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Road transportation of pigs.

Specification of acceptable conditions for animals in transit.

Should a single market mean a single standard?

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Introduction

The thermal environment experienced by animals within transport containers is the result of the external climatic conditions, the type and number of animals within the container, the heat and moisture generated by the animals and the volume air flow and its distribution throughout the container. Thus a major influence upon the animals well being is the ventilation regime which also offers a potential avenue for modification or improvement of the thermal conditions.

In the UK and the rest of Europe (EU member states) the topic of ventilation of road transport vehicles for livestock has been addressed and legislation and guidelines have been prepared and implemented with subsequent enforcement to varying degrees in the different countries.

The main recommendations and standards for livestock vehicle ventilation appeared in the European Council Directive 91/628 (European Council 1991), which was amended by Directive 95/29 (European Council 1995) and embodied in UK legislation within the Welfare of Animals (Transport) Order of 1997 (WATO 97).

The current legislation amends these earlier Directives and European Council Regulation EC/411/98 specifies additional animal protection standards applicable to road vehicles used for the carriage of livestock on journeys exceeding 8 hours. Within the annex of this regulation are specified the additional standards and in the section relating to ventilation it states:

"The vehicle must be equipped with an adequate ventilation system to ensure that the welfare of the animals being transported is permanently guaranteed, taking into account in particular the following criteria:

- the planned journey and its duration,
- the design of the vehicle used (open or closed)
- the inside temperature and the outside temperature resulting from atmospheric conditions which may occur during the planned journey
- the specific physiological needs of the various species transported,
- the loading densities provided for in Chapter VI of the Annex to Directive 91/628/EEC and the space available above the animals.

The system must also be designed in such a way that:

- it can be used at any time when the animals are in the vehicle whether it is stationary or moving,
- it ensures the efficient circulation of unpolluted air.

To that end, operators must provide:

- either a forced ventilation system, the details of which are to be determined after consultation of the Scientific Veterinary Committee in accordance with the procedure laid down in Article 17 of Directive 91/628/EEC,
- or a ventilation system which ensures that a range of temperatures from 5°C to 30°C can be maintained within the vehicle for all animals, with a +5°C tolerance depending on the outside temperature. This system must also be equipped with an appropriate monitoring device.

The possibility of choosing between these two systems shall not prejudice the principle of the free movement of the animals."

Though this regulation is still current, the Scientific Committee on Animal Health and Welfare (SCAHAW) considered that the provisions of EC/411/98 were not sufficient to ensure an acceptable level of protection for transported animals. Consequently a Working Group was set up by the Committee to review the "Standards for the Micro-climate inside Animal Transport Road Vehicles". The report of this Committee was passed via the Commission who, in turn, passed it on to the European Council.

The main conclusions were:

- adaptable ventilation systems were necessary on vehicles to ensure a satisfactory micro-environment around the animals

- high humidity was identified as a major determinant of the total thermal load on the animals
- ventilation rates were suggested in accord with those for housing, i.e. between 63 and 106 m^3/h/100kg of liveweight
- a minimum ventilation rate of 10 m^3/h/100kg of liveweight in cold conditions
- the ventilation system should be capable of operating independently of the vehicle engine

Maximum and minimum temperatures were specified for each species (Table 1). The maximum temperatures were also adjusted for high humidities.

Temperature limits (and adjustments for high humidity) for different species				
		Min. temp °C	Max. temp. °C	
			<95% RH	>95% RH
Pigs	10-30 kg	14	32	29
	30+ kg	12	32	29
			<80% RH	>80% RH
Cattle	0-2 weeks	10	30	27
	2-26 weeks	5	30	27
	26+ weeks	0	30	27
Sheep	Full fleece	0	28	25
	Shorn	10	32	29

Table 1. SCAHAW Working Group recommendations for maximum and minimum temperatures during transport.

With the specification of limits for thermal exposure, the recommendation was also made for compulsory monitoring, warning and recording systems for temperature and humidity in all road vehicles carrying livestock for journeys exceeding 8 hours.

In October 2003, the European Food Safety Authority (EFSA) invited members of the Working Group on the Micro-climate within road transport vehicles for their scientific opinion on whether the precise temperature and ventilation requirements described in the 1999 SCAHAW report were still valid in the light of more recent scientific data. The report is still awaited.

Range of climatic conditions

One of the main criticisms with EC legislation is that the intention of producing a single set of guidelines that are applicable across Europe is ill founded. This can be demonstrated by consideration of the “acceptable temperature limits” for livestock in transit. Across mainland Europe there is considerable variation in the expected temperature to which the livestock may be exposed, even ignoring diurnal variation, depending on where the journey is taking place.

For example if the meteorological data are compared between Moscow and Madrid (Figure 1) then it is evident that in the winter months conditions will be much colder in Moscow than Madrid, with the converse situation in summer. However, any legislation stipulating maximum and minimum temperature limits may prohibit movement of animals in certain countries at any time of the day or night.

The temperatures specified within EC legislation relate to the conditions within the transport container, however if a vehicle in Moscow is loaded with livestock in January then at loading and for the initial period of transport the temperature within the container will be below the prescribed limit. In the converse situation, where high temperatures might be expected then the journey may have to take place overnight.

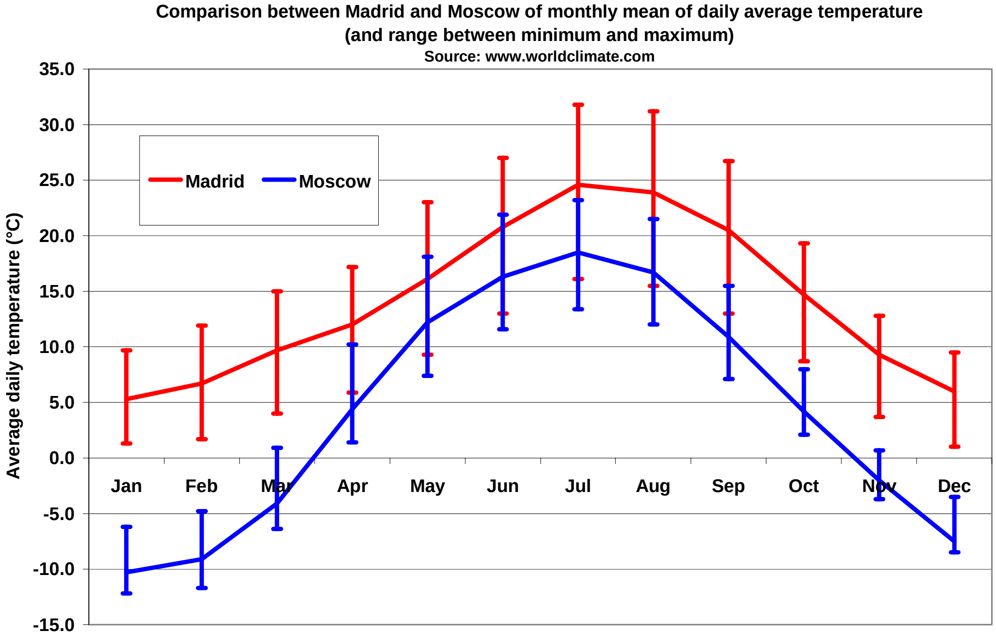

Comparison between Madrid and Moscow of monthly mean of daily average temperature
(and range between minimum and maximum)
Source: www.worldclimate.com

Figure 1. Comparison of the monthly mean of daily average temperatures in Madrid and Moscow.

This simple example does not consider the effects of high humidity that may confound further the situation.

There are still very little, if any, sound scientific data that define acceptable thermal limits for groups of animals under transport conditions. Current information used in the formulation of EC recommendations and legislation is based on dated studies, often using single animals kept under "typical" housing conditions.

Transport studies in the UK

These issues have been addressed in the UK within a combined research programme, funded by the UK Department for Environment, Food and Rural Affairs (Defra), at Silsoe Research Institute in England and Roslin Institute in Scotland.

The objectives of this research were fundamentally from an engineering standpoint. They were:

- development of a mathematical model of heat transfer from animals during transport
- validation of the model, including measurement of heat and moisture production of groups of animals during transport

- development of fan ventilation systems to optimise the thermal micro-environment within the transport container

Heat and moisture production

Silsoe Research Institute operates a commercially built, 3 deck livestock transport vehicle (Figure 2). The vehicle has been constructed as an experimental test bed facility and is fully equipped with an automated data recording system to measure and record a number of pertinent physical parameters during the transport of large numbers of animals.

Figure 2. The Silsoe Livestock Transport vehicle.

The instrumented livestock transporter provides a unique test facility for calorimetric measurements of the heat production of large groups of animals under commercial transport conditions. Measurement of the change in temperature and moisture content of the ventilating air-stream allows the determination of the sensible and latent heat released into the ventilating air. It is recognised that the airflow within the container removes not only heat and moisture produced by the animals but also moisture generated from excreta. Although this moisture is not a true component of the animals' thermoregulatory mechanism, this moisture does contribute to the overall micro-environment and its removal will help achieve a relatively drier micro-environment than would otherwise occur in conditions of minimal air movement. Additional avenues of heat loss from (e.g. heat loss through the structure) and heat gain (e.g. solar radiation) to the vehicle also need consideration.

For thermal equilibrium on the vehicle, the heat produced by the animals and that derived from solar gain, must be equal to the heat loss to the ventilating air and that lost through the structure of the vehicle.

heat from animals + solar gain = heat loss to air stream + heat loss through structure

The major unknown in this thermal balance is the heat produced by the animals, so the equation can be re-written:

heat from animals = heat loss to air stream + heat loss through structure - solar gain

During experimental journeys, the heat loss to the ventilating air stream and the solar gain of the vehicle can be measured. The heat loss through the structure of the vehicle is determined by simulated heat load tests on the stationary vehicle.

The metabolic heat production of the animals can be calculated from the production of carbon dioxide and the latent heat released into the ventilating air stream can be derived from the change in moisture content between inlet and outlet. The derived sensible heat is the difference between these two values. This derived sensible heat can be compared with the sensible heat released into the ventilating air stream, any differences being the result of heat losses through the structure of the vehicle.

Metabolic heat production

Metabolic heat production was derived from the difference in the carbon dioxide concentrations (outlet – inlet) and the volume flow rate. The determination was based on the respiratory equation in simplified form without any correction for urinary nitrogen. The basic equation is:

$$H = 16.18\ V_1 + 5.02\ V_2$$

Where H is the heat production in kJ, V_1 is the volume of oxygen consumed in litres and V_2 is the volume of carbon dioxide produced in litres. If a respiratory quotient (the ratio of oxygen consumed to carbon dioxide produced) of unity (a fully fed animal) is assumed then the equation can be simplified to:

$$H = 21.20\ V_2$$

If the animal is assumed to be fasted then the respiratory quotient becomes 0.7 and the revised equation becomes:

$$H = 28.13\ V_2$$

These equations make no allowance for heat exchange associated with the production of methane. They are directly applicable in pigs but require further consideration for ruminants.

Calculation of latent heat

The latent heat released to the ventilating air-stream is calculated from the equation:

$$LH = \delta mc \times L \times V$$

Where LH = sensible heat (W)

δmc = difference in air moisture content between inlet and outlet (g/m^3)

L = latent heat of vaporisation = 2400000 J/m^3/°C

V = volumetric flow rate (m^3/s).

Calculation of sensible heat

The sensible heat released to the ventilating air-stream is calculated from the equation:

$$SH = \delta T \times Cp \times V$$

Where SH = sensible heat (W)

δT = difference in air temperature between inlet and outlet (°C)

Cp = specific heat capacity of air at constant pressure = 1226 J/m^3/°C

V = volumetric flow rate (m^3/s).

Thermal characteristics of the vehicle

To determine the thermal characteristics of the vehicle itself, and in particular the heat loss through the structure of the vehicle, static heat load tests were conducted. These involved using a number of electric heaters distributed evenly over the deck area. A range of heat loads between 5 and 10 kW were used that are typical of the heat produced when carrying animals. For each test the electrical power consumption of the heaters was recorded.

The heat loss through the vehicle structure was determined by subtracting the heat lost to the ventilating air stream from the total heat supplied by the electrical heaters:

Heat loss through structure = Electrical heat supplied – Heat loss to ventilating air

All the tests were conducted under dry conditions so latent heat was not a consideration.

The data have been plotted (Figure 3) to show the heat loss through the structure of the vehicle in relation to the difference in temperature of the ventilating air stream (outlet temperature – inlet temperature). The significance of these data is that for every 1°C difference in temperature of the ventilating air stream, around 4 kW of heat is lost through the structure.

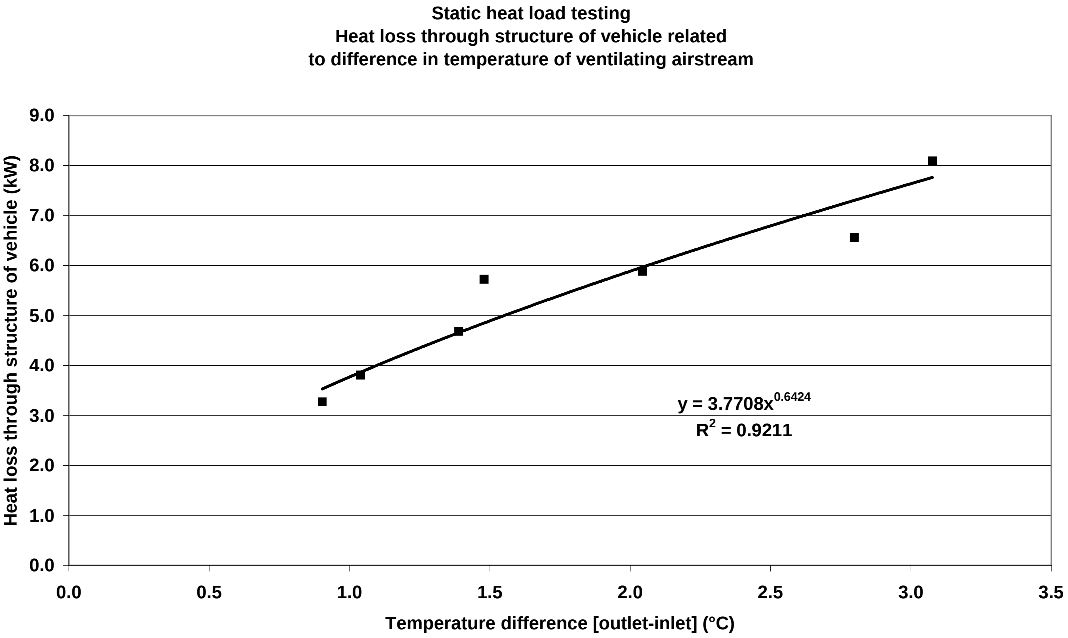


Figure 3. Heat loss through structure of static vehicle.

Experimental protocol

All experiments involving whole vehicle calorimetry were conducted on the lower mechanically ventilated deck of the transporter. As data were collected during routine commercial movements, livestock were often carried on the middle deck. Because of gross vehicle weight restrictions and instrumentation installed on the upper deck, the vehicle was only operated as a 2 deck transporter, and in the 3 deck configuration the upper deck remained empty.

Pen sizes, headroom and stocking densities during all journeys were in accordance with the recommendations in the Welfare of Animals (Transport) Order 1997 (Table 2).

Species	**Approx weight (kg)**	**m^2/animal**	**kg/m^2**
Pigs	100		235
Sheep in fleece	45	0.3 – 0.4	
Calves	55	0.3 – 0.4	

Table 2. Space allowances for animals during transport.

When transporting slaughter weight pigs or sheep (3 deck configuration), the deck height was set at 0.9m and pen lengths (5 off) limited to a maximum of 3.1m. For 60kg liveweight calves (2 deck configuration) the deck height was set to 1.35m with pen lengths (6 off) limited to a maximum of 2.5m.

Experimental data involving pigs and sheep were obtained during routine movement of animals to slaughter. The data relating to the transport of calves were collected during experimental journeys in Southern Ireland. The average liveweight of the animals being transported was obtained either by gross vehicle weighing (pigs and sheep) or individual weighing (calves). Journey times ranged between 6 and 8 hours.

The ventilation system and data collection were switched on prior to loading of the animals and operated for the whole of the transport period. Measurements continued for a minimum of 6 hours after unloading to check on sensor agreement post transport.

The carbon dioxide analyser was calibrated using test gas before and after transport.

Data were recorded at 10 minute intervals throughout the whole transit period and recordings were started well in advance of any animals being loaded. Changes in the temperature and humidity of the ventilating air were used to derive the sensible and latent heat lost to the ventilating air stream. The production of carbon dioxide by the animals was also determined and used with an estimate of the respiratory quotient to derive metabolic heat production.

The data for heat and moisture production are summarised below (Table 3).

	Pigs	Sheep (in fleece)	Calves
Liveweight (kg)	100	45	70
Nominal ambient temperature (°C)	20	10	10
Nominal ventilation rate (m^3/s)	1.1	0.7	0.9
Outlet temperature (°C)	23	12	14
Metabolic heat production (W/kg)	2.0	1.5	2.5
Water production (g/kg liveweight/hr)	1.2	0.8	1.0

Table 3. Summary of heat and moisture production data derived from UK studies.

It should be noted that changes in **relative humidity** (between inlet and outlet) during these experiments were negligible which emphasises the importance of an understanding of the meaning of relative humidity and how it must be considered in relation to the air temperature. Water production figures are derived from changes in the vapour density (an absolute measure of moisture content) of the air stream.

The water production figures quoted above are measured in the ventilating air stream and include moisture released from urine and faeces. This does not contribute to the total heat generated by the animals but it does modify the thermal micro-environment within the container experienced by the livestock.

It is important to recognise that though heat production is independent of time, water production is time dependent. To determine the absolute water production during a given journey the rate of water production must be multiplied by the duration of the journey.

Climate chamber studies in the UK

The primary objectives of this research were:

- definition of acceptable ranges and limits of thermal tolerance of groups of animals in controlled climate chamber studies
- validation of thermal limits during simulated transport journeys
- further validation under commercial transport conditions

The thermoregulatory responses of slaughter weight commercial pigs (Large White breed) were assessed by exposure to a wide range of dry bulb temperatures and “high” or “moderate” relative humidities. Groups of eight 100kg pigs were housed in controlled climate chambers for a period of eight hours without access to feed or water as a simulation of commercial pig transport. Measurements of rectal and surface temperature were made before (T0) and after (T1) the simulation and the results are displayed (Table 4).

Treatment	Rectal Temperature (°C)				Surface Temperature (°C)			
	T0		T1		T0		T1	
-5°C	39.8	± 0.1	38.1	± 0.3	26.8	± 1.2	18.3	± 2.8
5°C	39.9	± 0.1	39.5	± 0.2	26.8	± 2.9	21.9	± 1.9
15°C 50% RH	39.9	± 0.1	40.0	± 0.2	26.5	± 2.4	29.5	± 2.2
28°C 50% RH	39.2	± 0.1	38.9	± 0.1	21.8	± 1.3	36.6	± 1.2
28°C 70% RH	39.4	± 0.2	40.2	± 0.2	27.5	± 2.9	36.3	± 1.3
33°C 50% RH	39.8	± 0.2	40.1	± 0.1	25.1	± 1.8	38.2	± 1.4
33°C 70% RH	40.0	± 0.1	41.1	± 0.2	26.6	± 2.1	36.5	± 1.0

Table 4. Rectal and surface temperatures of pigs before (T0) and after (T1) transport.

Over this range of dry bulb temperatures the pigs were able to maintain rectal temperature (an index of deep body temperature) within acceptable limits. Mild hypothermia (-1.7°C) and hyperthermia (+1.1°C) occurred in the –5°C treatment and the 33°C 70% RH treatment respectively. The addition of high humidity at 33°C was responsible for the greater excursion in rectal temperature seen in this treatment. The surface temperature record indicates the importance of peripheral blood flow as a thermoregulatory mechanism. At low temperatures vasoconstriction conserves deep body temperature at the expense of a dramatic temperature decrease at the skin. With increasing environmental temperature this pattern reverses in a generally linear fashion as vasodilation occurs leading to marked elevations of surface temperature.

The extent of thermoregulatory effort in these pigs can be envisaged by calculation of the thermal gradient between core (rectal) temperature (RT) and peripheral (surface) temperature (ST) as shown below (Figure 4).

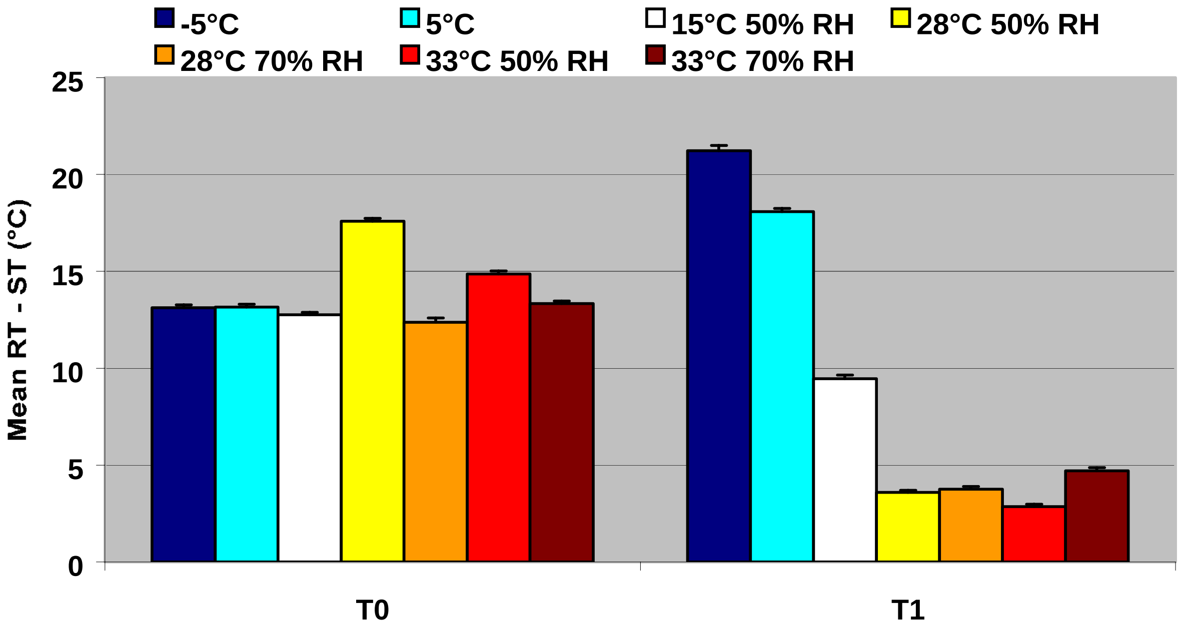


Figure 4. Difference between core and surface temperature of pigs during climate chamber studies.

It is clear that these pigs maintain a thermal gradient of 12 – 15 °C under “thermoneutral” environmental conditions. Environmental temperature down to -5°C will not pose a significant thermoregulatory threat over short periods but will induce considerable thermoregulatory effort. Environmental temperatures of 28°C induce an equivalent thermoregulatory cooling response although it would appear that further capacity is limited by this approach as higher temperature and the addition of high humidity resulted in no further response. Under this experimental regime slaughter weight pigs were capable of maintaining thermoregulatory homeostasis but at either ends of the range the limits have been approached. In practice it would be inadvisable to expose pigs to these extremes during transport and temperatures outside the range 5 to 25°C should be avoided.

Transport studies in Spain

The objectives of this ongoing research, which ahs been funded by Defra, are:

- quantification of the heat and moisture production of calves, lambs and pigs during transport journeys lasting up to 8 hours in hot weather.
- quantification the physiological and behavioural responses of the animals to these journeys (and during recovery).
- comparison of the efficacy of current practice (passive ventilation) with proposed future practice (mechanical ventilation) in accordance with trends in European legislation, under high thermal loads (ambient temperatures >25°C).
- provision of recommendations for appropriate vehicle ventilation requirements when transporting livestock in hot climates.

During the summer of 2003 a number of experimental journeys were undertaken in Spain using the Silsoe experimental vehicle. Groups of pigs (and lambs) were transported under fully commercial conditions for total transport times of 8 hours. On completion of loading, the vehicle was driven around for about 2 hours, stopped for about 30 minutes to simulate a driver's break, then the journey continued before finally returning to the source farm.

Experimental vehicle instrumentation system

As part of this research programme, the vehicle that was used for the UK based studies was completely overhauled to provide a fully automated turnkey system for controlling the ventilation system and monitoring and recording the physical environment around and within the transport container.

Revised ventilation regime

In the mechanically ventilated mode, the air inlets are still the rear grilles on each side of the container. The extraction fans are now housed within the front bulkhead, 2 on each side of each deck (i.e. 4 fans per deck). Air passing through the container leaves through louvred grilles in the front headboard and is then drawn through curved ducting to the extraction fans. The outlet from the ventilating fans is on either side of the front of the container where it joins the front bulkhead.

The ventilation rate is controlled by a commercial fan control unit where the control voltage to the fans is altered in response to changes in ambient temperature (Figure 5). The ambient temperature sensor is mounted within an aspirated housing on the bow front of the vehicle. At switch on, the system provides a minimum control voltage of 2.5 V and as the temperature increases above 15ºC the control voltage increases linearly to 10 V at an ambient temperature of 25ºC. This then corresponds with the maximum ventilation rate.

The resultant ventilation rate range is from 1.0 to 2.4 m^3/s per deck.

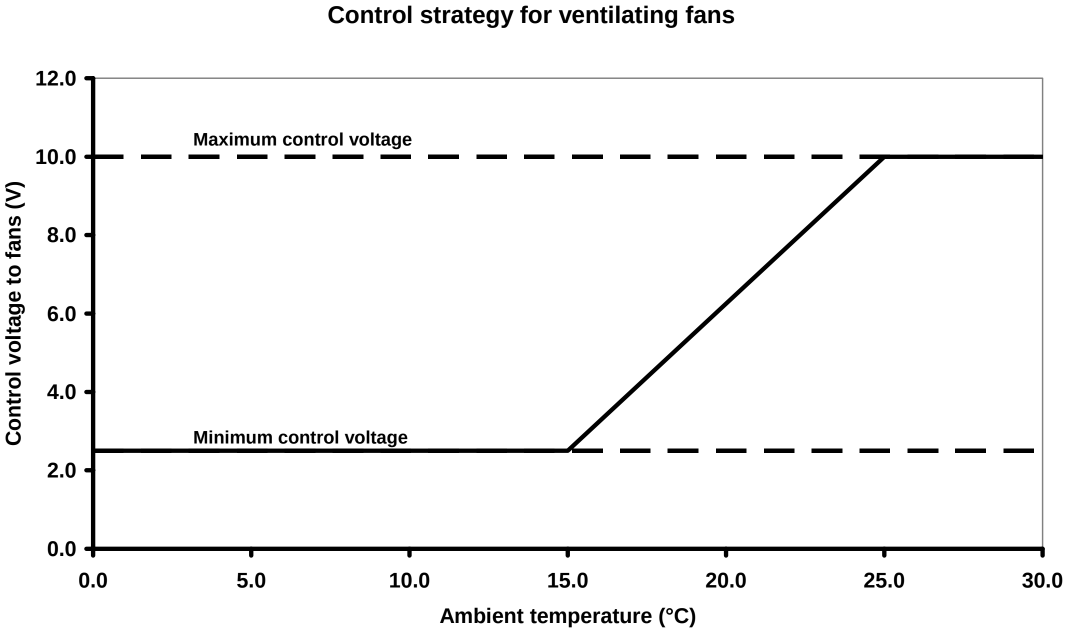


Figure 5. Control strategy for ventilating fans.

<u>Power supply for ventilation system</u>

One of the major issues in providing an active ventilation system on any vehicle has been the provision of a suitable power supply that is capable of operating the fans for prolonged periods independently of the vehicle engine. Initial testing of the fans showed that the typical maximum power consumption was about 7 amps per fan and with all 12 fans running on the vehicle the total current drain, at 24 volts would be 84 amps. Lead acid batteries fitted to commercial vehicles have a capacity of the order of 200 amp hours so a simplistic calculation would predict a fan running time of 2 to 3 hours. Even if the fans were running at minimal rate, the total power consumption would still be 24 amps and this would only extend this simple estimated time to 8 hours. In reality, these simple estimates take no account of the decline in battery performance. In normal operation the battery output voltage is maintained by simultaneous charging of the battery when the engine is running. If the charge rate exceeds the discharge rate then battery performance can be maintained, if not then battery performance decreases and output voltage will decrease. On a stationary vehicle, without the engine running, it is unlikely that battery output voltage would be maintained for more than a few hours. Once the battery voltage starts to decline then the fan performance is markedly reduced.

Because this research required prolonged consistent performance of the ventilation system the power supply was derived from an on-board diesel powered electrical generator. The generator provided a mains output (240V AC) which in turn powered 24V DC power supplies, one for each deck, that then powered the fans. This approach has ensured that (a) on a deck by deck basis there is sufficient power capacity for all the fans to operate continually, even at maximum speed/throughput, and (b) the supply to the fans will always be maintained at 24V.

The TOTAL current consumption with all 12 fans operating, measured during preliminary testing, ranged from 12 Amps (minimum ventilation rate) to 80 Amps (maximum ventilation rate). These data confirmed the results of the initial single fan test.

An additional 24V DC power supply was also installed for the on-board instrumentation system.

Measurement of air temperature and humidity

With the revised ventilation regime, combined temperature/humidity sensors have now been located within the ventilation ducts in the bow front. A total of 6 sensors, 2 on each deck, have been mounted centrally within each side of the outlet ductwork. Inlet air temperature/humidity is measured with similar probes mounted within aspirated housings located on the outer surface of the bow front.

Ventilation rate

The ventilation rate on any fan ventilated deck is determined by measurement of the pressure drop across the fan and the control voltage applied to that fan.

Measurements from fan calibrations derived in the laboratory on a British Standard fan test rig have derived an algorithm that can be used to convert the measured values to a resultant volumetric flow rate (Figure 6).

The resultant algorithm is:

$$\text{Flow rate} = 1.723 - (1.6754 \text{ x } (0.88696^{\text{control volts}}) \text{ x } (1.009155^{\text{pressure drop}}))$$

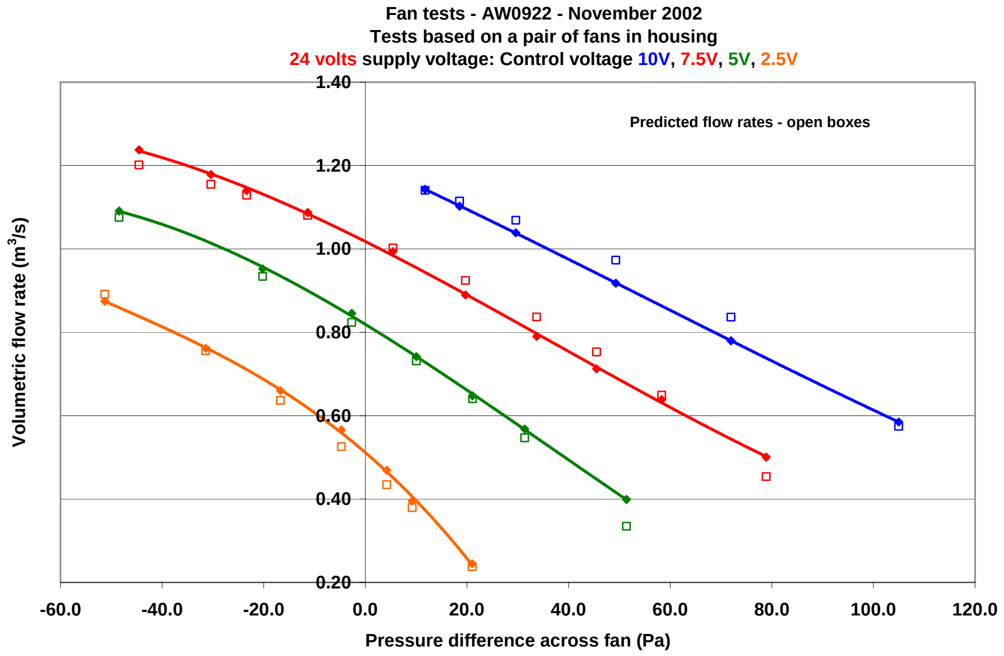


Figure 6. Calibration curves for volumetric throughput of a pair of fans at different control voltages over a range of pressure differences across the fans.

Global Positioning System (GPS)

The transporter has been fitted with a commercial GPS system to provide time stamped journey information of vehicle position and speed. The GPS system also provides the overall time synchronisation, via the satellite link, for ALL the data recording systems.

Radio communications

Short range radio communication packages have been employed to provide both (a) a local passive monitoring (within about 400 m) for diagnostic checks of the instrumentation system and (b) a wireless data link between the trailer and tractor unit. The latter package allows real time monitoring of the conditions within the livestock container without the requirement for “hard wire connections” between the two vehicle components (tractor unit and trailer).

Another independent system also provides long range radio communication using digital phone technology. This communication link is used to send data back automatically to Silsoe Research Institute at regular pre-defined intervals once the system has been started.

Data recording systems

All the measured parameters are recorded every 15 seconds to two independent on-board PC based systems located on the trailer.

The short range wireless data link allows the data to be stored onto a laptop within the tractor unit cab.

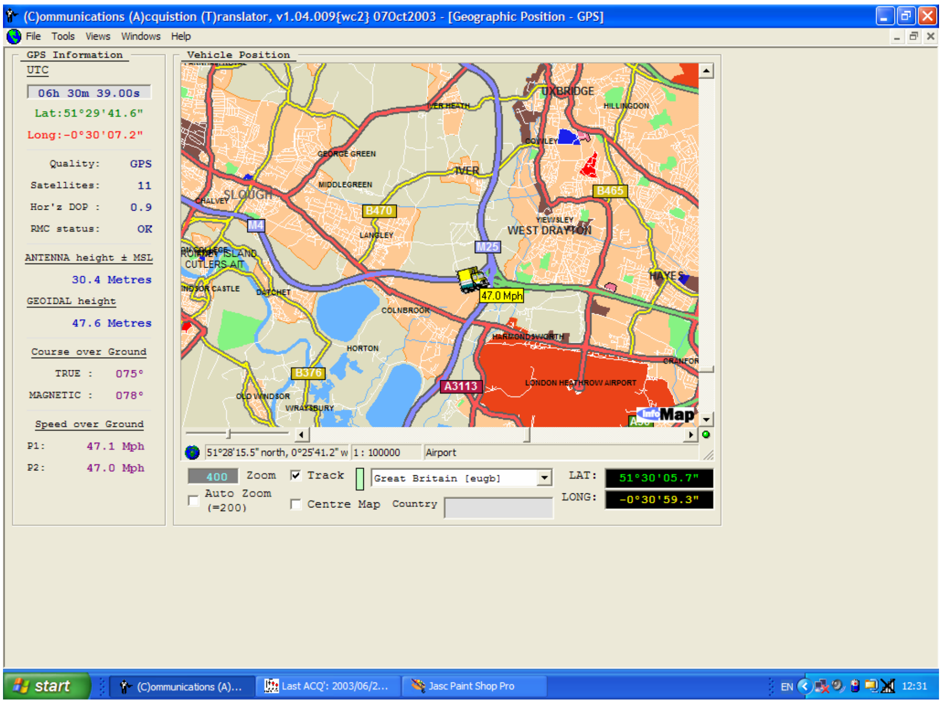
The long range radio communication link (mobile phone) also allows data to be transmitted back to Silsoe and stored on a dedicated PC server.

Thus, the recorded data are stored in 4 separate locations that ensures a high integrity of data storage.

The data files are stored in two formats. Firstly as a CSV (comma, separated, variable) type file that can be imported easily into standard spreadsheet and database packages. Secondly, the data are simultaneously stored in a type specific replay format (SRP, source replay format) for use with the custom-written data replay facility. An additional benefit of the SRP file format is that it can be used to regenerate the CSV file should that be lost or corrupted.

Data replay facility

The stored data can be “replayed” using custom written software that uses the GPS information to display an icon of the vehicle moving across a map. The recorded thermal conditions can also be superimposed on this replay (Figures 7, 8 and 9).


(C)ommunications (A)cquistion (T)ranslator, v1.04.009{wc2} 07Oct2003 - [Geographic Position - GPS]

File Tools Views Windows Help

GPS Information

UTC

06h 30m 39.00s

Lat:51°29'41.6"

Long:-0°30'07.2"

Quality: GPS

Satellites: 11

Hor'z DOP : 0.9

RMC status: OK

ANTENNA height ± MSL

30.4 Metres

GEOIDAL height

47.6 Metres

Course over Ground

TRUE : 075°

MAGNETIC : 078°

Speed over Ground

P1: 47.1 Mph

P2: 47.0 Mph

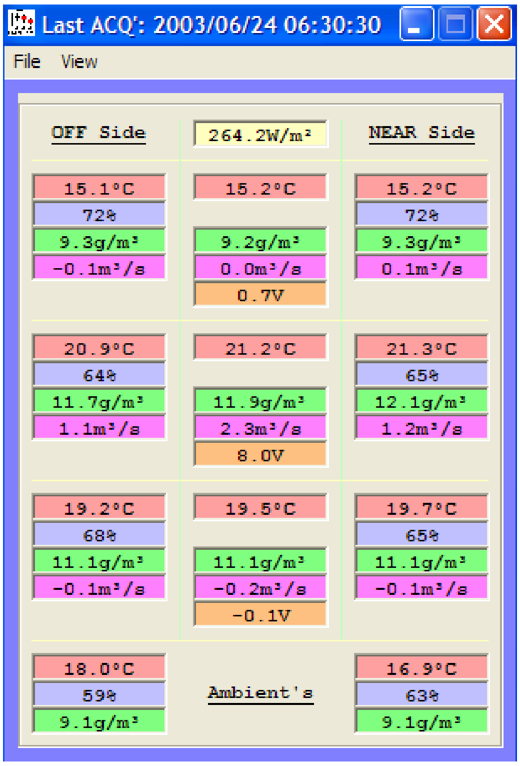
Vehicle Position

51°28'15.5" north, 0°25'41.2" w 1 : 100000 Airport

400 Zoom ☑ Track Great Britain [eugb] LAT: 51°30'05.7"

☐ Auto Zoom (=200) ☐ Centre Map Country LONG: -0°30'59.3"

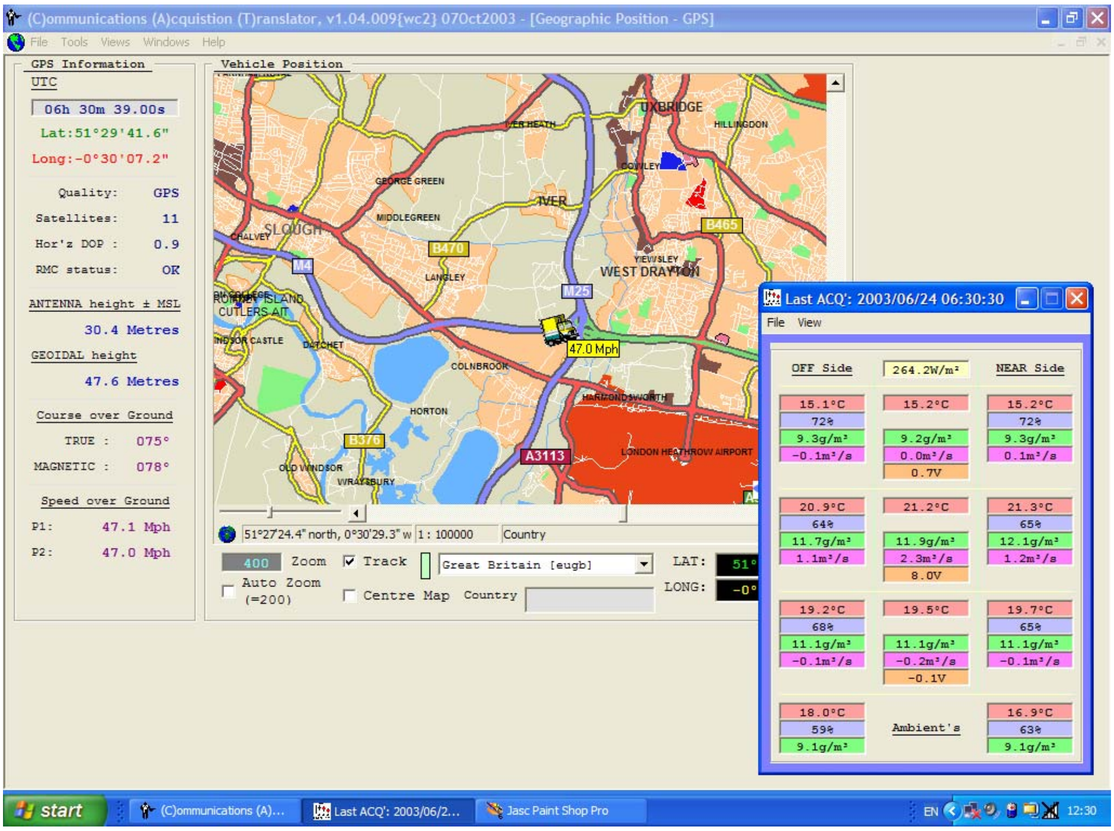
Figure 7. Example of replay information (from UK based testing) showing vehicle travelling along M4 motorway. Additional information on time (GMT), longitude and latitude, and ground speed are presented.


Last ACQ': 2003/06/24 06:30:30

OFF Side	264.2W/m^2	NEAR Side
15.1°C	15.2°C	15.2°C
72%		72%
9.3g/m^3	9.2g/m^3	9.3g/m^3
-0.1m^3/s	0.0m^3/s	0.1m^3/s
	0.7V	
20.9°C	21.2°C	21.3°C
64%		65%
11.7g/m^3	11.9g/m^3	12.1g/m^3
1.1m^3/s	2.3m^3/s	1.2m^3/s
	8.0V	
19.2°C	19.5°C	19.7°C
68%		65%
11.1g/m^3	11.1g/m^3	11.1g/m^3
-0.1m^3/s	-0.2m^3/s	-0.1m^3/s
	-0.1V	
18.0°C		16.9°C
59%	Ambient's	63%
9.1g/m^3		9.1g/m^3

Figure 8. Example of real time monitoring. Display represents view looking at front of transport container and is split into nearside and offside. The figure at the top is the solar radiation (264.2 W/m^2). Boxed figures on each side are outlet air condition (temperature, relative humidity and vapour density), volumetric flow rate for each

deck (top to bottom). Central boxed figures are average temperature and vapour density and total flow rate. The lower figures in the central block are the control voltage to the fans – in this example only the middle deck was mechanically ventilated. The bottom set of figures are the ambient (inlet) conditions.



UTC
06h 30m 39.00s
Lat:51°29'41.6"
Long:-0°30'07.2"

Quality: GPS
Satellites: 11
Hor'z DOP : 0.9
RMC status: OK

ANTENNA height ± MSL
30.4 Metres
GEOIDAL height
47.6 Metres

Course over Ground
TRUE : 075°
MAGNETIC : 078°

Speed over Ground
P1: 47.1 Mph
P2: 47.0 Mph

51°27'24.4" north, 0°30'29.3" w 1 : 100000 Country

400 Zoom
☑ Track
☐ Auto Zoom (=200)
☐ Centre Map
Great Britain [eugb]
Country
LAT: 51°
LONG: -0°

Last ACQ': 2003/06/24 06:30:30
File View

OFF Side	264.2W/m²	NEAR Side
15.1°C 72% 9.3g/m³ -0.1m³/s	15.2°C 9.2g/m³ 0.0m³/s 0.7V	15.2°C 72% 9.3g/m³ 0.1m³/s
20.9°C 64% 11.7g/m³ 1.1m³/s	21.2°C 11.9g/m³ 2.3m³/s 8.0V	21.3°C 65% 12.1g/m³ 1.2m³/s
19.2°C 68% 11.1g/m³ -0.1m³/s	19.5°C 11.1g/m³ -0.2m³/s -0.1V	19.7°C 65% 11.1g/m³ -0.1m³/s
18.0°C 59% 9.1g/m³	Ambient's	16.9°C 63% 9.1g/m³

Figure 9. Example of replay information with corresponding thermal data inset.

Operational strategy

The instrumentation system has been designed for robustness to withstand the rigors of commercial practice, reliability of data capture and recording, coupled with simplicity of operation. A simple commercial system is used to control the operation of the fans in accordance with the basic strategy described earlier. The instrumentation system only takes information from the controller. It has no direct interaction on the control system so that should the instrumentation system fail, the ventilation system will continue to operate. However, if the ventilation system fails then, because of the continuous monitoring, visual alarms will advise the driver of any problem.

In operation, the generator is started and all the required fan power supplies switched on. The ventilation system is then operational. The instrumentation system can then be started from a single push button located on the front of the trailer. The system goes through a start up routine and then records data. On completion of the journey the system is switched off in a similar manner.

In the event that the generator fails then the visual alarms will advise the driver that the fans have stopped. He may then open the ventilation panels to afford natural ventilation for the remainder of the journey. At the same time, the instrumentation system will automatically switch to a UPS (Uninterrupted Power Supply) that will allow the system to close down in a controlled manner and preserve the recorded data.

Thermal conditions during transport

The vehicle was configured (Figure 10) such that on two decks there was mechanical (fan) ventilation with the remaining (upper) deck being naturally ventilated.

Figure 10. Vehicle configuration – upper deck naturally ventilated, middle and lower deck naturally ventilated.

The average thermal conditions for the whole transport period are summarised below (Table 5).

		Temperature (°C)	Relative humidity (%)	Vapour density (g/m^3)	Enthalpy (kJ/kg)
Top deck	Average	29.5 ± 2.7	29.3 ± 5.1	8.5 ± 0.7	48.5 ± 3.4
Middle deck	Outlet	30.6 ± 2.0	39.6 ± 11.3	12.1 ± 2.2	57.7 ± 3.7
Bottom deck	Outlet	31.9 ± 1.8	43.3 ± 8.5	14.4 ± 1.8	64.5 ± 3.3
Ambient	Inlet	30.7 ± 4.2	27.4 ± 9.4	8.2 ± 1.7	49.1 ± 3.9

Table 5. Summary of thermal conditions during transport period.

Mechanical ventilation draws ambient air into the rear of the vehicle, which then passes over the animals before being exhausted through fans mounted in the front bulkhead of the trailer. The nature of this ventilation regime means that the air leaving those decks will have “picked up” heat and moisture as it passes over the animals. Consequently the heat content, or enthalpy, of the outlet air will be greater than the inlet (ambient) air.

The effects of the prevailing thermal conditions were assessed in groups of pigs loaded into four key locations; lower deck front pen (LDFP), lower deck back pen (LDBP) upper deck front pen (UDFP) and upper deck back pen (UDBP) representing the ventilation outlet and inlet on both mechanically ventilated decks. Measurements of surface temperature were made immediately before loading and after unloading. The results (Figure 11) indicate that despite a relatively hot thermal environment on board the vehicle a degree of peripheral cooling occurred during the period of transportation in all locations except the LDBP. This suggests the pigs detected a lower thermal load in their immediate environment, required less convective cooling to maintain deep body temperature and, therefore, reduced their peripheral blood flow accordingly.

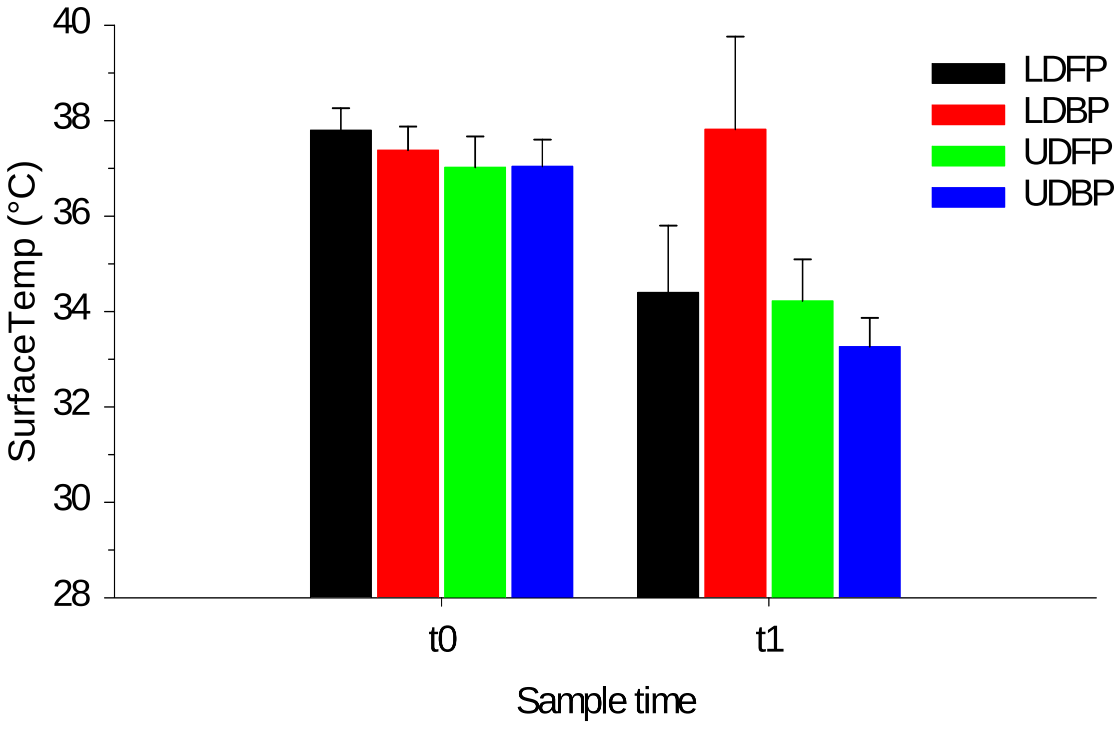


Figure 11. Changes in the surface temperature of pigs at specified pen locations following transportation.

Simultaneous, continuous recording of deep body temperature (DBT) was made by a surgically implanted radio-telemetry system in sentinel animals placed in each pen location (Figure 12). During loading DBT was seen to slowly increase in all four locations as the pigs were moved from there home pens to the vehicle and remained on the stationary vehicle while the remaining animals were loaded. Once the journey commenced, DBT decreased throughout the first half then stabilised for the remainder. On unloading and return to their home pen, DBT increased substantially. These results support the surface temperature data and when considered in context of the high environmental temperature of the home pen upon the animals return, it would appear that, paradoxically, these pigs enjoyed a more benign thermal environment aboard the vehicle than they did in their home pen. Air movement was observed (anecdotally) to be minimal within the home pen. On board the vehicle, however, the ventilation system would have ensured a constant level of air movement throughout the journey providing sufficient convective cooling to elicit a slight thermoregulatory cooling in spite of the "pick up" of heat and moisture mentioned above.

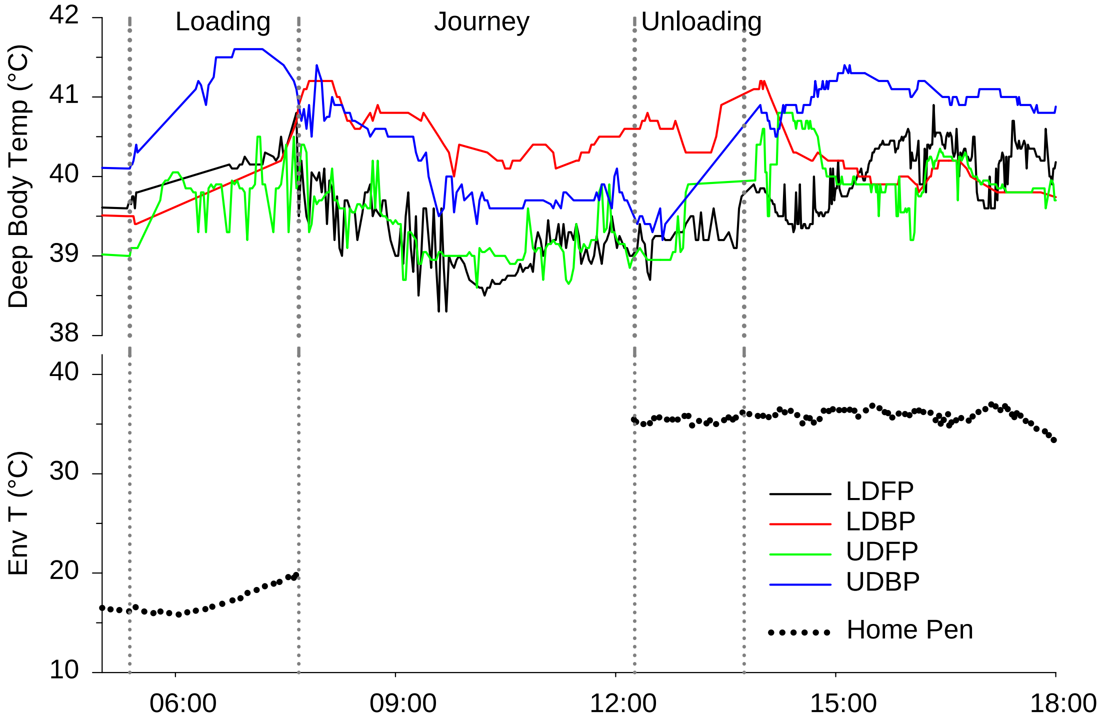


Figure 12. Changes in deep body temperature of sentinel pigs in specific pens for the whole transit period. Data were obtained using implanted radio-telemetric sensors.

Concluding remarks

Discussions within the EC seeking to define acceptable ranges and limits for the thermal conditions during transport of livestock are based on available scientific data, much of which is dated and in many cases relates to individual animals. There are NO scientific data that relate specifically to acceptable transport conditions for livestock on journeys exceeding 8 hours. Since long journeys involve major geographical and climatic changes, the animals are not exposed to constant ambient conditions. Conducting sound scientific research to address this scenario is thus challenging. It is NOT impossible, but it will be expensive!

The data presented here suggest that it is possible to conduct research to define acceptable thermal limits, under transport conditions, for pigs. These data can initially be derived under controlled conditions within climate chambers, then further validated under actual transport conditions using the unique research vehicle available to this research group. Further, the data can also be used to optimise mechanical ventilation systems that will be viable for commercial operation.

The UK based studies suggest that it would be inadvisable to expose pigs for long periods to temperatures outside the range 5 to 25°C. By contrast, the provisional results from the ongoing studies in Spain, where ambient temperatures were over 30°C, seem to suggest that there was minimal demand on the thermoregulatory capability of the pigs.

Further experimental work is scheduled for summer 2004 in Spain to provide additional scientific data.

These results demonstrate the need to consider adaptation of animals to their prevailing (home) environment. This is an important factor that may preclude meaningful "all-encompassing legislation" to cover countries as different climatically as Sweden and Greece. The question remains "Should a single market mean a single standard?"

Perhaps a more pertinent issue would be to determine acceptable conditions for pigs travelling from colder to warmer climates, where thermal changes will arise as the vehicle travels to its ultimate destination. In this case, the pigs will have been reared in cooler climates (e.g. UK) and then transported to hotter climates (e.g. Spain).

The scientific collaborators, research facilities, expertise and commercial collaborators (in many cases) are now well established to address these issues. All that is required is funding!

The impossible doesn't take longer – it just costs more!

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