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Standards for the Microclimate inside Animal Transport Road Vehicles

Report of the

Scientific Committee on Animal Health and Animal Welfare

Adopted 8 December 1999

Standards for the Microclimate inside Animal Transport Road Vehicles

Contents

1. Request for an Opinion

The Committee is asked to report on "Standards for forced ventilation for animal transport vehicles for road journeys of more than eight hours for the bovine, porcine, ovine and caprine species."

2. Background

Council has recently (16 February 1998) adopted Regulation 411/98 on additional animal protection standards applicable to road vehicles used for the carriage of livestock on journeys exceeding eight hours. This regulation lays down certain requirements as regards ventilation on these transport vehicles. The requirements, quoted from the Regulation, are as follows;

"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."

The role of this report, therefore, is to consider, for both stationary and moving vehicles, the requirements to guarantee an adequate microclimatic environment for the welfare of the animals carried, respecting their needs. Recommendations to achieve that goal are proposed. Other aspects of animal transport are not considered in this report.

3. Introduction

Transport of cattle, pigs, sheep and goats occurs on a large scale, both within and between European countries and between the European Union and non EU countries. The number of transported livestock in the EU countries is not exactly known. It is estimated that at least 25 million cattle, 6 million calves, 171 million pigs, 75 million sheep and lambs and 9 million goats are transported per year within the EU (Nagel, 1994). The number of exported animals to customers outside the EU as slaughter animals or for breeding purposes in 1995 was 660,000 cattle and calves, 71,400 pigs and 40,200 sheep and goats (SAEG, 1995). The animals are transported either from farm to slaughterhouse or through a market where they are off-loaded, handled and re-loaded.

During road transportation livestock animals are exposed to a variety of potential stressors such as motion of the lorry, noise, vibration, centrifugal forces, quickly changing light conditions, heat, cold, poor air quality and possibly lack or shortage of water and feed. Of these factors thermal stress is recognised as one of the major reasons of reduced welfare and health of the animals which can decrease product quality and may even cause death (Nielsen, 1982 for pigs, Dantzer, 1982).

The number of deaths during long haul road transport are not known. Warriss (1996) reports that losses in pigs during national short term (< 8 h) transports varied between different EU countries from 0.03% to 0.5%. About 70 % of the deaths occur on the lorry and the other 30 % after the pigs have reached the market or the abattoir (Christensen and Barton Gade, 1997). There are distinct seasonal differences in pig transit death rates with a clear peak in the summer months (van Logtestijn et al., 1982) when the conditions are hot and wet (Abbott et al., 1995). A French survey studied the mortality rate during transport on 10.3 million pigs (Colleu and Chevillon, 1999). The rate increased with the outside temperature from 0.07% for outside temperatures lower than 5°C to 0.11% for temperatures higher than 15°C. It also increased with the length of the journey from 0.084% for journeys shorter than 75km to 0.12% for journeys longer than 150km. Recent examples have shown that losses in the hotter regions, particularly for unacclimatised animals could be expected to be even greater (Palacio et al., 1996; Guardia et al., 1996).

When animals are transported e.g. from Northern to Southern Europe, they pass through various climatic zones within a relatively short span of time without any chance of acclimatisation. This has important implications for their welfare. During a single journey ambient temperatures might change from -5 °C in north-east Germany to 30 °C or more in the south of Italy or Spain (Barton Gade et al., 1993). Therefore, adaptable ventilation systems on the vehicles are necessary to ensure a satisfactory environment for the animals.

In addition, the internal construction of lorries varies with the type of animals being transported. Cattle are usually transported in two tier lorries. For the transport of fattening pigs three tiers are provided. Piglets are transported on lorries having up to five tiers. In these decks the air distribution will vary considerably.

This report will first examine the measurements that should be taken into account in considering the physical requirements for animals during transport. It will take temperature, humidity and certain gas levels more specifically into account. It will consider the situation of vehicles equipped only with natural ventilation and then the criteria required for vehicles equipped with forced ventilation systems, followed by conclusions and recommendations.

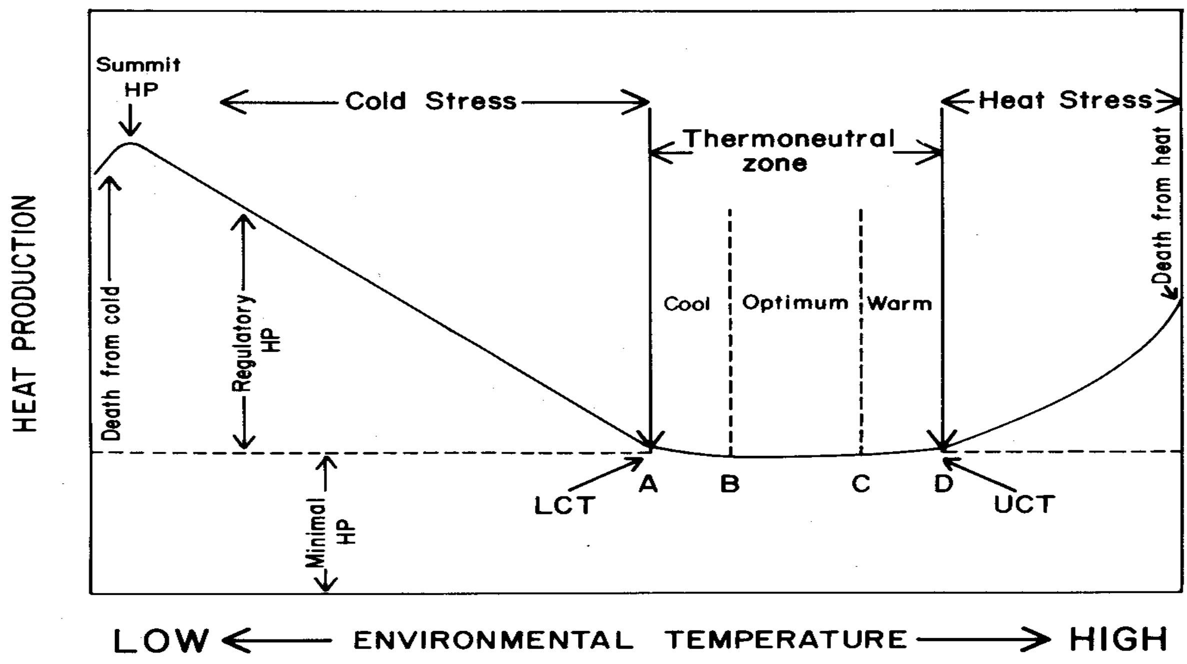
4. Requirements of the animals

4.1 Temperature

4.1.1 Definitions of the thermal zones of farm animals

Farm animals are homeothermic, which means they are, within certain limits, able to maintain a relatively constant deep body temperature different from the environmental temperature. A relatively constant deep body temperature means that heat production and heat loss are equal. An increased difference between deep body temperature and environmental temperature leads to higher heat losses to be compensated by a higher heat production. Body temperature will increase when heat loss is not sufficient (heat stress). Heat may be dissipated through conduction, convection, radiation and evaporation. Figure 1 presents the basic scheme of body core temperature control (Yousef,1985). The heat production of the animal is minimum within the thermoneutral zone. The body core temperature is kept constant in the zone of homeothermia but for temperatures lower or higher than the thermoneutral zone the heat production of the animal increases. When the loss of heat is higher than the heat production hypothermia results and eventually death may occur.

Fig. 1- Scheme of the thermoneutral zone of animals (Yousef, 1985). LCT: Lower critical temperature, UCT: Upper critical temperature.



Depending on the species, animals can increase heat dissipation by sweating or panting. They can also avoid activities, reduce feed intake, increase drinking or increase the distance between animals. Within each species heat production varies according to age, physiological state, feeding, performance and previous adaptation. The animals can adapt to cold or hot environments by changing their physiology and physical characteristics (hair in particular) (Berbigier, 1988). That acclimatisation process takes several weeks to be effective.
Lower Critical Temperatures (LCT) for cattle, pigs and sheep have been proposed by Bruce and Clark (1979), Blaxter (1979), Webster (1974, 1981, 1987) and Bruce (1981), Lindley and Whitacker (1996), Wathes et al (1983), Curtis (1983), Charles (1994) and Upper Critical Temperatures (UCT) by Bruce (1981) and Wathes et al. (1983), for goats by Constantinou (1987). A model of thermal interaction between an animal and its microclimate has been developed by McArthur (1987 and 1991) but it is difficult to use in practice due to the lack of good estimates of the parameters.

Common ventilation rules for all animals are difficult to establish because of the very different temperature requirements of the various animal species. Pigs, sheep, goats and cattle have different comfort zones and the higher and lower critical temperatures vary considerably. The age of the animals plays an important role. Young pigs need a distinctly higher ambient temperature than sows or lactating cows. Whether sheep are shorn or not is important. Together with the temperature, the relative humidity is crucial for the loss of energy both in winter and in summer conditions. High temperatures and high humidity prevent the animals releasing their heat. Low temperatures and high air humidity may enhance heat dissipation and the animals suffer from cold. Both situations can occur when the ventilation rates are too low and the insulation of the lorry is poor. High loading densities increase those problems.

4.1.2 Bovines

Adult cattle have the ability to adjust their zone of thermoneutrality by adapting to both high and low air temperatures. Thus the optimum temperature is greatly influenced by prior acclimatisation (Webster, 1981). However that acclimation process takes time. Yousef et al., (1967) observed some acclimatisation after 36 hours of cold exposure. Even more, Shrama et al. (1993) found that LCT of young calves increased over 6 days when subjected to cold temperatures. This implies that sudden transfer on transporters to environments very different from the usual one may cause acute heat or cold stresses. Wathes et al. (1983) have drawn together information from the literature which indicates that the ideal temperature for store cattle and cows lies below 20 °C and for one month old calves below 25 °C. Temperatures down to, and for some conditions below, 0°C are acceptable for adult cattle. However, given time (2-3 weeks) cattle can acclimatise to lower temperatures. Young calves and acclimatised cattle are tolerant of warm conditions. The main criterion is to remain below the UCT to which the cattle are acclimatised. Generally, temperatures up to 30 °C for cattle are satisfactory.

4.1.3 Sheep

Acceptable temperatures for sheep are more complex partly because of the major effect of fleece length. No data have been found for store or slaughter lambs. For poorly fed ewes with a full fleece, the LCT is around -10°C and when shorn around 20 °C. The UCT for a poorly fed shorn ewe already adapted to a hot environment is about 40 °C (Alexander, 1974), but could be reduced to around 28°C when unshorn. These figures seem to vary between breeds (Degen, 1977). Thus a maximum temperature selected for ventilation design in transit of 25 to 30 °C may be appropriate, but only when the animals have been previously acclimatised (Webster, 1981).

4.1.4 Pigs

Factors such as the type and insulation of flooring are especially important for pigs. When lying on a well bedded floor LCT for pigs are reduced by 3 to 5 °C (Bruce, 1981). When the type of floor may vary or it is not known if the pigs will stand or lie, then the highest value of LCT and the lowest value of UCT may be used, thus narrowing the acceptable range for each pig weight. During transport of animals on lorries the main criterion is to prevent the UCT from being exceeded. An air temperature of 32°C could be selected as a maximum design value. The use of water spray on pigs will act to increase evaporative cooling (Lambooij and Engel, 1991).

4.1.5 Goats

Goats seem to be more sensitive to cold than sheep. After shearing Angora goats are particularly sensitive to a cold environment. To lose heat, they do not sweat but pant. They can adapt to a hot environment (Hafez, 1968). However, goats are very susceptible to humidity and wind chill (Constantinou, 1987). Their haircoat is not as tight as in sheep for example, and if wet (rain or high humidity on the lorry or indoors), the heat loss can increase rapidly. Therefore optimal housing conditions for goats in temperate climates are reported as follows: Minimal (6°C) and maximal (27°C) temperatures, relative humidity 60 – 80 %, ventilation rates between 30 m^3/goat/hour (winter) and 150 m^3/goat/hour (summer) and maximum wind speed of 0.5 m/s (adults) and 0.2 m/s (kids) close to the animals (Smith and Sherman, 1994).

4.2 Humidity ranges

Humidity is a critical factor in the ability of animals to lose heat. As humidity increases the effectiveness of evaporative cooling decreases. As the ambient temperature approaches body temperature, sensible cooling becomes less effective and the animal relies increasingly on evaporative cooling. Thus the worst conditions for heat loss occur at high temperatures and high humidity. High humidity is a problem for animal welfare when the temperature is also high, especially for sheep, goats and cattle. Models (e.g. McArthur, 1987 and 1991) provide combined measures of temperature and humidity in parameters such as "standard environmental temperatures", but these are not readily applied in specific transport cases because of the large number of unknown values involved.

Water vapour in an animal enclosure originates not only directly from the animals. Evaporation from urine, faeces and washing water also occurs, but these factors are very difficult to estimate quantitatively (Randall, 1983).

The relationship between temperature and humidity and the effects these can have on the animals can be illustrated as in Figure 2, which has been worked out for poultry transportation (Kettlewell, personal communication).

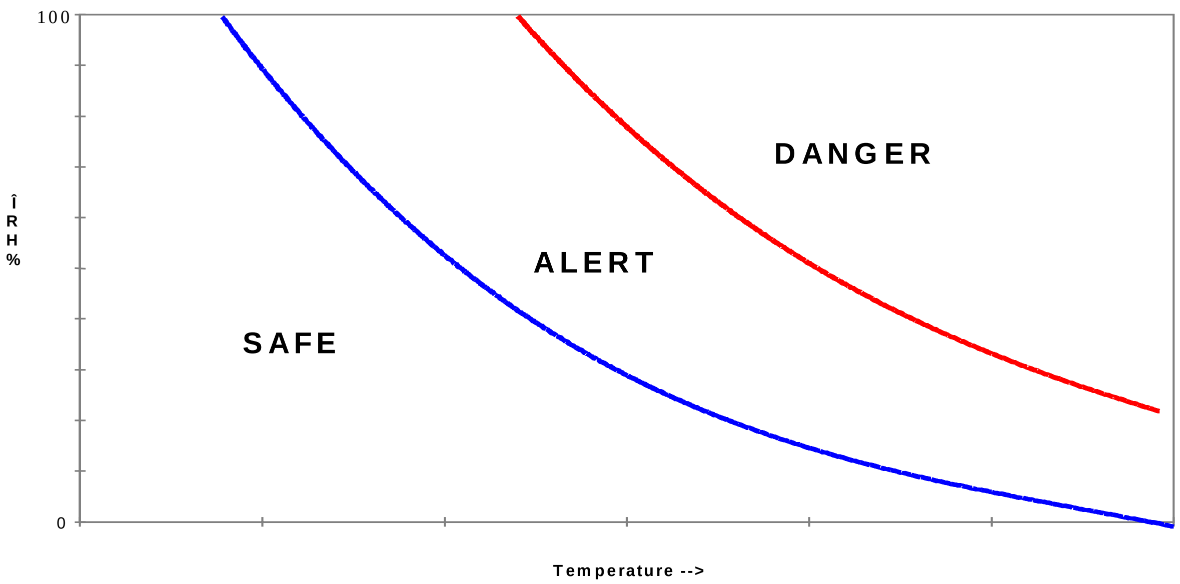


Figure 2 – Scheme of the relationship between temperature, humidity and the likelihood of poor welfare in the animals

Maximum and minimum relative humidity levels as a function of inside temperature have been proposed for animal housing (CIGR, 1984). However in the confines of a livestock transporter it may not be practicable or necessary to keep the relative humidity below 80% above temperatures of 10°C as recommended. For transport, Müller and Baumüller (1978) have suggested an upper limit of 85% relative humidity, whereas for normal housing Esmay and Dixon (1986) recommended 75 to 80%. The acceptable temperature is a function of humidity. For example, for calves Vermorel (personal communication) proposed that the UCT could reach 30°C if the humidity is lower than 60% and should be lower than 27°C if the humidity is equal or higher than 80%.

For pigs, water vapour or relative humidity are not particularly important for temperatures below 30°C (Randall, 1983). In dry conditions the dry-bulb temperature is much more important than the wet-bulb temperature since pigs do not pant or sweat. Yet in hot-wet conditions, wet-bulb temperature becomes very important. In general relative humidity can be allowed to rise to 95% (Bruce, 1981), unlike cattle, sheep and goats where a limit of 80% is more appropriate (see also Table 2).

4.3 Air velocity

Air movement over the body surface of animals is an effective means of heat dissipation. Air velocity increasingly affects the heat loss from dairy cows as the ambient air temperature drops below 25°C. At –7°C ambient air temperature and a 4.44 m/s wind velocity will increase total heat loss from dairy cows by 25% as compared to a 0.22 m/s wind (Esmay and Dixon, 1986). At –8°C an increase in air velocity from 0.18 m/s to 4.0 m/s lowers hair surface temperature by 16 °C and the skin temperature by 6°C. At 35°C, however, the skin surface temperatures are lowered by only about 1°C (Thompson et al., 1954, Esmay and Dixon, 1986).

Air velocity affect pigs even at high ambient air temperatures. At 32°C the heat loss due to high air velocity (0.18 vs 1.52 m/s) increases by 10%. At 10°C air temperature, the convective plus evaporative heat loss is increased by 23% when the air velocity increases from 0.18 to 1.52 m/s (Esmay and Dixon, 1986). Even though increased air velocity lowers radiation losses because the body surface temperatures are lowered, the combined total of convective and radiation losses are increased by the higher air velocity. At 20°C, for example; the convective and evaporative portion of total heat loss increases from 62% to 79% as the velocity is increased from 0.18 to 1.52 m/s Esmay and Dixon, 1986). Higher air velocities should be provided in the animal accommodation to help relieve heat stress conditions at high (>30°C) ambient temperatures.

4.4 Gas levels

Animals exhale carbon dioxide, and produce ammonia and hydrogen sulphide from their faeces.

Recommendations have been made for acceptable carbon dioxide levels in animal housing and for man in work environments. Carbon dioxide is an asphyxiant at relatively high concentrations (Wathes et al., 1983). In many countries the long-term, time-weighted average limit for workers exposed for 8 hours in any 24 hour period is 0.5 % (e.g. Health and Safety Executive, 1990; DFG, 1999). Bruce (1981) suggests that 0.3 % with occasional excursions to 0.5 % could be acceptable, based on a limit of 0.5 % proposed by Baxter (1969) and Nordstrom and McQuitty (1975). These last recommendations assumed that conditions should be provided which are an order of magnitude better than those known to have detrimental effects. Müller and Baumüller (1978), using data from the German Standard (DIN 18910, 1974), recommend that for long haul transport in ventilated freight holds the maximum allowable carbon dioxide level should be 3.5 %. Since at 1% to 2% concentrations for short duration, there is little effect on humans, Müller and Baumüller (1978) suggest that a concentration up to 2 % might be acceptable, but only briefly at the end of the journey. In the German Standard (DIN 18910, 1992) carbon dioxide is regarded as an indicator of ventilation intensity in animal housing and a carbon dioxide level of 0.3 % should not be exceeded. Summarising, a value of 0.3 % is selected as an acceptable maximum value (Randall, 1983).

The rate of ammonia production is not predictable and therefore it is not practicable to control ventilation rate based on ammonia levels. Ammonia levels of more than 20 p.p.m. should be avoided for health reasons (CIGR, 1984).

Hydrogen sulphide is unlikely to be formed during transport, as it results from the relatively long term anaerobic decomposition of faeces.

4.5 Acceptable temperatures

The ranges of acceptable temperatures for different types of animals varies in literature. Table 1 summarises data from the scientific literature relating to animal housing. The table summarises (where available) recommended ranges (rec. range), lower (LCT) and upper critical temperature (UCT) for cattle, pigs, sheep and goats.

Table 1: Temperature values for various types of animals

Cattle	**Rec. range °C (for housing and production)**	**LCT °C**	**UCT °C**
Calf 0-2 weeks		10[2]	30[3]
Calf 50 kg liveweight	10 - 26[2]	0[1]	30[3]
Beef cattle	4 - 26[2]	-40[2], 5[3]	28[3]
Beef cow *	0 - 20[7]	-21[8]	
Dairy cow	4 - 24[2]	-24[2], -30[4]	28[3]
Pigs			
2 kg *		31[8]	
20 kg *	26 - 32[7]	26[8]	
20 kg	20 - 32[7]	22[3]	33[3]
60 kg *		24[8]	
100 kg *		23[8]	
100 kg	18 - 22[7]	14[3]	32[3]
140 kg *		24[8]	
140 kg sow	12 - 20[7]	12[3]	30[3]
Sheep (general)	4 - 24[2]		
5-mm fleece*		25[8]	
50-mm fleece *		9[8]	
100-mm fleece *		-3[8]	
lamb 0-2 weeks	10 - 18[7]	10[3]	30[3]
Ewe full fleece	8 - 18[7]	-15[3], -9[6]	
Ewe shorn		15	30[3]
Goat	12 - 18[9]	0[10]	30[10]

[1] Webster (1981)
[2] Lindley and Whitacker (1996)
[3] Wathes et al. (1983)
[4] Webster (1987)
[5] Holmes and Close (1977)
[6] Charles (1994)
[7] DIN 18910 (1992)
[8] Curtis (1983)
[9] Hinrichsen (1974)
[10] Constantinou (1987)

(*maintenance diet)

In terms of transport it is possible to exceed the upper and lower critical temperatures for animal housing. The margins by which the upper critical temperature can be exceeded is less than that by which the lower critical temperature can be reduced (see Fig 1) as animals can cope better with the lower extremes than with the higher temperatures. Based on these data, therefore, the Committee proposes values (see Recommendations, Table 2) for the maximum and minimum temperatures during transport including a correction factor to take account of high humidity conditions.

5. Types of ventilation systems in vehicles

5.1 Natural vehicle ventilation

Natural ventilation occurs due to pressure differences arising on either side of the vent caused by density and temperature differences or wind. On a moving vehicle natural ventilation is supported by the pressure differences arising from vehicle motion and the wind force and direction.

In regulating ventilation systems in naturally ventilated vehicles, three aspects need to be considered;

- the speed of the moving vehicle
- adjustments made to the ventilation system
- the situation on the stationary vehicle

5.1.1 Speed of the vehicle

The first factor which significantly influences ventilation is the speed of the vehicle. The pressure field around and in the vehicle changes with the velocity of the vehicle and the prevailing wind direction and wind speed. Head winds create very different conditions as compared to cross winds which hit the vehicle from the side. Therefore, actual ventilation rates are very difficult to predict. Experience shows that under normal conditions when the ventilation slots are open and the lorry drives on a motorway, sufficient air is supplied even in summer.

In winter time, when most of the openings are closed, the air on the lorry can become highly contaminated with moisture and gases. This depends on the length of the journey and the quality of the litter. Eight p.p.m. of ammonia were found at head height of heifers after a 14 hours journey on a special transporter for long range transport with straw litter (Hartung, pers comm.). However, if the ventilation rate is increased too much, the temperature can fall below the lower critical temperature for the animals. This may particularly happen when the animals are wet and they are exposed to draught.

5.1.2 Adjustment to natural ventilation systems

Transport vehicles today are usually equipped with natural ventilation systems having openings in the sidewalls of the trucks. The ventilation rate is regulated by using flexible flaps which cover parts of the openings in colder ambient situations or which are removed to provide maximum ventilation under summer conditions. These facilities are operated by the driver. Some vehicles that are used only in warmer conditions have a very substantial side opening

5.1.3 The stationary vehicle

The third situation of concern is the stationary vehicle. This happens while the lorries are being loaded or unloaded which can last an hour or more or when they are stuck in the traffic or when the drivers have a break. Open ventilation flaps, doors and loading ramps may help to lower the heat burden in summer. Many lorries have the opportunity to lift the roof by 20 to 30 cm. This enlarges the head room for the animals on the upper deck and increases ventilation when the vehicle is stationary. Spraying the roof regularly with water and/or using insulated roof constuctions can reduce heat stress to some extent. Very little can be done when the lorry is stuck in the traffic on a motor way. In cold conditions poor air exchange will result in elevated gas, and moisture levels.

5.2 Systems for animal transport vehicles equipped with forced ventilation

Forced ventilation is the system when air is supplied by fans which provide a certain amount of fresh air according to the capacity and regulation of the fans. The objective is to have a controlled ventilation rate and air flow pattern independent of the surrounding conditions. Another advantage of forced ventilation is the better distribution of the fresh air in the stationary vehicle when ducts and adequate openings are provided for the air.

Beside the calculation of the appropriate amount of ventilation air it is very complicated to predict the circulation and distribution of the air inside a semiclosed vehicle. However, some principles exist. The most important fact is the location of slots for air suction out of the transport box. If a stationary single decker vehicle is used and fresh air is blown with fans in the front at the roof level, then fresh air circulates from the front to the rear. If there are slots in the rear wall most of the air leaves the vehicle via these slots. The location of these slots should be on the level of the animal's head. If the vehicle is moving the direction of the air flow changes. The pressure field which builds up around the vehicle as it increases speed draws the air through the openings in the rear inside the lorry. The air leaves the vehicle in the front or through the openings at the sides. Openings in the front must be protected from direct wind pressure.

Fig. 3 gives the principle of the pressure field around a moving vehicle (Capdeville, pers comm).

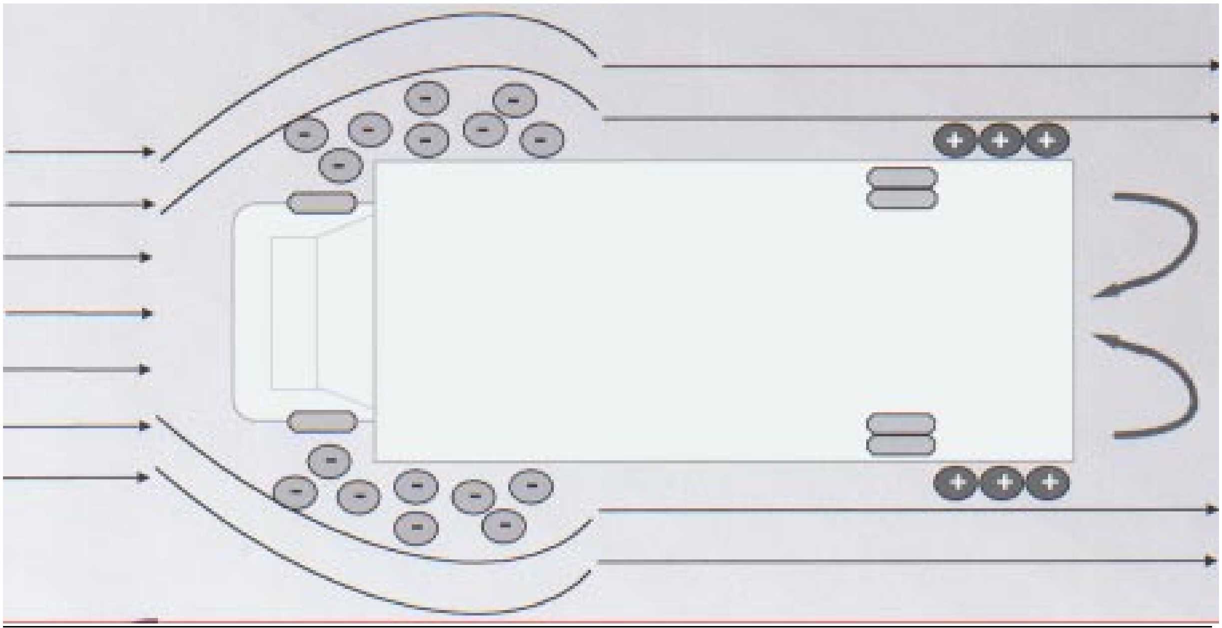


Figure 3: Pressure field and air stream in the vehicle when moving (Capdeville, pers comm)

The air exchange and distribution will depend on the animal density on the lorry and on the head room above the animals. If the animal density is high and the head room is small (in case of cattle mostly not more than 10 to 15 cm) the airflow is hampered. The consequence is that the air exchange is high in the rear of the lorry and low in the front part. Therefore the highest temperatures and relative humidities are often found in the pens directly behind the head boards of lorries and trailers. When air exhaust openings in the head boards are installed which are protected against direct wind pressure of the moving vehicle a sufficient airflow may be provided even in the front pen. This air flow may be supported by electric fans if necessary. These fans can also be used to supply an airflow when the vehicle is standing. In such a situation equivalent ventilation rates can be applied as in animal housing. For a situation given with an outside temperature of 30° C these ventilation rates must be high enough possible to remove the excessive heat which is produced by the animals. Under practical housing conditions 319 m³/h per animal (500 kg live weight) are recommended as a summer ventilation rate (> 26 °C ambient temperature) for cattle. Such ventilation rate will make sure that the heat produced by the animals is removed and that the indoor temperature does not raise by more than 3 degrees above the outside temperature. The equivalent ventilation rate for pigs is 106 m³/h per animal (100 kg live weight) at a temperature difference of 2 °C between outside and indoors. If a temperature difference of 3 °C is acceptable a ventilation rate of 71 m³/h per animal are required. These are practical values derived from German Standard DIN (1974).

The problem when using such a ventilation system is that the air has to pass through the whole length of the lorry. Most current forced ventilation systems on lorries are installed in the side walls blowing air across the animals from one side to the other. Little is known about the efficiency of these systems which can easily be disturbed when the wind is blowing from the opposite side. Additionally these systems will not have much benefit when the lorry is moving.

The size of the slots in the side walls usually varies from 0.10 to 0.20 m². Special constructions of lorries are used in various countries. In Finland e.g. fully climatically controlled vehicles are used for cattle transport. They provide heating in winter and cooling in summer. But only 16 cattle are transported in these lorries. In a Finnish lorry equipped with pens for two cattle one slot per pen was provided. The slots are situated at the level of the head of the animals or a little higher in order to remove the humidity and warm air from the animal chamber. Good ventilation can be effected via a roof channel system as it allows an even air transportation and circulation to each pen.

6. Monitoring methods

6.1 Measurements to assess the environment

The ventilation of livestock transport vehicles can be determined from physical and biological principles. The stock produce heat, moisture and carbon dioxide which need to be controlled to maintain acceptable levels for the stock. Production levels of these contaminants have been discussed in several countries (e.g. CIGR, 1984 and 1992; DIN 18910, 1992) and although precise values cannot be established, sufficiently accurate mathematical representations may be obtained for the purposes of ventilation design. However, there are no guidelines for the production of other contaminants (e.g. odour, hydrogen sulphide, ammonia) and therefore design procedures for these are not readily available. In practice it has been found that ventilation rates based on moisture and carbon dioxide usually control other contaminants within acceptable levels**.** These two measurements are particularly helpful to estimate ventilation rates in winter or during cold conditions (minimum ventilation rates). Under summer conditions heat production is the limiting factor. Under certain conditions moisture may also play a role. High temperatures together with high humidities impair the heat dissipation of the animals.The ventilation system must be able to remove excessive heat to keep the ambient temperatures for the animals as close as possible to the thermal neutral zone.

In practice the minimum ventilation rate is often chosen as the value at the intersection of the moisture and temperature criteria. For this ventilation rate, the moisture and carbon dioxide criteria are satisfied, but the inside temperature is not adequate for lower outside air temperatures. In such conditions the best selection has to be made by experience of the relative effects of carbon dioxide enrichment or temperature deficit and one or more of the criteria has to be compromised. As noted earlier, however, ventilation rates based on moisture and carbon dioxide usually control other contaminants within acceptable levels

Heat transfer through the vehicle structure is dependent on air movement over the surfaces as well as the thermal conductivity of the materials. This way of heat dissipation can be neglected under summer conditions when the vehicle is moving.

6.2 Monitoring the effectiveness of ventilation systems

There is no generally accepted standard measuring equipment e.g. for the measurement of temperature and humidity for the open ventilation lorries, though Regulation 411/98 which has just come into force does require that a monitoring device be fitted but it gives no further specifications in this regard.

Even though it should be possible to calculate theoretical maximum and minimum ventilation rates for a vehicle, variations caused by factors such as type of animals transported and ambient weather conditions, and the fact that most vehicles are not completely sealed mean that continuous adjustment of the ventilation rates will be necessary to provide a suitable environment for the animals being transported.

Adjustment to various external conditions is best done automatically and is technologically feasible. Ventilation systems should be connected to sensors measuring temperature and relative humidity located in the animal compartment. The system should be set to maintain the environment within the ranges described in Table 2. The read-outs from the sensors should be retained in a system akin to the tachograph system currently in use. It can also be linked to a warning system to make the driver aware if conditions are deteriorating. A similar system was recently described by Mitchell and Kettlewell (1998) for broiler transport. The ventilation system should be independent of the engine, allowing it to function effectively when the vehicle is stationary.

Sensors and an alarm system can also be fitted to vehicles which are not equipped with a forced ventilation system. This would have the advantage of warning the driver of deteriorating conditions and allowing him to take remedial action.

6.3. Recommended actions in the event of failure of the ventilation system

There have been a number of well publicised incidents where, because of failures of ventilation systems in animal transports, high mortality has occurred, particularly in very hot conditions. While the fitting of appropriate ventilation systems should avoid these occurrences, it is useful to record the emergency actions that should be taken in such cases in order to limit suffering and save as many animals as possible.

For the prevention of losses this may not be enough. In case of failure of the forced ventilation system the driver should drive on to provide a natural ventilation by the moving vehicle. When he is forced to stop all flaps and air slots have to be opened as wide as possible. Parking should be in the shade only. Adequate water should be supplied for drinking, spraying of water to cool the lorry is useful. Water spraying is particularly useful in the case of pigs, as the use of a water spray on pigs will act to increase evaporative cooling (Lambooij and Engel 1991).
The ultimate measure is to unload the animals in a sun protected area.

7. Suggestions for future work

Carry out developmental work to better define the actual devices (sensors, monitoring systems etc.) to ensure they provide a physical environment which ensures good welfare for the animals.

Build up a computer based programme on climatic zones in Europe which could be used in connection with the veterinary inspection and route plan for the transport. Such a programme could provide data about the climatic zones which are passed, the ventilation capacity of the vehicle, the number and weight of the animals, the area of the lorry calculating animal density. Based on heat production of the animals and the capacity of the ventilation system it can be calculated whether upper temperature limits are likely to be exceeded.

Fully investigate the welfare of animals in all humidity and temperature ranges and the usefulness of temperature-humidity indices for all the animal types in question

For better surveillance, collect data on the morbidity and mortality of animals during transport (at arrival).

Investigate the air distribution and air flow pattern in various types of lorries for the transport of different species. Specify the influence of the height and the number of tiers on the lorry.

8. Conclusions

1. Animals have specific needs in relation to their physical environment. Environment requirements vary both between and within the species. Typical examples are differences between pigs and cattle and full fleeced and shorn sheep.

2. Animals can acclimatise, but vary in their adaptability. During transport the time is too short for many of the adaptation processes. Hence, the definition of safe transport conditions (temperature etc.) should fit with the basic requirements of the least adaptable individuals of the type of animal being transported.

3. The possibility of maintaining an acceptable physical environment for animals on transport vehicles is influenced by many factors such as the ambient weather conditions, the type of animals carried, the stocking density, the ventilation system, the design of and the speed of the vehicle.

4. Natural ventilation depends mainly on the speed of the vehicle. With the exception of fully open-sided vehicles, most problems occur when the vehicle, is forced to be stationary under summer conditions. Forced ventilation can be designed to maintain the physical environment within acceptable limits when the vehicle is moving but also stationary.

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9. Recommendations

1. Ventilation systems on animal transport vehicles should be performance based in that they are capable to react to changes in the animals' environment and will maintain the conditions in the animal compartment within acceptable limits for the type of animals on board.

2. Ventilation systems should ensure even, but not draughty distribution throughout. The minimum air flow in a vehicle at all times must be 10 m^3/h/100 kg body weight **.**

3. All vehicles must have a temperature and humidity monitoring system, a warning system and a means of recording these data. The recording system should be compulsory to allow verification of compliance.

4. The linking of sensors to an automatic environmental control would be highly beneficial. Sensors should be located in the parts of the lorry which, depending on its design characteristics, are most likely to experience poor conditions e.g. behind the headboard.

5. The ventilation system must be designed so that it can operate independently of the vehicle engine.

6. When any animal transport vehicle is to be used for a journey, the ventilation system must be capable of maintaining the temperature and humidity in the vehicle between the maximum and minimum temperatures stated in the table below (Table 2). At any time during the journey including especially times when the vehicle is stationary, the temperature and humidity must be maintained by the ventilation, heating or cooling system within these limits.

Table 2. Proposed maximum and minimum temperatures within vehicles for the transport of animals, taking into account the influence of humidity on these limits

SPECIES	TYPE/ WEIGHT /AGE	MINIMUM. TEMPERATURE* ºC	MAXIMUM TEMPERATURE ºC	MAXIMUM TEMPERATURE ADJUSTED FOR HUMIDITY
			RH <95%	**RH >95%**
PIGS	10 - 30 kg 30 + kg	14 12	32 32	29 29
			RH <80%	**RH >80%**
CATTLE	0 – 2 weeks 2 – 26 weeks 26+ weeks	10 5 0	30 30 30	27 27 27
			RH<80%	**RH >80%**
SHEEP	Full fleece Shorn	0 10	28 32	25 29
			RH <80%	**RH >80%**
GOATS		6	30	27

*If the animals are within 10°C of the Minimal Temperature, they must not be wet

7. In order to be able to transport the animals all year round, the vehicle must be specifically adapted to the conditions to be encountered. Insulation of the vehicle and, in some conditions, heating will be required, in addition to ventilation, in Northern regions in periods of the winter. Insulation of the vehicle, and in some conditions, cooling will be required in addition to ventilation in Southern regions in periods of summer.

8. If it seems likely that the vehicle control system cannot prevent the maximal or minimal temperatures being reached, the journey should not be commenced or if already commenced it should be interrupted and the animals unloaded immediately, or as soon as possible if immediate unloading would be dangerous.

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