh

Load	*Contribution*
Transmission	**43%**
Precooling	**6.%**
Product load	**0%**
Door openings	**51%**
Other loads	**0.00%**

Insulation



Aging of insulation 3% - 7% per year

K coefficient increases from 0.4 to 0.62 in 9 years. Transmissions load increases by 50%

Refrigeration duties and fuel consumption

Body Inside Length/Inside Volume/Type	Minimum refrigeration capacity long distance transport (W)		Required refrigeration capacity, multi drop distribution (W)		Fuel consumption (litre/hr)	
	-20 °C k=0.4 W/m^2 K	0 °C k=0.7 W/m^2 K	-20 °C k=0.4 W/m^2 K	0 °C k=0.7 W/m^2 K	-20 °C k=0.4 W/m^2 K	0 °C k=0.7 W/m^2 K
6.2 m/ 33.42 m^3/ Rigid Lorry	3765	3876	5630	4554	2.0	1.5
10.4 m/ 61.15 m^3/ Rigid Lorry	6155	6353	9897	7920	3.0	2.5
13.4 m/78.79 m^3/ Semi Trailer	7730	7986	13500	10078	4.0	3.0

Refrigeration duties and fuel consumption

Vehicle class	Distance traveled and fuel consumption (motive)		Fuel efficiency (motive)	Fuel consumption of refrigeration engine	Overall vehicle fuel efficiency (motive plus refrigeration)	Percent refrigeration energy to motive energy
	km/day	Litres/day	km/litre	Litres/day	km/litre	%
Medium rigid	409	111.3	3.7	21.0	3.09	18.9
Large rigid	286	90.71	3.15	17.7	2.63	19.5
City artic	335	112.33	2.98	26.1	2.42	23.2
32 tonne artic	419	140.8	2.97	34.1	2.40	24.2
38 tonne artic	486	159.62	3.04	24.9	2.52	15.6

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Insulated Box

- Select an insulated box with low K-value (minimise heat gain)
  - The use of vacuum insulation can reduce K value by 50% and resulting in 30% energy savings (payback period of around 6 years)
- Select an insulated box of the correct dimensions for the application to minimise surface area (minimise heat gain)
- Select a light-coloured - ideally white - body colour (minimise heat gain)
- Have box cleaned frequently and check for damaged insulation (thermal imaging)

Energy Savings in Refrigerated Transport

Refrigeration unit

select the right refrigeration unit for the application (over or under-specified equipment can result in fuel wastage)

- reliability
- installed cost
- operational cost
- global warming potential
- weight
- engine emissions
- fuel efficiency
- fuel availability

Energy Savings in Refrigerated Transport

Operational considerations

- load the vehicle avoiding blockage of air passages & use maximum load - height lines to guide operators (maximise air circulation, minimise resistance)
- load goods fully pre-cooled to required set-point or below it (minimise heat load on unit)
- use a temperature controlled sealed loading dock (minimise heat gain)
- minimise frequency and duration of door openings
- use door curtains (up to 40% savings in frozen food multi-drop operation

Energy Savings in Refrigerated Transport

- Use door switches to automatically turn unit off when doors are open
- Select the appropriate refrigeration unit set-point for food transported, not a lower one (avoid unnecessary unit operation)
- Select the appropriate unit operating mode : stop/start for frozen, modulation for fresh (optimum unit efficiency)
- Park vehicle out of direct sunlight where possible
- Maximise vehicle utilisation - avoid partial loads
- Thorough driver training & established Standard Operating Procedures