



EUROPEAN FORUM

Livestock housing for the future

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Proceedings



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1 ■ Energy consumption in livestock housing (pigs)

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In a context of rising energy prices, pig breeders are examining the use of techniques designed to reduce their energy consumption. In pig production, “direct” energy, i.e. the energy consumed directly in the buildings where the animals are reared, represents approximately 1.9% of the cost of production (IFIP, GTE-TB 2008). Although this figure is low, it has increased by 12% over the last five years. Furthermore, the situation is likely to become more marked in light of the exhaustion of energy resources, thus increasing the necessity for better control of consumption. There also appears to be growing interest in the use of renewable energy sources, in particular anaerobic digestion, heat recovery systems and biomass boilers. Prior to embarking on investments in renewable energy sources, however, energy consumption must be controlled. This makes it necessary to have access to baseline figures. A study was therefore carried out in 2006 to pinpoint the levels of energy consumption on farms by specialism and by item. This detailed analysis can be used to produce an assessment of the measures required to limit energy waste and set out the priority actions to be taken in livestock housing.

Average levels of energy consumption

Farrowing and fattening units

Total average energy consumption in farrowing and fattening units is **983¹ kWh** per sow per year, with a significant degree of variation between units (standard deviation of 328 kWh). The average is 48 kWh per pig produced, i.e. 0.42 kWh per kg of live weight. Electricity accounts for 76% of the total, at 749 kWh. The second main energy source is diesel, at 21% of the total (209 kWh). Gas represents just 3% (24 kWh) of the total energy consumption recorded in the sample.

Farrowing units

Average energy consumption in farrowing units is **403¹ kWh** per sow per year, i.e. 19 kWh per piglet weaned, with a high degree of variation due mainly to feed distribution methods (manual or automated). Electricity represents 70% and diesel 30% of the energy consumed.

Post-weaning and fattening units

Average energy consumption in post-weaning and fattening units is 252 kWh per pig produced, i.e. 0.22 kWh per kg of meat. Electricity is still the primary energy source, with 86% of the total compared with 14% for diesel.

¹ These values do not include consumption resulting from treatment plants or farm-based feed production units.

² These values do not include consumption resulting from treatment plants or farm-based feed production units.
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Breakdown of consumption by item and by physiological stage

Almost 50% of the energy is used to heat farrowing and post-weaning units. As part of the study we obtained a breakdown of energy consumption by item (excluding farm-based feed production and treatment plants). The calculations for all items were based on estimates using the power ratings for the relevant equipment and its period of operation. **Heating and ventilation** are the items that consume most energy, with 46% and 39% of the total respectively. Together, they therefore represent **85%** and come in far ahead of lighting (7%), feed distribution (4%) and other items.

Over one third of energy consumption is in the post-weaning stage

Of the 983 kWh consumed on average per sow per year, post-weaning is the physiological stage that consumes the most energy, with 36% of the total, followed by fattening (27%), farrowing (22%) and other stages (15%). The first three stages listed above therefore represent 85% of total consumption.

- In the **nursery and post-weaning** unit, energy consumption totals **319 kWh/sow**. “Room heating” alone represents 80% of the total, ventilation 15%, lighting 6% and feeding 1%.
- In the **fattening** unit, energy consumption totals **237 kWh/sow**. Ventilation is the largest item, with 90% of the total. The remaining 10% is split between feeding (6%) and lighting (4%).
- In the **farrowing** unit, as in the nursery / post-weaning unit, energy consumption is mainly used for heating (81%), out of a total of **195 kWh/sow**; ventilation represents 10% of consumption, feeding 1% (manual distribution was frequent in the farrowing units in the sample studied) and lighting 8%.

Main variables in energy consumption

The size of the unit has an influence on energy consumption. The results obtained show that larger units tend to be associated with higher than average energy consumption per unit (per sow and/or pig produced). This is partly explained by the level of automation and equipment used.

Building age and insulation also have an impact on energy consumption, particularly buildings used for the post-weaning stage. In buildings constructed before 1992, for example, the average energy consumption observed was 1,095 kWh per sow, compared with 890 kWh for those built after 1992, illustrating the improvements made in building quality (particularly in terms of insulation). Similarly, buildings that breeders consider to have a “good” or “very good” level of insulation are associated with average consumption of 953 kWh per sow compared with 1,171 kWh for buildings considered to have “average” or “poor” insulation.

Finally, feed distribution is responsible for varying levels of energy consumption in livestock units. Distributing feed in the form of a mash is associated, on average, with a higher level of energy consumption than dry feed (1,111 kWh and 938 kWh per sow per year, respectively). This can be explained by the fact that distributing feed in the form of a mash requires the use of more powerful motors and involves moving higher volumes than dry feed. The number of distributions also has an impact on the energy consumption of feeding systems. Again, distributing feed in the form of a mash is often associated with a higher number of daily distributions.

What possible actions could be taken?

Access to tools for assessing energy consumption

The first way of limiting energy consumption is for the breeder to have access to analysis and monitoring tools. For electricity, suppliers generally provide annual consumption data.

Diesel consumption is more difficult to estimate, insofar as it also covers machinery use. An approximate figure for diesel consumption can be calculated by deducting the cost of 75 litres of diesel per hectare of UAA from the farm's total diesel consumption.

Finally, gas consumption can be analysed on the basis of bills. Once consumption figures have been established they need to be compared with existing baseline figures in order to position a particular breeder on a consumption scale.³.

It is now possible to have an energy advisory assessment carried out in order to calculate energy consumption item by item for each physiological stage, based on a particular unit's specific situation and the breeder's practices. The results generated by the tool can be used to quickly identify the items that consume most energy and the possible actions that could be taken.

Ensuring better building insulation

In order to limit heat loss and therefore reduce heating requirements, buildings must be well insulated and in general terms the building shell should be well sealed, i.e. from the load-bearing walls right up to the roof, including doors and windows. Insulation in existing buildings can be improved by carrying out renovation work (to be examined on a case-by-case basis) and taking into account the characteristics of the materials used. It is also important to examine the environment in which the buildings stand, ideally in a position with less exposure to prevailing winds. Planting a hedge as a wind-break and banking up open-air manure pits are simple techniques for improving the thermal performance of buildings and therefore limiting energy consumption for heating.

Optimising heating and ventilation

- In farrowing units, heating using electric plates in the ground can reduce energy consumption by 30% but requires expensive renovation work. Another possible technique is to create a separate house for the piglets. At birth, piglets have a thermal requirement of around 30°C whilst the ambient temperature for sows should not be in excess of 24°C.

³ A simple assessment tool is available from www.ifip.asso.fr in the toolbox section European Forum Livestock housing for the future – October 22/23 – LILLE (France)

- In post-weaning units, some radiant heaters are more economical than others in terms of energy consumption; standard radiant heaters, for example, provided they are set correctly, consume less energy than halogen radiant heaters. In addition, the position of the atmospheric thermostat is essential. Another way of limiting consumption may be to apply the concept of localised heating in the post-weaning unit, following the example of certain northern countries. It would also be interesting to assess the benefits in terms of energy consumption of installing separate houses the same as those used in straw-bed systems.
- Control heat loss associated with ventilation, based on proper control of minimum air flows (manual or automated management). With a flow of $3 \text{ m}^3 / \text{h} / \text{animal}$, for example, energy consumption for heating is half that required with a minimum flow of $5 \text{ m}^3 / \text{h} / \text{animal}$.
- Opt for energy-efficient ventilation systems and equipment: over the last five years, some manufacturers have been marketing a number of kinds of ventilation equipment designed to use less energy, with savings of up to 60% in operation. It also seems that centralised ventilation systems are more energy-efficient. In fact, regulating the system using a frequency changer as well as the better kWh / m^3 yield for the air extracted by the turbines in a centralised ventilation system can reduce energy consumption by up to three times.

Optimising lighting

Lighting is the third-largest consumer of energy; saving energy on lighting is therefore not something that should be ignored and is generally simple to implement. This involves allowing more natural light to enter, whilst avoiding direct light (using film or sun-shades) and using appropriate materials: fluorescent tubes with energy-efficient ballasts (generating energy savings of between 15 and 70%) and installing sensors in offices and annexes.

Other

Regular checks and good equipment maintenance will contribute to optimising energy performance.

Heating appliances should be positioned in accordance with the recommendations of technicians and manufacturers, in particularly in terms of fixing height and their position in relation to air flows.

Finally, energy savings can be achieved by taking care to combine heating and ventilation effectively. Settings need to carefully controlled, insofar as the two parameters have opposing functions in thermal terms; the ideal is for the same thermostat to control both heating and ventilation. Otherwise, when the temperature setting for the heating is higher than the temperature setting for the ventilation, the rate at which fresh air is pulled into the room is higher than the minimum flow required and heat is therefore wasted. In heated buildings, it is important that the minimum recommended air flow for ventilation can be achieved by choosing a temperature setting for heating that is slightly lower than or the same as the temperature setting for ventilation.

Energy savings and renewable energy sources

- Air-air heat exchanger: based on the principle of recovering heat from the air extracted from the building. This system offers direct benefits in post-weaning units, insofar as it offers a 40 to 60% saving in electricity consumption for heating. However, this system is not sufficient to achieve the temperatures required to start off a batch of animals and heating is essential once the piglets arrive. Centralised ventilation is highly recommended to optimise air exchange and therefore for installing a system of this kind.
- Air-ground heat exchanger: based on the principle of fresh air circulating in pipes buried around two metres underground. Although this technique performs well, it requires a sizeable area of available land, which unfortunately limits its use on farms. The cost can also prohibit implementation of this type of system.
- Heat pumps (HP): these are based on recovering energy from a range of environments and transferring it into the units where livestock is reared. A coolant liquid is used to transfer heat from one environment to another. There are three kinds of heat pump: water-air heat pumps, bio-reactor heat pumps and geothermal heat pumps. In a best-case scenario this type of heating system can reduce energy consumption for heating by around 60%.
- Farm-based anaerobic digestion: This is now particularly common in Germany. Although it is expensive, this technology has a number of advantages, insofar as it can be used to produce both electrical energy and heat and at the same time helps to deodorise the effluent. Nonetheless, its profitability needs to be studied carefully based on the specific installation conditions (size of installation, type of substrate used, etc.); the availability of a substrate suitable for anaerobic digestion is often a limiting factor.

Conclusion

This study provides some initial baseline figures in respect of energy consumption in pig rearing as well as on the breakdown of different types of energy use. Although energy still represents a small proportion of the costs of production, some actions, which are easy to implement, can be used to improve the competitiveness of livestock units by reducing expenditure on energy. Pig breeders can reduce their energy bills by optimising settings and maintaining equipment on a regular basis. They can also become less dependent by installing energy recovery systems and thus protect themselves from future price rises.

In addition to the economic aspect, steps to reduce energy consumption are also an integral part of an environmental protection approach. Intensive production processes pose sometimes serious risks to the environment, and reducing dependence on fossil fuels is a key factor in the long-term viability of agriculture itself.

It is because of this that the French veterinary institutes and Chambers of Agriculture in Brittany and the Pays de la Loire have been working to develop an assessment and advice tool since 2008. Used in conjunction with advice from technical experts, this can be used to assess direct energy consumption in livestock housing item by item and identify areas for improvement.

Other work on energy is scheduled to be undertaken in 2010, for example on developing an energy-positive livestock building, i.e. a building that produces more energy than it consumes.

2 ■ Combined electrical and thermal use of photovoltaic panels

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Integrating photovoltaic panels (PV) into the roof allows to increase the energy efficiency by ventilating the underside of the panels. Investigations carried out at the research station ART Taenikon show that the heat production of the PV panels is four to five times higher than the electricity production. The results indicate that the temperature difference between solar panels and outside can be limited to about 20°C. The temperature decrease of the panels amounts to 15°C, resulting in a 6% increase in electricity production. The higher the air speed in the collector, the greater the electrical and thermal efficiency. The heated air from the PV can be used to dry hay, cereals or wood chips. Using the warm air for drying hay permits significant saving of energy by reducing the drying time. A numerical model has been developed and validated allowing the calculation of the electrical and thermal efficiency of the photovoltaic plant as a function of the air speed in the collector, geometry of the plant, thermal conductivity of the solar panels and outside conditions.

Description of the pilot solar plant

The pilot plant of the ART research station consists of a mobile wooden platform on top of which 8 photovoltaic panels (PV) have been installed on purlins to form a roof about 1m wide and 10.5 m long (Fig 1). Particle boards are fixed to the underside of the purlins, forming a collector channel between the PV panels, the purlins and the particle boards. The collector channel is ventilated by an axial fan (\varnothing 50 cm). The ventilation rate is controlled by a measuring fan (FANCOM). A DC/AC inverter is connected to the panels, displaying operating data (power, tension, intensity). During operation, a computer records the measured parameters (air and panel temperature, air speed in the collector, wind speed, global radiation, ventilation rate and electrical power).

Fig 1: Experimental PV plant ART Taenikon



Measurements

Measurements have been conducted for a period of 14 days in July, 6 days in August, 3 days in September and 2 days in October. The speed of the air in the collector varies between 2.33 m/s and 6.83 m/s (Table 1). According to the measurements, the amount of sun's energy transformed into heat is four to five times higher than that transformed into electricity (measured after the inverter). The variation of the heat efficiency (40-65%) is mainly due to the different values of the air speed in the collector and the wind speed on top of the solar panels.

Table 1: Data from the measurements made in July, August, September, October 2008

| Date | Time | Average wind speed [m/s] | Average air speed in the collector [m/s] | Average panel temperature [°C] | Average outside temperature [°C] | Global radiation on a horizontal plane [kWh/m ²] | Electrical efficiency [%] | Heat efficiency [%] |
|---|-------------|--------------------------|--|--------------------------------|----------------------------------|--|---------------------------|---------------------|
| 01.07.08 | 11:00-17:05 | 1.71 | - ¹ | 51.9 | 27.5 | 5.15 | 9.18 | - |
| 02.07.08 | 07:56-16:46 | 1.69 | - ¹ | 47.9 | 27.4 | 6.58 | 9.33 | - |
| 04.07.08 | 07:42-16:05 | 1.99 | 3.85 | 32.6 | 18.2 | 5.25 | 9.81 | 54.29 |
| 08.07.08 | 07:53-16:45 | 3.97 | 4.26 | 27.6 | 17.9 | 5.26 | 9.83 | 46.77 |
| 10.07.08 | 07:22-16:25 | 2.32 | 2.18 | 41.6 | 22.9 | 6.80 | 9.50 | 44.71 |
| 11.07.08 | 10:07-16:25 | 2.42 | 2.95 | 47.2 | 27.6 | 5.23 | 9.58 | 48.37 |
| 15:07.08 | 08:13-16:07 | 1.81 | 5.60 | 35.4 | 18.6 | 6.25 | 10.13 | 63.84 |
| 16:07.08 | 07:50-16:34 | 2.81 | 3.76 | 36.8 | 21.6 | 6.54 | 10.05 | 49.54 |
| 21.07.08 | 07:50-16:34 | 3.52 | 4.37 | 25.4 | 15.9 | 4.14 | 10.22 | 46.86 |
| 23.07.08 | 08:10-23:59 | 1.80 | 6.00 | 26.2 | 18.0 | 7.56 | 10.09 | 50.26 |
| 24.07.08 | 00:00-24:00 | 1.51 | 5.45 | 21.6 | 17.4 | 7.72 | 9.97 | 44.95 |
| 25.07.08 | 00:00-16:06 | 1.22 | 2.84 | 25.2 | 17.0 | 6.02 | 10.00 | 11.52 |
| 28.07.08 | 08:11-16:44 | 2.01 | 2.03 | 43.0 | 25.6 | 5.60 | 9.54 | 41.96 |
| 29.07.08 | 08.14-16:52 | 1.89 | 3.35 | 39.8 | 25.2 | 5.52 | 9.82 | 45.83 |
| 30.07.08 | 08:09-16:25 | 1.56 | 4.24 | 39.7 | 25.8 | 5.21 | 9.94 | 54.51 |
| 31.07.08 | 07:58-16:22 | 1.65 | 5.08 | 40.7 | 25.5 | 6.03 | 9.98 | 57.55 |
| Average July | | 2.12 | 4.00 | 36.42 | 21.4 | 5.93 | 9.81 | 49.57 |
| 06.08.08 | 08:40-16:55 | 1.57 | 3.57 | 39.9 | 25.0 | 5.59 | 10.21 | 51.04 |
| 07.08.08 | 13:02-16:22 | 2.82 | 3.54 | 41.5 | 22.1 | 1.93 | 9.79 | 49.84 |
| 11.08.08 | 10:05-16:06 | 1.37 | 5.79 | 36.2 | 23.9 | 3.51 | 10.14 | 56.81 |
| 13.08.08 | 13:18-16:42 | 3.16 | 3.54 | 35.4 | 20.9 | 2.18 | 10.55 | 48.62 |
| 18.08.08 | 10:09-17:48 | 2.52 | 4.38 | 39.0 | 23.3 | 5.31 | 10.98 | 52.69 |
| 21.08.08 | 11:00-16:13 | 1.61 | 0.20 | 42.9 | 27.6 | 3.31 | 10.15 | - |
| 27.08.08 | 10:11-12:49 | 1.63 | 4.28 | 37.3 | 25.8 | 1.88 | 11.44 | 64.04 |
| Average August | | 2.10 | 3.61 | 38.87 | 24.1 | 3.39 | 10.47 | 53.84 |
| 08.09.08 | 07:48-17:05 | 1.02 | 4.44 | 34.8 | 18.0 | 3.84 | 12.27 | 63.28 |
| 09.09.08 | 08:18-16:43 | 1.27 | 3.52 | 35.5 | 15.2 | 4.84 | 12.06 | 61.16 |
| 30.09.08 | 14:09-16:05 | 2.26 | 2.09 | 18.3 | 14.1 | 0.42 | 11.03 | 33.33 |
| Average September | | 1.52 | 3.35 | 29.53 | 15.8 | 3.03 | 11.79 | 52.45 |
| 14.10.08 | 12:12-17:18 | 2.50 | 3.37 | 30.76 | 20.7 | 1.23 | 14.40 | 53.7 |
| 15.10.08 | 11:45-17:42 | 2.60 | 4.08 | 28.26 | 19.8 | 1.41 | 14.80 | 51.2 |
| Average October | | 2.59 | 3.73 | 28.5 | 20.3 | 1.32 | 14.60 | 52.45 |
| ¹ Under roof not installed on 1 st and 2 nd July . | | | | | | | | |

Relation between wind/air speed and panel temperature

The wind speed above the panels and the air speed in the collector influence the temperature of the panels. When the wind speed and the air speed increase, the temperature of the panels decreases. On the 10th of July 2008, the difference between the temperature of the panels and the outside temperature is 24.6°C at an average wind speed of 2.8 m/s and an air speed in the collector of 2.2 m/s. The minimal difference, 19.3°C between the temperature of the panels and the environment has been recorded on the 16th of July at an average wind speed of 3.4 m/s and an air speed in the collector of 3.8 m/s.

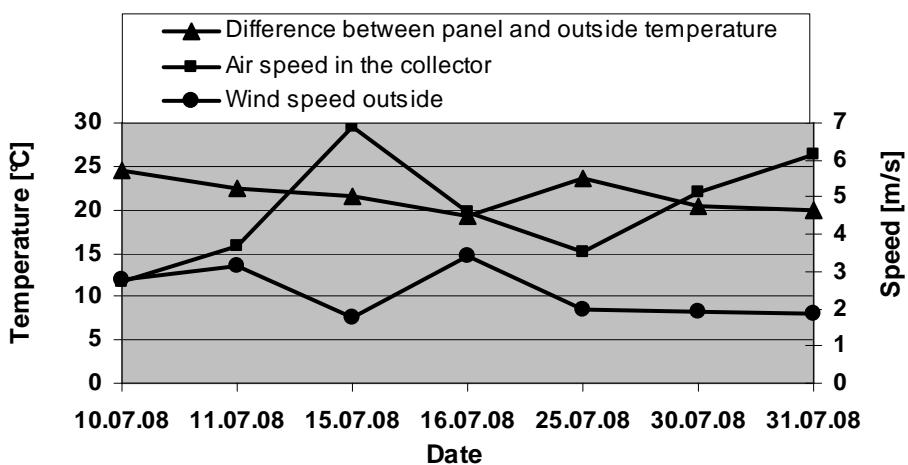


Fig. 2 – The difference between the panel temperature and the outside temperature shows a good correlation with the wind speed and the air speed in the collector. Time interval 13:00 - 13:30, July 2008

Relation between panel temperature and electrical efficiency

The higher the temperature of the panels, the lower the electrical efficiency. On 27.08.2008 at 12:49 the ventilator has been switched off. The air speed in the collector drops from 5.2 m/s to 0.3 m/s. The remaining air speed in the collector is due to the wind outside and the thermal buoyancy. Reducing the air speed results within half an hour in an increase of the panel temperature from 42°C to 55°C. In the same time period the electrical efficiency decreases from 11.2% (at 42°C) to 10.4% (at 55°C).

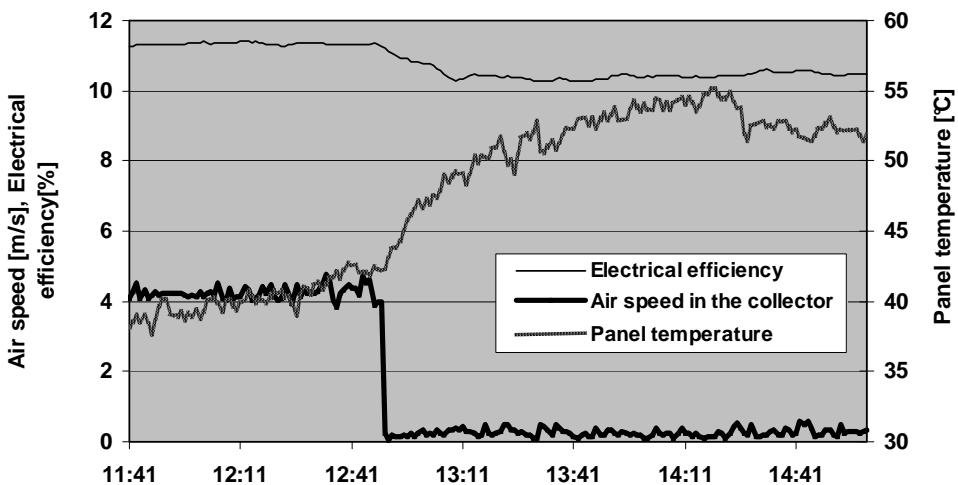


Fig. 3 – Switching off the fan leads to a rapid increase in the panel temperature from 42°C to 55°C and a decrease in electrical efficiency from 11.2 to 10.4%

Relation between air speed in the collector and heat efficiency

The higher the wind speed, the more heat will be dissipated to the surrounding environment and the less heat can be recuperated in the collector. Hence, the greater the difference between the air speed in the collector and the wind speed, the greater the heat efficiency. At an air speed in the collector of 2.21 m/s and a wind speed of 2.79 m/s (difference between air speed and wind speed -0.58 m/s), the heat efficiency is 43.5%. For an air speed of 5.64 m/s and a wind speed of 1.77 m/s (difference of 3.87 m/s), the heat efficiency increases to 59.5%.

Use of heat

On sunny days, the heat production can amount to 4 kWh per m². Because of the temperature increase, the relative humidity of the air in the collector will decrease and its humidity absorbing capacity will rise. Using the heated air of the photovoltaic plant for drying hay, the drying period can be halved (Table 2). The results are based on the air temperature at the end of the collector calculated with the numerical model, for a sunny day in July. The size of the PV plant is 300 m². The roof inclination is 20°. The height of the collector is 0.2 m, and the air speed in the collector is 3.8 m/s. The average water absorption of the air between 09:00 and 21:00 has been determined for the outside temperature (ventilation without PV installation) as well as for the temperature recorded at the end of collector. It has been assumed that the air leaves the hay stack with a relative humidity of 70% and that the water content of the air entering the drying plant is constant during the whole day (10.9 g/kg). The results of simulation show that using outside air, the absorption of the air passing through the haystack is in average 1.11 g/kg air. Using the heated air leaving the PV plant the average water absorption is 2.19 g/kg (Fig. 4, Table 2). The energy saving by reducing the running time of the fan is estimated at 30 Wh per kg DM of hay.

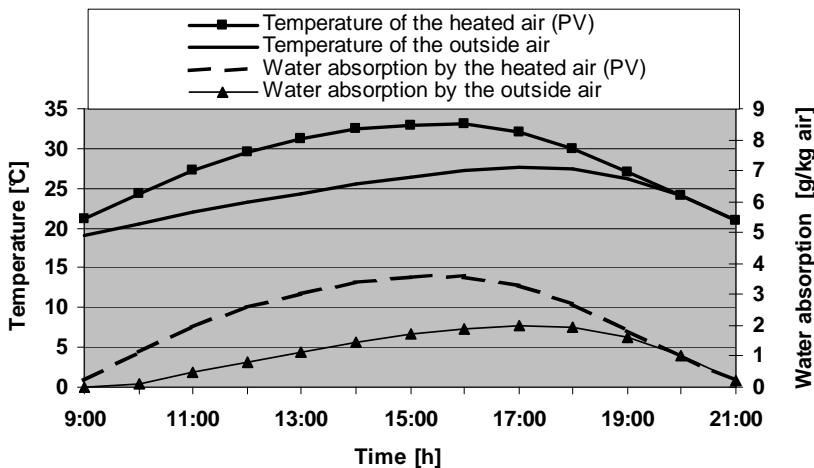


Fig. 4 – Water absorption capacity of the outside air and of the air heated in the PV plant

Table 2 – Comparison of the time and energy needed for hay drying with outside air (without PV) and with air heated by the PV plant (with PV) based on weather conditions in July 2008.

| | | |
|--|------------|---------|
| Surface of the PV plant (m^2) | 300 | |
| Air speed in the collector (m/s) | 3.8 | |
| Free section of the collector (m^2) | 4.5 | |
| Air flow in the collector (m^3/h) | 17.1 | |
| Surface of the haystack (m^2) | 155 | |
| Air flow through the hay ($m^3/s m^2$) | 0.11 | |
| Thickness of the haystack per charge (m) | 1.5 | |
| Hay quantity (kg DM) | 18655 | |
| DM content of the hay before drying (%) | 65 | |
| DM of the hay after drying (%) | 87 | |
| Required dehydration (kg/kg DM hay) | 0.39 | |
| Total required dehydration (kg) | 7257 | |
| | Without PV | With PV |
| Average water absorption(g/kg air) | 1.1 | 2.2 |
| Total water absorption (kg/h) | 76 | 150 |
| Theoretical drying time (h) | 96 | 48 |
| Total pressure drop (Pa) | 450 | 525 |
| Fan power ($\eta=0.60$), (kW) | 12.8 | 13.8 |
| Energy demand of the fan (kWh) | 1227 | 670 |
| Saved energy for the fan (kWh) | | -557 |
| *Additional electricity produced by the PV plant (kWh) | | 38 |
| Total energy gain (kWh) | | 595 |

* Average electricity production 65 W/m² between 09:00 and 21:00, Temperature decrease of solar cells: 10°C

Numerical method

A numerical and analytical model have been developed allowing the calculation of the thermal and electrical efficiency as a function of different parameters. The energy balance of the solar panel for steady heat flow conditions can be expressed analytically by the following equation: sun's energy absorbed ($a_s G_{PV}$) - energy reflected by the solar panels (Q_{IR}) + energy absorbed by the solar panels due to sky reflection (Q_{refl}) - energy converted into electricity (E_{el}) - heat dissipated by wind ($U'_{PV}(\theta_{PV}-\theta_a)$) - heat dissipated by air flow in the collector $\alpha_{PV}(\theta_{PV}-\theta_L) = 0$.

$$[(a_s \cdot G_{PV} - Q_{IR,x} + Q_{refl,x} - E_{el,x} - U'_{PV} \cdot (\theta_{PV,x} - \theta_a)) \cdot B_{PV1} - \alpha_{PV} \cdot (\theta_{PV,x} - \theta_{L,x}) \cdot B_{PV2}] \cdot dx \cdot dt = 0$$
 To resolve the equation, $\theta_{PV,x}$ needs to be expressed as a function of $\theta_{L,x}$. As this is not possible because of the interdependence between Q_{IR} and $\theta_{PV,x}$, only approximate results can be obtained by assuming a constant value for θ_{PV} over the entire surface of the PV installation.

The problem of the interdependency between Q_{IR} and θ_{PV} can be avoided by using a numerical method, dividing the length of the collector into n sections Δx . The panel temperature $\theta_{PV,i}$ and the heat fluxes $Q_{PV,i}$ and $Q_{u,i}$ of each section Δx_i are calculated consecutively by using the air temperature ($\theta_{L,i-1}$) of the previous section (Δx_{i-1}). To achieve sufficient precision Δx should be less than 0.05 L.

The temperature (°C) of the solar cells in section Δx_i is calculated by:

$$\theta_{PV,i} = \frac{(a_s \cdot G - \varepsilon \cdot Q_{IR,i} + Q_{refl} - E_{el} + U'_{PV} \cdot \theta_a) B_{PV1} + \alpha_{PV} \cdot \theta_{L,i-1} \cdot B_{PV2}}{\alpha_{PV} \cdot B_{PV2} + U'_{PV} \cdot B_{PV1}}$$

The air temperature (°C), $\theta_{L,L}$ at the end of the collector is calculated by:

$$\theta_{L,L} = \theta_{L,0} + \sum_{i=0}^{i=n} \frac{Q_{PV,i} + Q_{u,i}}{V \cdot 0.28 \cdot \rho}$$

Conclusion

The heat energy which can be recuperated by ventilating the photovoltaic panels is four to five times higher than the electricity produced by the PV plant. When the wind speed above the panels and the air speed in the collector increase, the temperature of the panels decreases. With the increase of the temperature of the panels, the electrical efficiency reduces. The higher the wind speed, the more heat will be dissipated to the surrounding environment and the less heat can be recuperated in the collector. Hence, the greater the difference between the air speed in the collector and the wind speed, the greater the heat efficiency. A mathematical model has been developed to describe the correlations between the different parameters affecting the efficiency of the PV plant. Using the air heated in the PV plant instead of outside air for drying of hay, the drying time can be halved. The energy saved by reducing the running time of the fan is estimated at 30 Wh per kg DM of hay. During the time when there is no demand for heat, minimal cooling of the panels by natural convection, on the underside as well as on the upper side should be ensured. Therefore, the collector should allow a stack effect (buoyancy).

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3 ■ An eco-construction charter for livestock housing

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Eco-construction is about creating a building that takes the environment into account as far as possible. The guiding principles behind eco-construction are set out in the High Environmental Quality (HQE[®]) approach and various quality labels (Hautes Performances Energétiques (High Energy Performance), Habitat et Environnement (Home and Environment) certification, etc.) in France and abroad. The agricultural sector is increasingly involved in sustainable development approaches in relation to farming systems and livestock rearing practices. These approaches can be extended to livestock housing through the use of the “Eco-construction for livestock housing” charter that is currently being written.

A definition of eco-construction for a better understanding of the current issues

An eco-building must minimise its impact on the environment. The building must therefore be appropriate to the site on which it stands whilst taking full advantage of natural environmental assets and making use of local resources. The HQE[®] (High Environmental Quality) benchmark is the first formal expression of this approach.

It involves creating a building with the technologies that enable it to minimise its impact on the environment in terms of its construction, whilst integrating it into the environment as unobtrusively as possible by using local natural resources.

Eco-construction for livestock housing

Very few eco-construction initiatives currently focus on agricultural buildings. Nonetheless, breeders are increasingly involved in sustainable development approaches in relation to farming systems and livestock rearing practices. In the future these may also cover livestock housing. As a result, professionals involved in building livestock housing are organising themselves so as to take such environmental concerns into account, thus responding to the demand from both breeders and the wider society.

Work carried out as part of a multilateral research programme

The Institut de l'Elevage and its partners⁴ have launched a programme entitled “Eco-construction and livestock housing: applying an eco-construction and environmental management approach to livestock housing.” This study, which won the CASDAR 2007 call for projects in the field of agricultural and rural development, aims to adapt the HQE[®] approach to livestock housing. The programme will run for three years. The work carried out by the research

⁴ ADEME, APCA, Association HQE, CAUE Loiret (Planning and Environmental Advice), Brittany Chambers of Agriculture, Ain, Isère and Haute Marne Chambers of Agriculture, IFIP, Institut de l'Elevage, ITAVI, French Ministry of Agriculture and Fisheries, French Ministry of Ecology, Energy, Sustainable Development and Regional Planning, MRE Provence Alpes Côte d'Azur, SICA HR Poitou.

team gave rise to the idea of a charter for “Eco-construction for livestock housing”, which is applied by breeders on a voluntary basis. The charter enables them to construct a building that takes account of the environment whilst also taking into consideration the specific constraints associated with livestock rearing.

Points to consider for building eco-friendly livestock housing

When designing a building, it is important to take account of the overall project and not focus the thought process simply on the building to be constructed. To achieve this, the “Eco-construction for livestock housing” charter has drawn inspiration from the charters for good livestock rearing practices and the charter for environmental quality in building and renovation work in the Mediterranean region. The charter is based on four main areas covering the choices to be made when constructing and/or renovating eco-friendly livestock housing:

Area 1. Integration into the site, for environmentally friendly design or renovation of livestock housing – *at design stage*.

Area 2. Construction materials, resources and nuisance: limit use of raw materials, reduce waste and optimise recycling – *at construction stage*.

Area 3. Energy, water and waste from operations: limit requirements, reduce polluting waste and prioritise the use of renewable energy sources – *at construction stage – at operational stage*.

Area 4. Comfort and health: protect the health of staff and livestock and improve comfort. – *A cross-cutting approach that influences the two previous points*.

These four areas are made up of 69 points, a third of which are considered essential and must be adhered to for any eco-construction or eco-renovation project. In addition to these essential points there are various additional targets (the number of which has yet to be defined) designed to strengthen the commitment of the breeder/main contractor, who must select the appropriate targets according to preference; these are then implemented during the construction of the building. Involving breeders in the eco-construction process should help to strengthen the relationship between the quality of the animals produced on the farm and the quality of the buildings in which they are produced. Taking environmental issues into account should improve the image of livestock farms and therefore society’s acceptance of them.

Develop a charter and frame of reference appropriate to livestock housing

A guidance document aimed at breeders and their advisors will be made available to make it easier to use the approach. The document will on the one hand help them to understand the objectives and issues associated with the various points and on the other help to provide appropriate advice. The guide will use real-life examples to illustrate the technical solutions available and provide a brief reminder of the regulations for each point on the charter.

The “Eco-construction for livestock housing” charter and its guidance document are currently being tested to check for ease of understanding and feasibility for both breeders and building consultants. As a first step, some 15 French farms, including cattle, sheep/goats, horse, pig and poultry producers were studied as part of a series of pilot projects between April and August 2009. These were used to clarify the conditions under which the charter would apply and to determine whether the targets it sets out are comprehensible and achievable.

The next stage will involve analysing the results obtained during the pilot stage to define the number of additional targets to be met for the approach to be validated.

Building consultants and technical advisors will also be consulted during the validation stage for the technical documentation. They will also contribute to defining the tools they will need to advise breeders as effectively as possible.

The pilot stage highlighted the importance of involving builders. Plans have therefore been put in place to create a document that will act as a link between the breeder/main contractor, designer and builders. The aim of the scheme is to help builders to take more account of the commitments made by breeders/main contractors when responding to invitations to tender.

Benefits of the future charter

The charter can be used to set out environmental requirements based on an analysis that is specific to the farm concerned when designing a production building. Evaluations will be carried out at each stage of the project. The process will help breeders to understand and assimilate the notion of environmental quality through the choices they make. This will improve the quality of the built environment at an early stage in the process whilst taking full advantage of the skills of advisors specialising in livestock housing.

The “Eco-construction and livestock housing” research programme will run over a three-year period. The process and tools developed within the framework of this programme will be available in early 2011. These will be disseminated by each of the partners involved in the programme.

4 ■ Agricultural buildings: from blending into the landscape to enhancing the landscape

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It was some forty years ago that concerns about the landscape first became a factor in the design of agricultural buildings. In the years since, production facilities have increased significantly in size, while at the same time urbanization has spread into rural areas. A number of experimental initiatives have once again brought this issue to the fore in recent years. New tools have been developed to foster dialogue among stakeholders and improve the architecture of agricultural buildings. These tools go beyond mere integration into the landscape by offering a variety of ways to respond to the greater concentration of farm operations and the expectations of surrounding residents in terms of quality of life.

Our image of contemporary agriculture is influenced by the thousands of farm buildings constructed each year. These facilities are all the more notable for being among the few buildings to be situated outside urbanized areas. Whether erected on a flat plain, deep in a valley, on a mountainside or in the shadow of a forest, they dot the landscape with their presence. For more than half a century now, they have followed a standard architectural path, of which the archetypal example is the hangar with double-slope roof: a structure built on posts and clad in weatherboarding of varying levels of sophistication.

New challenges

The architectural concepts used in France to develop these buildings arose out of discussions and experiments conducted between 1975 and 1985. As the first oil crisis was marking an end to thirty years of consumer prosperity in France, the impact on the landscape of these new facilities prompted the Fondation de France, with support from the central government, to fund the BAP ("agricultural buildings and landscapes") network. At the same time, numerous regional and departmental directorates within the Agriculture Ministry enlisted the services of consultant architects. Based on the work that was produced, developed and disseminated by the *Conseils d'Architecture, d'Urbanisme et d'Environnement* (CAUEs), as well as the agriculture bureaus, new building design came to be guided by two major options. One was to "prevent the worst" by attempting to offset the lack of an architectural plan through the use of practices designed to help integrate the building into the landscape (colour of the exterior, support for the landscape, greater efforts to take the building site into account). The other, more difficult option was to encourage an architectural approach.

The gradual consolidation of production facilities since the 1990s has generated an increase in the size of new construction. A cosmetic approach intended to hide the buildings from view has proven ineffective, especially since, for regulatory reasons, new construction is often sited a considerable distance away from traditional built areas (small towns and villages). The size of the related facilities along with sustainable development concerns are now prompting designers to rethink certain assumptions, while the diversification of agriculture and changing community demands, notably in terms of quality lifestyles and food supplies, are renewing interest among consumers in farm architecture. Experimental programmes and approaches.

This finding is shared by numerous experts in Europe, where several experimental approaches and programmes in recent years have once again addressed the topic of landscapes and production facility architecture. This research is targeted to designers but also to farmers and construction manufacturers, who still play a dominant role in a sector where architects are often notable for their absence. Several of these studies draw on the options made available by new technology for aiding the design process, in order to simulate construction sites, test building sizes or attract media coverage for the finished work.

In Europe

A study conducted in Finland, **Farmstead planning as a functional and landscape challenge**, on “defining a scale of construction that is compatible with the small scale of previous production facilities and the rural habitat”⁵ addresses the larger size of production facilities by comparing expanding farms to small hamlets. One new practice is the use of urban planning methods. Long-term development plans are established based on projected future farm production and strategies. From the outset, environmental and landscape concerns play just as critical a role as functional considerations. An array of modelling methods can be used to present a clear vision of the farm, showing the orientation of the future buildings and production equipment, and to indicate how the farm infrastructure will be developed, how the microclimate will be taken into consideration and how the building façades will be blended into the landscape, both at close perspective and from far away.

The Interreg-III A interregional project known as **BAULA (Rural construction and landscape)**⁶ is addressing similar questions. The BAULA study, conducted in Switzerland, Germany and Austria, has systematically examined the various architectonic configurations and components that can help resolve the constraints posed by the increase in agricultural programmes. The study mobilizes the entire formal language of architecture. A full range of dimensions is used to find an intelligent match between projects and their sites. With regard to structures, the study addresses curved roofs, flat roofs, single-slope coverings, building frameworks, offset roof ridges, shed systems, etc. This approach emphasizes the need to consider the landscape before deciding on a building’s site, volume and materials. The procedure to be followed is illustrated with notably successful buildings constructed in a variety of sites and landscapes. It includes virtual modelling to evaluate a building’s impact on its environment and refine its siting.⁷

In France

In France, the **APPORT - Agriculture and Landscape** project⁸, which is being carried out by the country’s technical institutes, is addressing the issue by highlighting the links between production facilities and the land. The impact of farm operations on the landscape is being defined in detail using an interactive computer tool that is currently still in development. Modelled on a role-playing approach, www.batiment-et-paysage-elevage.fr will enhance the dialogue between farmers and designers as each building project is being developed. This will

⁵ Kivinen, Tapani. Farmstead planning as a functional and landscape challenge. 2005, Report/Summary; in Farmstead planning as a functional and landscape challenge. MTT Agrifood Research Finland.

⁶ BAULA. ART reports. Rural construction and landscape. <http://www.art.admin.ch/themen/00774/01050/index.html?lang=fr>

⁷ Choosing an optimal site for rural construction using visibility analysis
http://www.fat.admin.ch/pdf/ART_Bericht_668_F.pdf

⁸ Agriculture and landscape. <http://81.252.198.184/apport/> A network of tools for regional projects. <http://www.agriculture-et-paysage.fr>

facilitate collaboration among the various stakeholders and encourage the use of multidisciplinary teams. The impact in terms of equipment, buildings and production on plots will be measured as a preliminary step before the development of projects relating to cattle, goat, sheep, poultry and pig farming. Pages on “observing, analysing, planning and designing” will provide access to resources and tools that will help users establish genuine architectural projects. This approach--still an unusual one--is expected to result in projects that are more in tune with their surroundings, heralding a landscape initiative in which architecture is not defined in advance and then incorporated into the landscape, but instead--similar to policies adopted in other areas of the construction industry--formally defined from the standpoint of landscape in conjunction with technical and functional expectations.

The examples presented at the site www.architecturesagricultures.fr⁹are consistent with this approach. Launched in 2007 with support from France’s Ministry of Agriculture and Fisheries and the Ministry of Culture and Communication, this programme brings together every stakeholder in the field of agriculture. Its aim is to foster expertise among those who work with the built environment in the architectural design of today’s agricultural buildings, by pooling a range of contributions regarding the future development of these buildings. Intended for owners (farmers, local governments, associations, etc.), designers and builders, www.architecturesagricultures.fr is intended to highlight, encourage and raise awareness of quality architecture and landscapes within the field of agricultural construction. The site draws on surveys, a tracking service for documents on related topics and bibliographical and technical research. Model initiatives carried out in France or Europe by regional governments, individual owners and universities can be found at the site. Completed buildings that incorporated an architectural focus are included in a reference database of notably successful projects.

A diversified expression of agriculture

These various approaches all have one objective: to provide ways of incorporating increasingly imposing agricultural buildings into the landscape. They demonstrate that a genuine commitment to architectural design can address this challenge beyond simply integrating and concealing buildings within their surroundings. Thanks to research into sites, shapes, proportions and materials, a diverse expression of agriculture is now possible. It will be interesting to see how future agricultural buildings contribute to the rural landscape and thereby raise the profile of each region and its farmers.

⁹ <http://www.archiagri.fr>



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5 ■ Out-Wintering Pads (O.W.P.): the French experience

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Trials were conducted and observations made in France on out-wintering pads (*parcs stabilisés d'hivernage* in French) at the Trévarez experimental station in Brittany (2006 to 2009) and on four other livestock farms (2007 to 2009). This work has made it possible to verify the feasibility of OWPs (as regards construction, bedding materials etc.) and assess them under various angles (i.e. costs, milk production, growth, animal welfare, mammary pathology, work issues, excreta management etc.). OWPs in continuous use are suited for adult cattle except for dairy cows in lactation and at calving time. They could also be used as a useful complement to outdoor wintering. Straw is the best suited bedding material. Woodchips should be reserved for use as a draining layer under the straw. Liquid effluents collected under the OWP can be drained into the secondary treatment stage of a treatment system for lightly charged effluents.

Trials at the Trévarez experimental farm

Dairy cows in production (2006-2007 trials)

Two trials were conducted, one with cows at the start of lactation (March and April 2006) and the other at the end of lactation (November 2006 to January 2007). For each trial, a control group was housed in a building with a cubicle housing system (with scraping of slurry), while the other group was accommodated on an OWP with woodchip-based bedding. The results show that there was no difference in food consumption or milk production between the two groups. Animal welfare was improved on the OWP in comparison with the control building, with fewer injuries (tarsitis in particular) and less lameness. The cleansing frequency for the OWP, scheduled every two months, was not respected during the very rainy winter of 2006-2007. As a result, clogging of the woodchip-based bedding was observed at the end of five weeks. Cell counts and the frequency of clinical mastitis due to environmental microbial infections were higher for the OWP group. Furthermore, scratches and petechia on the teats were more numerous in the OWP group with woodchips. A decline in the quality of cleanliness amongst animals on the OWP required more time to prepare the teats for milking and increased contamination of milk by butyric spores. The OWP in continuous use would thus seem to increase udder hygiene risks and health risks for cows in lactation.

Dry cows and dairy heifers (2007-2009 trials)

The trials continued with two categories of animals (dry cows and pregnant heifers, and then with heifers to be inseminated). Two groups were formed for each category of animals, one housed on an OWP with straw-based bedding, the other accommodated in a building comprising a straw yard and an exercise area with scraping of liquid manure:

- Similar zootechnical performance: For equivalent food consumption, the animals had comparable weight and fatness at calving in both groups (Table 1). Their milk production (milk, protein and fat content) during the first month of lactation was also comparable. Growth and fat scores for 15 to 18 month-old heifers on OWPs were just as good as for those housed in the building (Table 2).
- Animal welfare was preserved: Lameness, injuries and the quality of human-animal relations were not worsened by the OWP in comparison with a standard building with a straw yard (Table 3). These results confirm those obtained by Irish researchers (O'Driscoll *et al.*, 2008).
- Animal cleanliness: As a whole, the cleanliness of dry cows and pregnant heifers was comparable in the two groups (Table 4). However, the cleanliness of heifers to be inseminated was significantly worse on the OWP. It is possible that this was due to a difference in conduct between the two groups: the heifers on the OWP were kept in the same box while heifers in the building occupied several boxes. The disruption of animals due to the hyperactivity of a heifer in heat could therefore have negative consequences on all the heifers in the OWP group, contrary to the control group.
- Mammary pathology: At the start of lactation, cell counts were highest for the OWP group (Table 5). The difference diminishes later and is no longer significant beginning with the third week of lactation. The frequency of clinical mastitis in the first week after calving was equivalent for the two groups. Pregnant heifers in the straw yard were more frequently infected by major pathogens (*streptococcus uberis*) than those in the OWP (Table 6), while the trend was reversed for dry cows at calving (Table 7). These isolated pathogens of infected quarters were generally of faecal origin and related to bacteria development in the bedding. Moreover, there were numerous infections with coagulase-negative staphylococci (Tables 6 and 7), which were more frequent for dry cows in the OWP group (Table 7). To reinforce prevention of infections during the dry period, it is recommended to use a teat canal obturator (Roussel, Heuchel, 2005) in addition to other measures (regular upkeep of bedding, antibiotic therapy etc.). Mammary pathology can thus be controlled, as was shown by the results obtained by O'Driscoll *et al.* (2006).
- Environment: Liquid effluents retrieved at the drainage output positioned under the OWP had weaker concentrations of COD, suspended material and nitrogen than those obtained with lightly charged effluents after primary treatment (Table 8). The OWP therefore serves as a very effective filter for these effluents. The presence of nitrogen in its oxidized form (primarily nitrate) also shows that the OWP functions well in aerobiosis. The liquid effluents output from the OWP can therefore go directly into the second stage of a treatment system for lightly charged effluents, where they will be denitrified, among other things.

Construction and upkeep of the OWP

Recommendations were established based on findings at the OWP on the Trévarez experimental farm and the four additional cattle farms and based on the Irish experience (French, Scully, 2007).

OWP construction techniques and costs

OWP design varies depending on the nature of soil:

- If the soil is sufficiently impermeable, water tightness can be obtained naturally via an appropriate level of compacting (French, Scully (2007), farms A and C (Table 9)),
- With a naturally permeable soil or on fill, water tightness can be obtained either by using a tarpaulin protected with a geotextile (French, Scully, 2007), or by concrete (farms D and E, Table 9) or even asphalt (farm B, Table 9).

The cost of the OWP at the Trévarez experimental farm remained high (table 9) for various reasons: its construction by an outside contractor, the substantial amount of surface area allocated per animal and the need to manage three types of effluents (manure from bedding, slurry in the exercise area and liquid effluents retrieved under the OWP). There are several alternatives that can be used to reduce costs:

- Obtain only one type of excreta (solid manure) and process lightly charged effluents in order to avoid the construction of storage structures, thus eliminating the need for slurry pits (farms B, C, D, E), or dungheaps if the duration of accumulation of bedding under the animals is greater than two months (farms C, D, E). Liquid effluents collected under the OWP can then be treated via one of the approved channels (Institut de l'Elevage et al., 2007).
- Reduce surface areas: For 100% wintering, the recommended dimensioning process for OWPs is to multiply the surface area per animal by 1.7 in comparison with the recommended area for "standard" buildings. The surface area per animal can be reduced, however, to that of a "standard" building with regular maintenance and weekly scraping (dunging) of the bedding (farm B at end of construction) or when access to grasslands is provided (the New Zealand experience). These options will continue to be studied.
- Simplify the drainage system: PVC drains can be replaced by small trenches filled with large pebbles (farm C); this simplifies the design and makes it possible to reduce the thickness of the gravel drainage layer.
- Optimize existing concrete structures such as the fitting out of self-feeder silos on the OWP (farm E).
- Construction by breeders themselves (farms C and D): the simplicity of the OWP makes this option feasible.
- Use asphalt flooring, which is less costly than concrete flooring installed by a contractor (farm B).

Secondly, animals must be protected from dominant or cold winds via hedges already in place (farms A, C) or by planting hedges or installing artificial windbreakers. The latter are more costly and difficult to install. Shelters must also be provided for calves (farm E) and sheltered facilities for calving (farms A and E).

The OWP must also be oriented towards the sun. The floor must have a slope of at least 2% to promote the flow of liquids under the bedding, and drinking troughs must be protected or equipped with devices to prevent freezing.

Upkeep of the OWP: straw supply and cleansing

Straw was the bedding material selected by all farms. Upkeep of OWP bedding must be adapted to rainfall levels in order to control animal cleanliness. During wet periods, straw must be supplied more frequently and in larger quantities. On the whole, the quantity of straw used was equivalent to quantities used in a "standard" building. According to observations made in 2006 and 2007 at the Trévarez experimental farm, woodchips are more costly and less comfortable than straw (and entail a risk of injuries to the teats). Woodchips are more difficult to spread on the bedding area and do not permit sufficient upkeep in rainy periods. Cleansing is more difficult and the manure is not decomposed as well as on straw-based bedding. Woodchips may be used under bedding to promote the drainage of rainwater and facilitate cleansing. To reduce the cost of bedding, livestock breeders can use other available materials, such as reed straw (farms C and D) or crop remains (canola, corn).

Conclusion

In view of the trials conducted at the Trévarez experimental farm and observations made at other farms, it would appear that OWPs can be used continuously for most adult cattle (dry, suckling and young cows) with the exception of dairy cows in production, providing that certain rules are respected concerning the dimensioning, design and upkeep of bedding. Installing an OWP combined with outdoor wintering also contributes to the preservation of grasslands in poorly supported soils, particularly during rainy periods, and helps protect the environment due to improved management of excreta.

Table 1: Weight and fatness at calving, milk production, fat and protein content during the 1st month of lactation according to type of housing and parity

| Group | Straw yard | | | OWP | | | Statistical test | |
|---------------------------|-------------|-------|-------|-------------|-------|-------|------------------|--------------|
| | Parity (1) | Multi | Primi | combined | Multi | Primi | combined | Group effect |
| Consumption (kg of DM/d) | 12.2 (0.25) | | | 12.2 (0.30) | | | P = 0.98 | |
| Fatness (2) | 2.9 | 3.2 | 3.0 | 2.8 | 3.1 | 2.9 | P = 0.33 | P = 0.90 |
| Weight after calving (kg) | 596 | 520 | 557 | 597 | 513 | 555 | P = 0.63 | P = 0.47 |
| Weight of calf (kg) | 41.7 (0.9) | | | 43.5 (0.8) | | | P = 0.12 | |
| Milk production (kg/d) | 33.0 | 24.0 | 28.5 | 32.1 | 23.1 | 27.6 | P = 0.41 | P = 0.96 |
| Fat content (g/kg) | 42.8 | 42.4 | 42.6 | 42.7 | 42.9 | 42.8 | P = 0.87 | P = 0.80 |
| Protein content (g/kg) | 32.8 | 32.3 | 32.5 | 32.2 | 31.9 | 32.1 | P = 0.29 | P = 0.78 |

(1) Primi. = Primiparous cows (n = 18 per group); Multi. = Multiparous cows (n = 20 per group)

(2) Fatness score at calving on a scale of 5 (0 = very thin; 5 = very fat)

Table 2: Weight, average daily fatness gain of heifers to be inseminated according to type of housing (Winter 2008/09 trial, Trévarez)

| | Stage | Straw yard | OWP | Statistical test |
|--------------------------|-----------------------------|------------|------------|-----------------------------|
| Consumption (kg of DM/d) | / | 10.3 | 10.0 | |
| Weight (kg) | Before trial After trial | 396 485 | 396 494 | P = 0.95 P = 0.19 |
| Fatness (1) | Before trial After trial | 2.6 2.3 | 2.4 2.6 | P = 0.13 P = 0.08 |
| ADG (g/d) | / | 836 | 929 | P = 0.06 |

(1) Fatness score at calving on a scale of 5 (0 = very thin; 5 = very fat)

Table 3 – Development of injuries, lameness and quality of human/animal relations for 59 cattle dairy (heifers and dry cows) by type of housing (2007-2009 trials, Trévarez)

| Criteria | Housing | Worsening | Stability | Improvement | Statistical test |
|----------------------------|------------|-----------|-----------|-------------|---------------------|
| Injuries (1) | Straw yard | 22% | 68% | 10% | Insignificant |
| | OWP | 17% | 75% | 8% | |
| Lameness (2) | Straw yard | 8% | 92% | 0% | Significant (trend) |
| | OWP | 0% | 97% | 3% | |
| Human/animal relations (3) | Straw yard | 15% | 35% | 49% | Insignificant |
| | OWP | 11% | 39% | 49% | |

(1) 9 areas scored (neck, dewlap, knees, shoulders, backbone, ribs, pelvis, tarsus, tail),

(2) 3 lameness levels scored (none, suspected, proven),

(3) Animal's willingness to be approached by humans rated in 3 categories (permits touching, accepts presence within 2m, flees).

Table 4 – Animal cleanliness according to type of housing (2007-2009 trials at Trévarez)

| Type of animals (numbers) | # of checks per animal | Type of housing | | Statistical test |
|------------------------------------|------------------------|-----------------|----------|---------------------|
| | | Straw yard | OWP | |
| Heifers to be inseminated (n=19) | 6 | 3.16 (1) | 3.94 (1) | P < 0.001 |
| Heifers at end of gestation (n=19) | 4 | 4.03 (2) | 3.75 (2) | P = 0.41 |
| Dry dairy cows (n=24) | 4 | 3.45 (2) | 3.29 (2) | P = 0.61 |

(1): Average score out of maximum of 8 = sum of 4 areas scored (thigh, hindquarter, hock, belly) from 0 (very clean) to 2 (very dirty).

(2): average score out of maximum of 10 = sum of 5 areas scored = same as (1) + udder

Table 5 - Mammary pathology according to type of housing and parity: Somatic cell counts (SCC) at start of lactation (x 1000/ml; geometric averages) and frequency of clinical mastitis in week following calving (2007-2009 trials, Trévarez)

| Group | Straw yard | | | OWP | | | Statistical test | | |
|--------------------------|------------------------|--------|--------|-----------------------|--------|--------|------------------|-----------------|----------------|
| | Parity (1) | Multi. | Primi. | combined | Multi. | Primi. | combined | Group effect | Group x parity |
| SCC 2 nd week | 94 | 156 | 121 | 188 | 285 | 231 | | P = 0.07 | P = 0.90 |
| SCC 3 rd week | 81 | 153 | 111 | 153 | 199 | 174 | | P = 0.13 | P = 0.52 |
| SCC 4 th week | 67 | 156 | 102 | 125 | 146 | 135 | | P = 0.33 | P = 0.22 |
| SCC 5 th week | 27 | 138 | 61 | 91 | 126 | 107 | | P = 0.45 | P = 0.36 |
| Clinical mastitis | 10% (4 out of 39 cows) | | | 8% (3 out of 39 cows) | | | P = 0.69 | | |

(1) Primi. = Primiparous cows (n = 18 per group); Multi. = Multiparous cows (n = 20 per group)

Table 6 - Infection of quarters of primiparous cows at calving (2007-2009 trials, Trévarez)

| Nature of infections | Straw yard (1) | | OWP (1) | | Statistical test |
|---------------------------------------|----------------|-------|---------|-------|------------------|
| | Number | % (1) | Number | % (1) | |
| No infections | 22 | 45.8 | 27 | 45.8 | P = 0.99 |
| Infections by major pathogens | 12 | 25.0 | 6 | 10.2 | P = 0.04 |
| Including <i>Streptococcus uberis</i> | 7 | | 3 | | |
| <i>Escherichia Coli</i> | 2 | | 3 | | |
| Infections by minor pathogens (2) | 22 | 45.8 | 27 | 45.8 | P = 0.99 |
| Number of quarters | 48 | 100 | 59 | 100 | |

(1) Due to combined infections, the total no. of infections may be higher than the total no. of infected quarters.

(2) predominantly Coagulase-negative staphylococci, except *C. bovis* for a "straw yard" quarter

Table 7 - New infections during the drying off period according to type of housing (2007-2009 trials, Trévarez)

| Nature of infections | Straw yard (1) | | OWP (1) | | Statistical test |
|---------------------------------------|----------------|------------------|---------|------------------|------------------|
| | Number | % ⁽¹⁾ | Number | % ⁽¹⁾ | |
| New infections | 17 | 26.2 | 28 | 40.6 | P = 0.99 |
| By major pathogens | 10 | 15.3 | 12 | 17.4 | P = 0.75 |
| Including <i>Streptococcus uberis</i> | 3 | | 10 | | |
| <i>Escherichia Coli</i> | 1 | | 1 | | |
| Enterococci | 6 | | 1 | | |
| Coagulase-negative staphylococci | 7 | 10.8 | 16 | 23.2 | P = 0.06 |
| Number of quarters | 65 | 100 | 69 | 100 | |

(1) Due to combined infections, the total no. of infections may be higher than the total no. of infected quarters.

Table 8 - Concentration (in mg/l) of effluents output from the OWP with straw in comparison with lightly charged effluents (LCE) (white, green and brown water) (2007-2009 trials, Trévarez)

| | Effluents output from OWP | | | LCE after primary treatment | | |
|------------------------|---------------------------|------|-------|-----------------------------|-----|-------|
| | average | Min. | Max. | average | Min | Max. |
| Organic matter | 1,024 | 648 | 2,980 | 1,549 | 479 | 4,499 |
| Suspended matter | 177 | 16 | 1,400 | 933 | 177 | 5,725 |
| Chemical Oxygen Demand | 1,068 | 502 | 1,600 | 2,651 | 734 | 7,817 |
| Kjeldahl nitrogen | 36 | 8 | 128 | 254 | 100 | 603 |
| Ammonia nitrogen | 12 | 0 | 113 | 170 | 65 | 325 |
| Nitrates | 27 | 0 | 64 | 0 | / | / |
| Nitrites | 0.2 | 0 | 2.1 | 0 | / | / |
| Phosphorus | 28 | 9 | 56 | 35 | 16 | 55 |
| Potassium | 477 | 201 | 752 | 346 | 119 | 700 |
| pH | 7.5 | 7 | 8.1 | | | |

Table 9: Characteristics of the various OWPs monitored from 2006 to 2009

| Identification | Use of OWP | Description (m ² /animal) | Original construction features | Cost (annual) |
|-------------------------------------|--|--|--|----------------------------------|
| Farm A (150 dairy cows) | 100% wintering 30 dry cows (or heifers) | Straw yard (12) + exercise area (4), manure + scraped slurry | Constructed 100% by contractor, in conformity with Irish recommendations | €1,642 per cow (1) (2006) |
| Farm B (70 dairy cows) | 100% wintering, 15 dry dairy cows + 20 heifers | Straw yard (7) + exercise area (3), 100% scraped manure | Asphalt floor, weekly scraping of bedding area and working chute | in finishing stage (winter 2009) |
| Farm C (80 suckling cows) | 100% wintering, 30 beef cattle | Integral straw yard (10) | natural floor, simplified construction (drains, barriers), 100% self-construction | €100 per steer (2) (2008) |
| Farm D (70 suckling cows) | Wintering with access to grasslands, 2 groups (heifers; cows) | Integral straw yard (13), covered trough, under hay barn | Concrete paved area with exterior drainage channels, self-constructed | Not estimated (2000) |
| Farm E (40 suckling cows) | 100% wintering of herd | Straw yard (7.7) + exercise area (7.3), | Remodelling of old self-feeder silos, trough and covered shelters (for calves and calving) | €26 per cow (3) (2006) |

(1) Per item: bedding = €499/animal; Exercise area + feed = €548/animal; excreta = 595 €/animal

(2) Cost of materials only, working hours = 124 hours (farm C) and 16 hours (farm E)

6 ■ Outwintering pads for beef cattle - factors affecting improved performance

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Out wintering pads (OWP's) are an animal accommodation system that are constructed by placing a bed of woodchips over a lined (compacted subsoil, geomembrane or concrete) and artificially drained surface. The woodchips provide a soft interface with the animals, the drainage system collects all of the leachate from the woodchip bed and the liner prevents any downward movement of effluent into the groundwater. This report compiles the results of three consecutive winter trials, which examined the effect of outwintering on measures of animal production and welfare for fattening crossbred steers. Each year a control treatment was included, which was defined as counterpart animals housed at an industry standard stocking density, in slatted floor accommodation. A consistent management criteria established from the outset for OWPs was that the dirty woodchip bedding was removed from the system and replenished, when animals had less than 2.2 m²/head of dry lying area available to them.

The objective of Study 1 was to examine the effect of space allowance and provision of shelter, animal performance and feed efficiency. In Study 2, the first objective was to evaluate the effect of offering cattle free access to an OWP in conjunction with a slatted floor shed on animal performance. The second objective was to determine if the production advantage achieved by accommodating animals on an OWP relative to a slatted floor shed can be achieved by covering a slatted floor shed with rubber mats or straw. In study 3 the objective was to determine if environment (indoor vs. outdoor), space allowance or surface type (slat vs. buttchip) influenced animal intake and performance

Study 1: The effect of space allowance and wind shelter on the performance of finishing cattle when compared with animals housed on slats

Materials and methods

One hundred and twenty six Charolais x Friesian steers (474 kg mean initial liveweight (± 45.9)) were blocked on liveweight and assigned at random from within blocks to one of seven treatments, such that there were 3 replicate groups per treatment with 6 animals per group. The first six treatments were accommodated outdoors on OWPs. These six treatments were arranged in a three (space allowances) by two (wind sheltered by 40 % porosity netlon fence or exposed) factorial design. The three space allowances were 6, 12 and 18 m²/head. A seventh treatment group (control) was housed indoors in a slatted floor shed at a space allowance of 3 m²/head.

All animals were offered forage (0.08 straw, 0.92 grass silage) *ad-libitum* and 5 kg concentrate fresh weight. Forage intake was recorded on four days each week and group intakes calculated on a DM basis. All animals were slaughtered after 151 days on experiment, and cold carcass weight (hot carcass weight x 0.98) was recorded. Carcass gains were calculated as the difference

between the final carcass weight and proportionately 0.53 of the initial liveweight. Heat energy production (HE) was calculated from metabolisable energy (ME) intake and net energy required for gain using the equations of NRC (1996) and heat of evaporation (He) was assumed to be 0.15 of HE. Body surface area (SA) was calculated from liveweight^{0.67} * 0.09 (NRC, 1996). Net energy required for the gain (NEg) achieved, and for maintenance (NEm) assuming no climatic energy demand, were also calculated using the equations of NRC (1996).

Climatic energy demand (CED) estimation

The climatic energy demand (CED) was estimated on six animals from each of three treatment groups (indoors, outdoors sheltered 18 m²/head and unsheltered 18 m²/head). The CED was calculated on a daily basis, where $CED = (T_b - T_a - (r.R_n.l_a)) / (l_t + l_h + l_a)$ where the CED = climatic energy demand (W/ m²), T_b = core body temperature (°C), T_a = air temperature (°C), r = interception factor associated with radiation exchange (0.62), R_n = net radiation (W/m²), l_a = environmental thermal resistance (Km²W⁻¹), l_t = tissue thermal resistance (Km²W⁻¹) and l_h = hair coat thermal resistance (Km²W⁻¹). To complete this equation the following measures were made:

1. Meteorological data: Daily temperature and relative humidity were recorded hourly indoors and outdoors. Rainfall and evapo-transpiration were measured daily at 9:00 and 16:00 h. Wind speed and wind direction for sheltered and non-sheltered OWP sites and net solar radiation were recorded every hour using a continuous data logger system.
2. Animal core body temperature: Each week rectal temperatures were recorded twice daily at 8:00 and 15:00 h for six animals from each of the seven treatment groups.
3. Hair length: was approximated by sub-sampling to approximately 80 hairs, on three separate occasions. The length of each hair was categorised at 0.5 to 1.0 cm, 1.0 to 2.0 cm, 2.0 to 3 cm and 3.0 to 4.0 cm. The mean hair length was then estimated from these values.
4. Estimation of subcutaneous fat depth: Subcutaneous fat depth was measured over the 13th rib at three points on each side of the carcass, 24 h post slaughter.

Results and discussion

When indoor and outdoor environments were compared over the experimental period the ambient air temperature was lower outside (3.5 and 5.0 °C, respectively; p<0.001), while relative humidity was higher indoors (90.6 and 86.0 %, respectively; p<0.001). Daily rainfall averaged 2.2 mm during the experimental period, with a recorded minimum and maximum fall of 0.0 and 28.4 mm, respectively. The perception of cold (LCT) by a homeotherm is not merely dependent on ambient temperature but on a complex interaction of wind, temperature, moisture and level of nutrition (Young, 1981). Wind direction at the experimental sites was mainly east to northeast in direction. Wind speed was significantly reduced by the provision of shelter (0.77 and 0.53 m/s, respectively; p<0.001) but this reduction did not influence the estimated CED values, which were higher for animals out wintered on OWPs, when compared with their counterparts indoors (70.3, 71.1 and 59.2 W/m² for animals sheltered, exposed and indoor animals, respectively, p<0.001). The CED (energy required to keep warm) and the HE/SA – He (energy released due to feed digestion) over the period mid-December to mid-March is shown in Figure 1. On no occasion during the winter did the CED exceed the HE/SA – He for any group of animals. Animals retained outside showed some level of adaptation to this higher CED by increasing hair length (1.11 and 1.36 cm for indoors and outdoors respectively, p < 0.05), which can reduce the bovine LCT (Wagner, 1988). There was no effect of shelter on mean hair length. Among the animals on the OWP there was no significant effect of stocking density or provision of shelter on growth rate, carcass traits or feed efficiency. The cattle accommodated on the OWP's had higher liveweight and carcass gains than those in a slatted floor shed as well as better feed conversion efficiency and lower fat scores than those in slatted floor sheds.

Study 2: The effect of confining animals on OWP, OWP plus slats or indoors on slats, or modified surfaces on measures of animal performance and welfare

Materials and methods

Seventy five steers were assigned at random to one of five treatments. The treatments were (1) animals housed on slats at 2.5 m²/head, (2) animals confined on OWP at 18 m²/head, (3) animals housed on slats at 2.5 m²/head with free access to an OWP at 15 m²/head, (4) animals housed on matted slats at 2.5 m²/head, (5) animals housed on straw at 4m²/head. For the animals accommodated on slats the space allowance was increased to 3.33m²/head after 89 days of the experiment.

All cattle were offered a total mixed ration consisting of approximately 500g of concentrates DM and 500g grass silage/kg total DM. Each treatment was divided into 3 pens of 5 and intake was recorded on a pen basis. All animals were slaughtered at the end of the 151 day experiment, and carcass data recorded.

Results and discussion

For the experimental period the average ambient air temperature was 5.2 °C (min. -2.08 °C and max. 10.9 °C) and the average daily rainfall was 2.7 mm (min. 0.0 mm and max. 34.6 mm).

Relative to animals housed indoors on slats, animals accommodated outdoors on OWPs or given free access to an OWP had higher daily liveweight gain ($p<0.001$), carcass gain ($p<0.05$), and feed intake ($p<0.01$) (Table 2). Also there was no significant effect of housing system indoors on liveweight gain, carcass gain, and feed intake when compared with animals housed in slatted floor pens. There was no significant effect of accommodation system on carcass fat score or feed efficiency. These results would indicate that underfoot comfort at intensive stocking densities does not improve animal performance. However incorporating an option of free access to an outdoor OWP facility when animals are being fed in a slatted floor shed, supported improved performance.

Study 3 : The effect of housing system, space allowance and floor surface on the performance of fattening steers

Materials and methods

Ninety steers were assigned at random to one of six treatments. The first three treatments were accommodated indoors in a conventional shed. Animals were either housed in a slatted floor pen at 2.7 or 10.4 m²/head or on an artificial solid floor bedded with woodchip material at 10.4 m²/head. The remaining three treatments were accommodated outdoors, where animals were either in a slatted floor pen at 2.4 or 10.4 m²/head or on a solid floor OWP facility bedded with woodchip material at 10.4 m²/head. Each treatment was divided into 3 pens of 5 and intake was recorded on a pen basis. All cattle were offered a total mixed ration consisting of approximately 500g of concentrates DM and 500g grass silage/kg total DM. All animals were slaughtered at the end of the 115 day experiment.

Results

There was no significant effect being inside or outside on liveweight gain, carcass gain, feed intake or feed efficiency (Table 3). Relative to animals housed indoors on slats at 2.7 m², increasing space allowance to 10.7 m² increased daily liveweight gain ($p<0.001$) and carcass gain ($p<0.01$). Similar to previous experiments, the animals on the OWP had substantially (0.35) higher growth rates than those indoors on slatted floor sheds at 2.7m² space allowance. Approximately 0.6 of the advantage was achieved by increasing the space allowance from 2.7m² on to 10.4m² on slats and the remainder was achieved by providing a softer lying surface in the form of woodchips. There appeared to be no production advantage to accommodating animals outdoors rather than indoors.

References

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Table 1: Animal performance, carcass characteristics and feed efficiency of finishing steers out-wintered on wood-mulch pads at different stocking densities with or without shelter relative to indoor housing on slats

| Conditions (C) | Space allowance (m ²) | Indoors (I) | | | | | | | | | F test | | |
|------------------------------|-----------------------------------|-------------|-------|-------|------|-------|-------|------|-------|------|--------|-------|---------------------|
| | | 6 | 12 | 18 | 6 | 12 | 18 | 3 | s.e. | C | S | C x S | CS v I [†] |
| Liveweight gain (g/day) | | 116 | 1174 | 1216 | 1174 | 1136 | 1229 | 991 | 51.4 | n.s. | n.s. | n.s. | *** |
| Carcass gain (g/day) | | 695 | 700 | 710 | 656 | 657 | 734 | 616 | 26.1 | n.s. | n.s. | n.s. | * |
| Feed intake (kgDM/day) | | 9.92 | 10.01 | 10.22 | 9.85 | 10.08 | 10.06 | 9.64 | 0.110 | n.s. | n.s. | n.s. | * |
| Feed efficiency [†] | | 57.7 | 57.7 | 57.3 | 54.3 | 53.3 | 60.7 | 51.3 | 2.91 | n.s. | n.s. | n.s. | * |

[†]Indoors versus all outdoor treatments,[†]g carcass gain/kg feed DM consumed,

Table 2. The effect of housing system on feed intake and efficiency, liveweight and carcass gain and carcass fat score

| Housing system | Feed intake (KgDM) | Liveweight gain (kg/day) | Carcass gain (g/day) | Fat score | Feed efficiency (mj/kg carrass) |
|----------------|-----------------------|-----------------------------|----------------------------|-----------|--|
| OWP | 10.88 ^a | 1.40 ^a | 766 ^a | 3.77 | 170 |
| OWP & slats | 10.58 ^a | 1.33 ^a | 759 ^a | 3.57 | 167 |
| Slats | 9.50 ^b | 1.01 ^b | 631 ^b | 3.51 | 181 |
| Matted slats | 9.56 ^b | 1.02 ^b | 643 ^b | 3.62 | 178 |
| Straw | 9.79 ^b | 1.10 ^b | 636 ^b | 3.66 | 185 |
| s.e. | 0.173 | 0.059 | 33.2 | 0.098 | 5.352 |
| f. test | ** | *** | ** | | |

Table 3. The effect of winter accommodation system on growth, feed intake and efficiency of finishing beef cattle

| Conditions | | Inside | | Outside | | | | | | Inside V | Slats @ 2.7 V slats | Slats V Pads |
|------------------------|-----------------------------------|--------|------|---------|------|------|------|------|------|----------|---------------------|--------------|
| Surface | Space | Slats | Pad | Slads | Pad | s.e. | | | | | | |
| | allowance (m ² /hd) | 2.7 | 10.8 | 10.8 | 2.7 | 10.8 | 10.8 | | | @ 10.8 | | |
| Liveweight (g/day) | gain | 972 | 1289 | 1408 | 1088 | 1258 | 1419 | 45.3 | n.s. | *** | * | |
| Carcass gain (g/day) | | 577 | 701 | 767 | 574 | 694 | 782 | 11.9 | n.s. | ** | 0.08 | |
| Feed intake DM/day) | (kg | 10.1 | 10.5 | 11.0 | 10.5 | 10.7 | 11.0 | 0.34 | 0.09 | 0.09 | n.s. | |
| Feed efficiency | | 17.6 | 15.0 | 14.3 | 18.3 | 15.4 | 14.1 | 0.55 | n.s. | 0.09 | n.s. | |

7 ■ Environmental aspects of out-wintering cattle on woodchip pads

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Woodchip pads are a reduced cost over-wintering system for cattle, minimising damage to pasture and, potentially, reducing environmental emissions. Originally developed in New Zealand for out-wintering livestock, out-wintering pads (OWPs) are now gaining popularity within Ireland and the UK. These provide benefits to animal welfare and, dependent upon their management, can also impact positively on the environment, viz. water quality and gaseous emissions. The objective of this research project is to better understand the effects of livestock, feed and woodchip management on animal welfare and the environment, based around the monitoring of four commercial dairy/beef units and a replicated research facility (with four separate pads, each 10m x 10m), constructed at North Wyke Research Station in Devon, in 2008.

Introduction

In the past, there has been considerable interest in the use of low-cost OWPs, which can offer an economic means of wintering animals, reducing or avoiding the need for conventional housing, reducing labour inputs for feeding and avoiding the high cost and sometimes low availability of straw for bedding. Moreover, OWPs have been shown to bring animal health, welfare and production benefits (Hickey et al. 2002; Smith et al. 2006; O'Driscoll et al. 2008). Research in Ireland has confirmed improvements in daily live-weight gain, in feed conversion and decreased fat deposition (Hickey et al. 2002; Boyle et al. 2008; Dunne et al. 2008). However, concerns about increasing regulatory requirements, which preclude the installation of unlined and undrained facilities (known as corrals), and some catastrophic pad failures have seen a decline in interest.

Some problems of drainage failure in corrals appear likely to have been due to the sealing of the base of the corral by solids in the effluent. One strategy which appears to reduce the risk of solids accumulation at the base of the OWP or in the drainage system, is to include a surface layer of fine chips/bark for solids retention and which can be removed (with the solids) annually (French, personal communication). The collection and recycling of effluent from OWPs will greatly reduce the risk of water pollution from the pads. The aim of this study was to develop improved guidance on pad design and management, to promote best practice and, thereby reduce the risk of environmental pollution or of pad failure; in this paper, only preliminary results can be reported.

Materials and Methods

Commercial pads

We identified three commercial OWPs across England and Wales, based on the following criteria: impermeable base or lining; convenient access to the pad drainage system for effluent collection; stocking of the pad during 2008/2009 and, importantly, farmer co-operation. A fourth OWP was monitored on a dairy unit at Ballyhaise College, Co. Cavan, Ireland, with the help of Teagasc, though no results are presented in this paper. Records were made at each farm of

animal numbers, feeding practices and time stock spent on the pad. Surface soiling of the woodchip bed was estimated according to a 1-5 point scale. Effluent flow was monitored via an overshot waterwheel or tipping bucket, with samples collected on a flow-proportional basis for analysis of total solids, total N, total P, K, NH₄-N and COD. Animal cleanliness was also recorded according to the Meat Hygiene Service scale (Anon 2004). Ammonia emission measurements were made using passive samplers on masts around each pad, exposed for 48 hours on 6 occasions per site per year. Wind direction and speed were recorded on each occasion and atmospheric dispersion modelling was used to calculate fluxes (Hill et al. 2008).

Experimental OWPs at North Wyke Research

Four lined OWPs were constructed at North Wyke Research, South West Devon, England, between October and December 2008. The initial study undertaken between December 16th 2008 and July 3rd 2009 evaluated three factors: woodchip size (7.5 cm; 4 cm; 2 cm; and sawdust); feeding management (On or Off the Pad) and area allowance (11.8 and 18.6 m²/head) on animal performance, effluent quality and gaseous emissions. Each of the pads comprised a 30 cm base layer of 7.5 cm chip, on top of which was placed another 20 cm of one of the four different chip sizes. A Graeco-Latin square experimental design (Federer, 1955) with 6-7 week time periods was used to investigate the interaction between the three factors. Thirty four (34) Charolais steers were distributed between the pads in four groups, remaining on the pads for 24 hours/day and fed silage ad-libitum plus concentrates (2kg/head/day). The flow of effluent from each pad was monitored using tipping buckets and sampled, twice per week, for total N; total P; total solids; nitrate-N; and ammonium-N.

Results and discussion

Commercial Pads

The pads in all the farms were being used for out-wintering cattle. On the Welsh farm a 1,155 m² pad (33x35m) was completed in November 2008. In this first winter, the pad was used to accommodate 40 organic beef finishers, 24 hours/day. Effluent volume was recorded and samples collected for analysis; ammonia emission measurements were also recorded on four occasions. Concentrations of N and P on this pad (Table 1) were lower than the average concentrations (500mg/l N, 300mg/l NH₄-N, 44mg/l P) in dirty water (Chambers and Nicholson 2004). Concentrations of N were lower than those obtained on the experimental pads at North Wyke (Table 3) but similar to the results of Augustenborg *et al* (2008) and McDonald *et al* (2008). Ammonium-N concentrations were lower than from the corral studies of Vinten *et al* (2006). These differences might be due to weather conditions; stocking density or stock/feeding management; pad size or design.

Table 1 - Effluent quality from the OWP on the Welsh farm (preliminary data).

| Analysis | | 27 Jan | 11 Feb | 20 Feb | 18 Mar | Ave | CV% |
|-------------------------|------|--------|--------|--------|--------|------|------|
| Total | g/l | 3.45 | 3.55 | 3.16 | 3.27 | 3.36 | 5.3 |
| Total N | mg/l | 224 | 222 | 222 | 248 | 229 | 5.0 |
| NH₄-N | mg/l | 148 | 115 | 150 | 153 | 142 | 11.1 |
| Total P | mg/l | 33.3 | 41.5 | 41.6 | 34.9 | 37.8 | 10.7 |
| Total K | mg/l | 392 | 486 | 468 | 405 | 438 | 9.6 |
| COD | mg/l | 4400 | 3590 | 3900 | 3270 | 3360 | 24.0 |

Experimental OWPs at North Wyke Research

Chip size: There was no effect of chip size on silage intake or pad performance. Daily live-weight gain (DLWG) was greatest on Sawdust (1.44 kg/head/day) and lowest on the 7.5cm chip (1.17 kg/head/day) (Table 2). Differences were observed in body condition scoring (BCS) with the greatest overall improvement (BCS change) on sawdust and the 4cm chip, which correlated with the better DLWG (Table 2). There was no effect of chip size on effluent quality averaged over the four measurement periods. The average concentrations of total P in the effluent were lower than typical for dirty water, whilst average concentrations of total N and NH₄-N were higher than for dirty water, but considerably lower than those from beef cattle slurry (Table 3).

Table 2 - Effect of Chip size on Body Condition Scoring (BCS) and Daily Live Weight Gain (DLWG).

| | Period | Chip size (cm) | | | |
|-------------------|-------------------|----------------|-------------|-------------|-------------|
| | | 7.5 | 4 | 2 | Sawdust |
| BCS | 1 | 4.8 | 4.7 | 5.1 | 4.8 |
| | 2 | 5.0 | 4.9 | 5.1 | 5.1 |
| | 3 | 5.3 | 5.3 | 5.3 | 5.3 |
| | 4 | 5.6 | 5.7 | 5.6 | 5.9 |
| BCS change | | 0.83 | 1.05 | 0.54 | 1.08 |
| DLWG | Average 4 Periods | 1.17a | 1.39ab | 1.32ab | 1.44b |

Table 3 – Average (four periods) effluent leachate concentration from North Wyke woodchip pads.

| Chip Size cm | Total N (Kjeldahl) mg/l | Ammonium (NH ₄ -N) mg/l | Nitrate (NO ₃ -N) mg/l | Total P (TP) mg/l | Total Solids g/l |
|--|-------------------------------|--|---|-------------------------|------------------------|
| 7.5 | 1130 | 883 | 2.2 | 45 | 8.7 |
| 4 | 1217 | 864 | 2.1 | 50 | 9.6 |
| 2 | 1019 | 723 | 1.4 | 45 | 10.5 |
| Sawdust | 1014 | 757 | 5.3 | 64 | 8.2 |
| Dirty water¹ | 500 | 300 | Trace | 44 | 5.0 |
| Dirty water² | 825 | 457 | Trace | 135 | 10.7 |
| Beef cattle¹ slurry (6%) | 4200 | 1850 | - | 785 | 60.0 |

¹ (Chambers and Nicholson 2004)

² (Cumby et al. 1999)

Area allowance (AA): This factor had no effect on effluent leachate quality, silage intake, BCS or pad performance. However, significant differences ($P<0.05$) were observed on DLWG, where a greater AA ($18.6 \text{ m}^2/\text{head}$) gave higher DLWG (1.40 kg/head/day) compared to $11.8 \text{ m}^2/\text{head}$ with 1.20 kg/head/day. In studies in Ireland (Boyle et al. 2008) reported DLWG of 0.77 kg/head/day, for heifers on out-wintering pads at $14 \text{ m}^2/\text{head}$, fed silage *ad libitum* plus concentrates. Hickey et al (2002) found that an AA of $18 \text{ m}^2/\text{head}$ for finishing steers on out-wintering gave a DLWG of 1.17 kg/head/day, while Dunne et al (2008) confirmed similar results of 1.34 kg/head/day in steers accommodated on out-wintering pads using an AA of $18 \text{ m}^2/\text{head}$.

Feeding management – On/Off pad: This factor had no significant effect on live-weight gain, effluent leachate quality, Body Condition Score or silage intake. However feeding on the pad proved more susceptible to weather conditions, giving rise to a badly soiled pad surface and dirty animals, especially following long dry periods when faecal solids accumulate on the surface.

Effluent leachate and rainfall: There was a greater release of nitrogen (N) from the woodchip bed during heavy rains, and at higher N concentrations, compared to drier periods. During the spring-summer period the pad's surface remained dry and the animals clean. Comparison of the estimated total drainage from the pads with rainfall and excretal input volume could account for only a relatively small proportion (c. 20-50%) of the total input, suggesting, at different times, that the woodchip provided both a substantial reservoir for absorption of effluent and promoted significant evaporative losses. A well drained OWP has considerable potential to hold within its matrix cattle excreta and rainfall without waterlogging.

Conclusion

Preliminary data on OWP effluent quality from both the experimental pads at North Wyke and from two commercial pads suggest that these effluents must be stored, managed and recycled to land, carefully to avoid environmental pollution. However, effluent quality generally appeared unaffected by the experimental treatments and is more consistent with dirty water than with slurry.

Livestock performance was good on all chip sizes and area allowances. Greater area allowance ($18.6 \text{ m}^2/\text{head}$) resulted in greater DLWG than $11.8 \text{ m}^2/\text{head}$. The 7.5cm chip size resulted in the lowest DLWG (1.2 vs. 1.4 kg/d on sawdust). There was no effect of woodchip size/area allowance or of feeding on/off pad on effluent volumes. The volume of effluent draining from OWPs appears to be significantly less than anticipated, based on input rainfall volumes and excretal inputs and needs further study. Dry over-wintering periods, if followed by intense rainfall, can result in poor performance of the woodchip pad, as a result of faecal solids accumulation.

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8 ■ Simplified cubicle housing systems for cattle

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Eight simplified cubicle buildings combined with an open-air exercise area, intended for use with dairy cows and heifers, were monitored between 2006 and 2009. Recommendations are made regarding the design and construction of these simplified buildings based on the results of this monitoring, discussions with building and construction consultants and lessons drawn from experience in Switzerland (fact-finding visit in July 2007 and ART publications). This method of housing facilitates the tasks performed by breeders and reduces investment costs by nearly half compared with traditional buildings.

The various construction options (Table 1)

Ventilation in the simplified cubicle housing systems

The buildings under study are between 4 and 9 m in width (Table 1) and are limited in height (from 4 to 5 m to the ridge). As a result, they are conducive to natural ventilation, even during the summer months. The primary issues of concern involve the risk of draughts in the area where the animals sleep.

When there is no siding on the sides exposed to dominant or cold winds, protection can be provided by means of an existing building used for other purposes: milking and storage of forages (Figure 1), barn hay drying (Figure 2), distribution of forages (Figure 3). Another solution is to take advantage of a natural windbreak. When buildings are used during the summer months, removable siding is essential for smaller-sized buildings that are low in height. Innovative, cost-efficient solutions with wood siding have been deployed (Farms 72 and 24).

Four farms erected single-slope buildings, which allow for simpler roofing ventilation. Six of the farms built at least one double-slope building. At Farm 61-B, the ridge is closed off with a steel roof. After two years of use, signs of condensation became visible. Several roofing ventilation options were recommended:

- An open ridge of about 20 cm with windbreak sheets: This solution is highly effective but costly. It was used only at Farm 61.
- A ridge set back about 12 to 15 cm, oriented opposite the dominant winds (Farm 14).
- A large one-metre opening with no protection (Farm 72).
- No opening on the ridge; the two rows of fibro-cement plates closest to the ridge are raised higher, or vents are created when other materials are used (with a clearance of several centimetres between plates): These solutions are simple and appear to be well suited for these buildings.

Length of roof overhang

The roof overhangs must be adequately long to protect the rear of the stalls from rain and sun (Zähner et al., 2000). Overhangs of various lengths were installed at the farms that were monitored, depending on the specific circumstances:

- one metre for building heights of between 3.3 and 3.5 m (Figures 1, 3 and 4);
- 1.5 metres for a height of 4.3 m (Farm 50);
- the addition of a 0.5-m deflector to reduce the height (Farms 53-B and 72).

By monitoring these buildings, researchers were able to identify the level of protection provided by these installations. The rear of the stalls can become exceptionally damp, but daily maintenance eliminates any negative impact.

Cubicles/framework links and position of the posts

Stall separators connected to the wood framework were installed at two farms (Farms 14 and 61). The stall separators made of wood are thicker than the commercial metal tubes (12-14 cm compared with 5-7 cm). Consequently, for the comfort of the animals, the wood stalls must be wider from axis to axis than is the case with metal separators. In addition, the position of the ground retainer and neck bar is fixed and cannot be adapted to the animal's frame. As a result, modifications to the stall structure have been proposed.

The position of the structural posts should be considered, with several possible solutions:

- The position in the front of the cubicle stalls that was recommended in Switzerland (Agroscope FAT Tänikon, 2005) was adopted at two farms (Figures 3 and 4).
- The position to the rear of the cubicle stalls that was recommended in Switzerland was adopted at one farm (Figure 4). In order to protect them from excreta, the posts are raised by 20 cm on a concrete block encased in a PVC sleeve.
- The midpoint position was not recommended in Switzerland for new facilities. It was deployed at three farms, where the posts were set back either 30 cm from the cubicle threshold (Graphic 2) or 60 cm (Graphic 1).

Roofing materials

Given the presence of an open-air exercise area, there is no need to install translucent plates in the roof in order to provide light. Translucent plates were installed in the roof at two buildings with closed double-slope roofs (Farms 14 and 61).

Since the simplified buildings are low in height, there is a significant risk of heat radiance on the animals during the summer. There is consequently a need for an insulating component at a low cost.

- Fibro-cement has been very widely used (Farms 14, 24, 31, 61, 72). Condensation is limited, and it helps to maintain the soundness of the building structure.
- Non-insulated steel is not recommended, given its very high capacity to radiate heat. It has been installed at two farms (Figures 2 and 4), but the animals pasture during the summer.
- PVC (Elycolor®) has been installed at one farm (Figure 3) where the animals do not remain in the building during the day in the summer months.

Open-air exercise yards and excreta management

Characteristics of open-air areas

For reasons of the animals' health and welfare, minimal open-air areas are recommended in Switzerland for new construction (M. Zähner, 2008). At the farms that were monitored, this area was an average of 2.9 sq.m per cow and varied from 1.5 to 5.5 sq.m (Table 2).

The use of hot-poured bituminous concrete as a ground surface was studied at several farms and adopted at one (Farm 72). The coating mixture costs 40% to 50% less than commercially produced concrete. It requires compliance with a set of specifications specific to animal husbandry that must still be validated.

For efficient drainage of contaminated rainwater, the recommended slope for open-air exercise yards is 2%. At four of the farms, the slope was between 1% and 2% (Table 2). This appears to be adequate for open-air exercise areas that are small in size with only a moderate volume of water to be drained. There are two potential solutions for separating blackwater from manure for treatment:

- The installation of collector pits before the manure storage: This solution is effective when scraping is performed with a tractor (Farms 14 and 50). But when mechanical scraping is used, there is a risk the pits will clog up more often.
- The solid manure could potentially be scraped in the direction opposite the slope. The blackwater then collects at the low point of the alleys.

It is preferable to protect the forage in the trough. A covering at a height of two metres, with a roof overhang of 1.50 m on the trough side, appears to be adequate (Figure 1). With the mobile troughs, the amount of work time required for the feeding process is cut in half, and the concrete surface area is reduced compared with a traditional trough. They can be installed in connection with open-air exercise areas (two farms monitored).

Manure management

In order to reduce the cost of manure storage, the ideal solution is to manage only one type of manure (seven of the farms studied) and to treat low-content effluent from open-air areas (all farms monitored).

There are several possible solutions for effectively managing manure in open-air spaces: give preference to dry feed (Farm 50), provide an adequate supply of straw in the stalls, create a solid manure platform with a drainage wall and liquid collection (Farms 53-A and 72), install a pit that collects scraped manure and provides for initial drainage before transfer to storage (Farm 72).

Investment cost and sources of savings

The solutions that were studied offer significant savings over a traditional building. Costs are reduced by an average of 46%, varying from 35% to 67% (Table 3). These results confirm the findings of the Swiss researchers at ART (Gazzarin and Hilty, 2002).

The following factors, which vary by farm, contributed to these savings:

- By building a great many of these features themselves, several farms saw significant additional savings (Table 3). Buildings that are low in height are easier for breeders to construct (Van Caenegem et al., 2004).
- Some breeders took the time to negotiate the cost of each construction job with contractors (as at Farms 50 and 53-A).
- A number of the buildings are quite compact, with three or four rows of stalls (Farms 24, 50, 53-B) or less space for the trough thanks to a mobile trough (53-B).
- The treatment of low-content effluent from open-air exercise areas and manure heaps ensures that this effluent can be managed at a lower cost (Institut de l'élevage et coll., 2007).
- With regard to the milking centre, several solutions have been adopted: Used milking parlour (Farms 50, 53-A), a collecting yard integrated into the housing (Farm 53-B), self-supporting prefabricated walls installed by the breeders (Farms 50, 53-B).

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Table 1: Description of eight simplified stall buildings with an open-air exercise area

| Farm (placed in service) | Stalls | | Shape and type of framework (width) | Roofing (slope) | Characteristics and unique features |
|--------------------------------|---------------------|-----------------|---|--------------------|--|
| | Number | Position | | | |
| 14 (2006) | 44 spots, 2 rows | Back to back | Double-slope, wood (8 m 20) | FC* (28%) | Self-built, including framework, kit covering (made by Intrabois) |
| 24 (in progress) | 98 spots, 3 rows | Head to head | Double-slope, wood (7 m 95) | FC* (21%) | Covered trough, 2 robotic milkers built into the building, siding that is removable in summer, kit produced by Roiné |
| | | Single row | Single slope, wood (3 m 95) | | |
| 31 (in progress) | 50 spots, 2 rows | Head to head | Double-slope, wood (8 m 60) | FC* (21%) | No siding, protection via hangar, kit produced by Roiné |
| 50 (in progress) | 79 spots, 4 rows | Head to head | 2 single-slope, metal (8 m 80) | Steel (10%) | No siding, two separate troughs, completely self-built |
| 53-A (2008) | 52 spots, 2 rows | Head to head | 2 single-slope, wood | PVC** (8.5%) | Largely self-built (concrete with hired help, siding, tubular) |

Table 1: Description of eight simplified stall buildings with an open-air exercise area
..../....

| Farm (placed in service) | Stalls | | Shape and type of framework (width) | Roofing (slope) | Characteristics and unique features |
|--------------------------------|---------------------|-----------------|---|--------------------|--|
| | Number | Position | | | |
| 53-B (2007) | 81 spots, 4 rows | Head to head | Central double- slope, wood | Steel (23%) | Compact building, with built-in holding area including exercise area, mobile trough, 2 x 12 spots under double-slope |
| | | Single row | 2 lateral single- slopes, wood | Steel (30%) | |
| 61 (2005) | 72 spots, 2 rows | Back to back | Double-slope, wood | FC* (24%) | Covered trough, kit framework installed by Chaignard (53) |
| 72 (in progress) | 82 spots, 2 rows | Back to back | Double-slope, metal and wood | FC (24%) | Covered trough, kit framework, removable siding, surfaced ground |

*FC = fibro-cement plates **Elycor®

Table 2: Characteristics of open-air living areas and management of manure and low-content effluent from milking in the eight farms monitored

| Farm | Open-air living area | | Manure management | | | Treatment of low- level effluent |
|------|-------------------------|-------|-------------------|----------------------------------|---|--|
| | sq.m per cow | Slope | Type | Scraping | Storage | |
| 14 | 5.5 | 5% | Manure | Scraper pulled behind tractor | Open-air manure pile | SBT* + spreading over meadow |
| | | | Slurry | | Concrete pit | |
| 24 | 1.5 | 2.5% | Slurry | ? | | SBT* + spreading over meadow |
| 31 | 3.7 | ? | Manure | ? (work in progress) | | SBT* + filters planted with reeds |
| 50 | 3.9 | 2% | Manure | Scraper pulled behind tractor | Open-air manure pile, front slope | SBT* + ponding |
| 53-A | 1.7 | 1% | Manure | Mechanical scraper with jack | Open-air manure pile + drainage wall | SBT* + ponding |
| 53-B | 2 | 1.5% | Slurry | Mechanical scraper with jack | Pit with geomembrane | SBT* + spreading over meadow |
| 61 | 1.7 | 1% | Manure | Mechanical scraper with cable | Open-air manure pile, front slope | Straw filter + spreading over meadow |
| 72 | 3 | 1.5% | Manure | Mechanical scraper with jack | Open-air manure pile + drainage wall | SBT* + ponding |

*SBT = sedimentation and stormwater basin tank

Table 3: Investment cost (€ per spot) of 6 simplified stall buildings with open-air exercise area and savings (%) compared with a standard building (1)

| Farm (number of spots) | Project | Housing | | Milking station | Excreta management | Total |
|------------------------------|----------------|--------------|----------------|--------------------|-----------------------|--------------|
| | | Self-built | Not self-built | | | |
| 14 (44 stalls) | Completed | 768 (2) | 943 | / | / | 768 |
| | Standard (1) | 1,686 | | / | / | 1,686 |
| | (% difference) | (54.4%) | (44.1%) | / | / | (54.4%) |
| 53-A (52 stalls) | Completed | 1,896 (4) | 2,527 | 887 | 425 | 3,274 |
| | Standard (1) | 3,300 (4) | | 2,020 | 1,126 | 6,446 |
| | (% difference) | (42.5%) | (23.4%) | (52.8%) | (62.3%) | (49.2%) |
| 53-B (81 stalls) | Completed | 1,697 (5) | 1,845 (5) | 1,184 | 302 | 3,183 |
| | Standard (1) | 2,703 (5) | | 1,811 | 1,006 | 5,520 |
| | (% difference) | (37.2%) | (22.2%) | (34.6%) | (70.0%) | (42.3%) |
| 50 (79 stalls) | Completed | 767 | Not estimated | 453 | 501 | 1,722 |
| | Standard (1) | 2,504 | | 1,682 | 986 | 5,172 |
| | (% difference) | (69.4%) | / | (73.1%) | (49.2%) | (66.7%) |
| 61 (72 stalls) | Completed | / | 1,678 (6) | / | 743 | 2,421 |
| | Standard (1) | 2,334 (6) | | / | 1,070 | 3,773 |
| | (% difference) | / | (37.9%) | / | (30.6%) | (35.8%) |
| 72 (82 stalls) | Completed | 1,570 (7) | Not estimated | / | / | 1,570 |
| | Standard (1) | 2,645 (7) | | / | / | 2,645 |
| | (% difference) | (40.6%) | / | / | / | (40.6%) |
| Average savings | | 46.1% | | 52.2% | 51.9% | 46.5% |

- (1) Same-year reference cost for a fully covered, semi-open traditional standard building, with 2 rows of stalls, commercially built, slatted floors over slurry and effluent pit, open-air manure pile.
- (2) Work time for 2 persons = 429 hours (masonry = 47%, construction = 53%)
- (3) including cost of mechanical scraper with jack for manure (€460 per spot)
- (4) including cost of mechanical scraper with jack for slurry (€207 per spot)
- (5) including cost of mechanical scraper with chain for manure and slurry (€204 per spot)
- (6) including cost of mechanical scraper with jack for manure and slurry (€304 per spot)

Figure 1: Sectional view of building at Farm 31 (Agriculture Bureau 31)

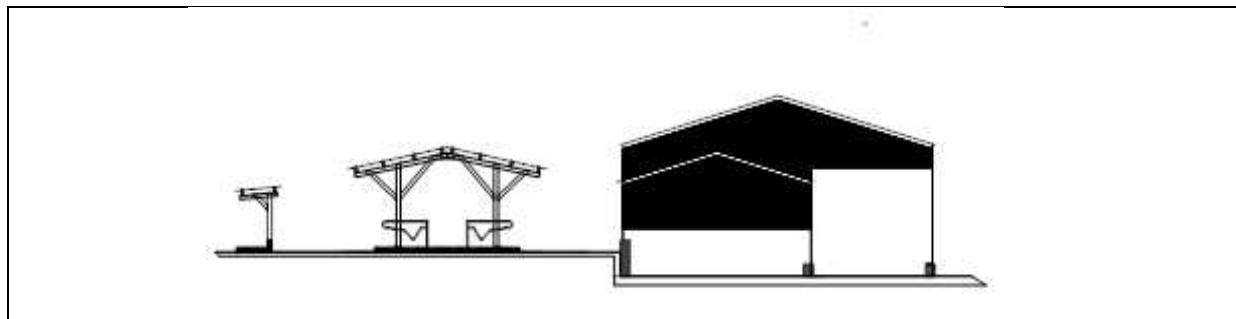


Figure 2: Sectional view of building at Farm 50 (Agriculture Bureau 50)

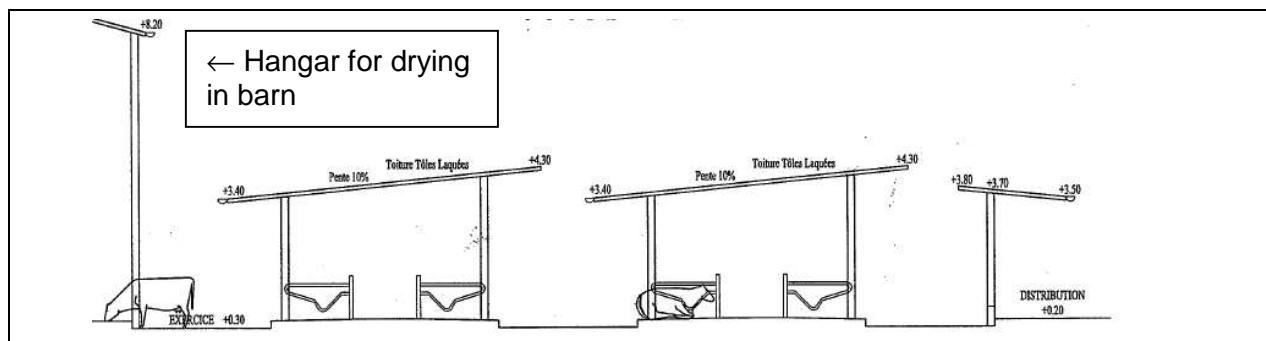


Figure 3: Sectional view of building at Farm 53-A (Agriculture Bureau 53)

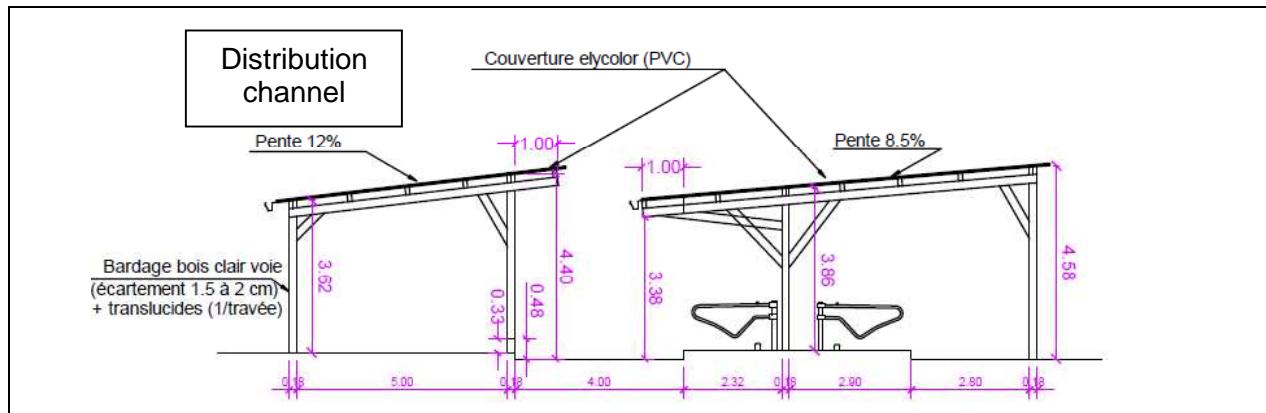
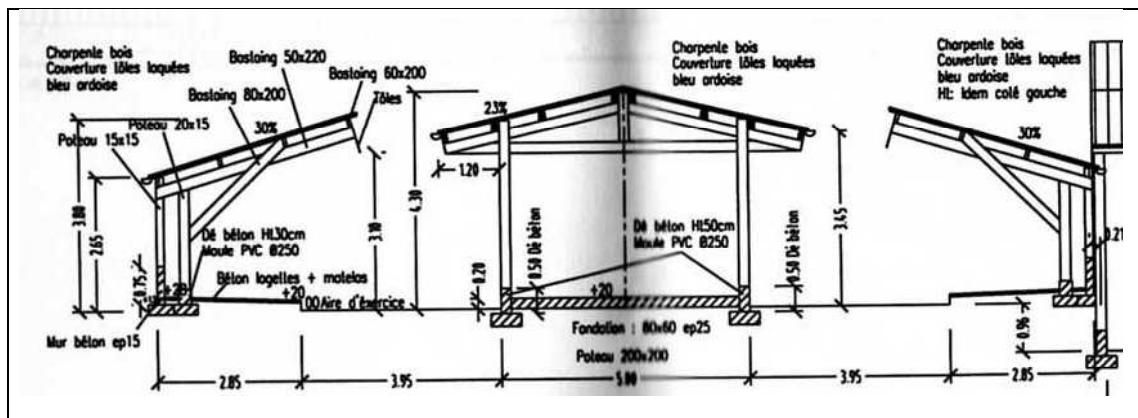


Figure 4: Sectional view of building at Farm 53-B (Fromageries BEL Evron)



9 ■ Building and labour cost in dairy production depending herd size, level of mechanization and building construction

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Summary: Better planning, appropriate mechanization and logistic is more important to profitabale dairy production than low investment costs.

Building and equipment investment cost

When calculate the cost in milk production the costs for building, equipment and labour are very important for the economic result. However the investments in the building and level of mechanisation and automatisation have a very strong influence on the labour costs i.e. to build cheap does not mean increased profit. In order to make fair calculations both building and labour cost must be looked at simultaneously.

In order to compare the building costs as a function of herd size, shelter type and level of mechanisation/automatisation, a commercial calculation programme for buildings was used and complemented with prices of equipments specific for dairy cow buildings. Herd sizes were 120, 250 and 400 cows. All measures for cubicles, gutters and feed space allotments was according to the Swedish Animal Protection Regulations, L 100. The milking equipments were automatic milking system (AMS), parallel parlour with 32 stalls (2x16) and rotary parlour with 24 stalls. Costs for two types of building constructions were calculated, insulated buildings and uninsulated buildings respectively. Furthermore different levels in mechanisation were considered. For the **insulated alternatives** insulated concrete elements were chosen as outer walls and the manure handling was assumed to be cable driven scrapers on open walkways. The feeding was assumed to be done by using an automatic feed wagon on rail. In the **uninsulated alternatives** not insulated concrete wall elements of 1 500 mm height and sidewall curtains up to 3 000 mm were chosen, manure handling was made with "Bobcat" and feed was distributed with a tractor driven mobile mixer wagon on a drive-through feeding table. All housing alternatives had feeding stations for concentrate.

The results of the calculations are shown in Table 1. The total investment cost and cost per square metre and cost per cow and year are presented for the different housing alternatives. The caption "Building area" represents the area available for the cows, i.e. walkways and stalls. Finally the building cost tribute to the production cost was calculated assuming building cost depreciation time for construction and , equipment etc was 20 years and interest rate 6 %, and that the annual milk yield is 9 500 kg/cow*year.

Structure effect is almost neglectable, 3-4% higher for an insulated structure than in an uninsulated for 400 and 120 herd respectively. This is much lower compared to what is normally argued in Sweden.

Herd size effect is very evident. A barn for 120 cows with AMS is 11% more expensive than a barn for a 240 cow herd.

Mechanisation/automatisation effect shows that an AMS-barn for a 240 cow herd is 29% more expensive compared to a barn with conventional parlour.

Cost per kg milk. Neglecting the minimal structural differences on costs the cost per kg milk was 0,065 and 0,054 € in an AMS-barn with 120 respectively 240 cows. In a 250 cow herd with parallel parlour and 400 herd rotary parlour the cost per kg milk was similar 0,039 and 0,037 € respectively.

Table 1. Investment cost, annual cost, and cost per kg milk for eight types of housing systems with different numbers of dairy cows, milking systems and building insulation levels

| Number of dairy cows, type of milking system, level of insulation | Total investment cost , € | Cost €/ m ² | Building area m ² /cow | Annual cost €/ cow | Cost €/kg ECM |
|---|---------------------------|------------------------|-----------------------------------|--------------------|---------------|
| 120 cows, AMS, insulated building | 880 450 | 650 | 8.6 m ² | 640 | 0.067 |
| 120 cows, AMS, uninsulated building | 835 810 | 580 | 8.6 m ² | 605 | 0.064 |
| 250 cows, AMS, insulated building | 1 489 330 | 550 | 9.0 m ² | 520 | 0.055 |
| 250 cows, AMS, uninsulated building | 1 439 550 | 485 | 9.0 m ² | 502 | 0.053 |
| 250 cows, parallel parlour, insulated building | 1 069 500 | 420 | 7.0 m ² | 375 | 0.039 |
| 250 cows, parallel parlour, uninsulated building | 1 031 680 | 395 | 7.0 m ² | 360 | 0.038 |
| 400 cows, rotary parlour, insulated building | 1 628 050 | 410 | 6.8 m ² | 355 | 0.037 |
| 400 cows, rotary parlour, uninsulated building | 1 570 340 | 380 | 6.8 m ² | 340 | 0.036 |

Time studies

In order to get figures of how herd size and level of mechanisation or automatisation are influencing working time LBT has carried out time studies of daily work in 20 different farms with herd sizes from 70 to 450 dairy cows. Hedlund (2008) studied 13 farms during winter season and Bennerstål (2009) 14 farms during grazing season of which 8 farms were the same as Hedlund studied. The Swedish Animal Protection Ordinance states that dairy cows must be outside on pasture between two milkings at least 4 months a year in Southern Sweden. The studied farms have both automatic and manual parlour milking. In 7 of 8 farms labour time for the dairy cows increased slightly during the grazing season and was the same for the young stock and calves.

Gustafsson (2009) at JTI (Swedish Institute of Agricultural and Environmental Engineering) performed time studies at 16 farms with manual parlour milking system and 14 farms with AMS. The Swedish Dairy Association, SDA, has a project where the dairy farmers themselves estimate their time consumption for the different working moment. LBT and JTI used the same working moments during their time studies. Hence it is fair to compare the results from these three studies, shown in table 2.

Table 2. Working time for milking + cleaning milking equipment according to different sources. Hours per cow and year.

| | LBT | | | | Swedish Association | | Dairy | JTI |
|--------------|-----------------|-------------|------------|------------|------------------------|-------------|------------|------------|
| | Parlour milking | | AMS | | Parlour milking | AMS | Parlour | AMS |
| Milkings/d | Inside | Pasture | Inside | Pasture | | | | |
| Farms | 2 | 2 | | | 2 | 3 | 2 | |
| | 8 | | 4 | 6 | 23 | 8 | 16 | 13 |
| Milking | 14.4 | 16.4 | 2.7 | 2.7 | 14.7 | 18.0 | 3.3 | 6.9 |
| Cleaning | 2.7 | 1.6 | 1.3 | 0.5 | 2.5 | 2.5 | 2.5 | 1,3 |
| Total | 17.1 | 18.0 | 4.0 | 3.3 | 17.2 | 20.5 | 5.8 | 8.2 |

The AMS-farms have in all studies the lowest working hours; LBT has the lowest figure and JTI considerable higher. For farms with manual milking in parlour or carousel there is a very good agreement between the studies.

Model farms

To get a good overview according to time consumption in different types of milking systems with a variation in feeding system and organization for pasture, 6 fictional model farms have been compiled and described in Table 3. The working time for the different models is illustrating the influence of barn planning, logistics and level of mechanisation or automatisation. Working time for different working moments in combination with equipment and methodology have been derived from LBT-studies and presented in table 4.

Table 3. Description of 6 different model farms for dairy production according to size, level of mechanisation and logistics

| Farm | A1 | A2 | B | C | D | E |
|----------------------------------|--|--|--|--|---|--|
| Number of cows | 120 | 120 | 240 | 250 | 250 | 400 |
| Milking system | 2xAMS | 2xAMS | 4xAMS | Herringbone 2x9 | Parallel 2x10 | Rotary 40 |
| Pasture organisation | Minor grazing area, close to barn, outside day time, 4 months on pasture | 6 hectares, close to barn, outside day and night time, 4 months on pasture | 6 hectares, close to barn, outside day time, 5 months on pasture | 2*5 hectares grazing areas, one opposite side of road, outside during day, 4 months on pasture | Minor grazing area, close to barn, outside day time, 4 months on pasture | Minor grazing area, close to barn, outside day time, 4 months on pasture |
| Feeding and mixing of feedstuffs | Automatic stationary mixer, automatic feeding wagon, short distance feed storage to mixer, scraper under feeding wagon | Stationary mixer, truck operated feeding wagon, long distance feed storage – mixer, scraping feeding table 5 times/d | Automatic feeding wagon, stationary mixer, short distance from feed storage to mixer | Mobile mixer, tractor driven feeding table, long distances when mixing feed, many feedstuffs | Total automatic feeding system | Mobile, tractor driven mixer drive through feeding table, few feedstuffs |
| Littering/ cleaning cubicles | Manual littering every other day with wheelbarrow w and shovel, cleaning cubicles 2 times/d | Manual littering every other day with wheelbarrow and shovel, cleaning cubicles 2-3 times/d | Mini loader 1-2 times/w, cleaning cubicles 2-3 times/d | Manual littering every other day with wheelbarrow and shovel, cleaning cubicles 4 times/d | Mini loader equipped with a auger that dispenses the sawdust once/week, cleaning cubicles 2-3 times/d | Mini loader 2 times/week, cleaning cubicles 2-3 times/d |

The highest working time is generally under the category milking, but the working time is very much influenced by how the work is organized and how the farms resources are used. In a 120 cow herd with AMS and high mechanisation (A1) the working time for the dairy cows is 2.1 min/cow *day but with herringbone parlour and bad logistics takes 6.28 min/cow*day. This means a difference in daily working time of 8 hours. In a 450 head herd with carousel 3.9 min/cow*day is needed.

Table 4. Working time to manage the dairy cows on model farms. Notice footnotes.

| Model Farm | A1 | A2 | B | C | D | E |
|--------------------|------------------|-------|-------|------------------------|----------------------|----------------------|
| Number of cows | 120 | 120 | 240 | 120 | 250 | 400 |
| Milking system | 2xAMS | 2xAMS | 4xAMS | Herringbone 2x9 | Parallel 2x10 | Rotary 40 |
| Milking | 0.5 ^a | 0.7 | 0.5 | 4.0 ^{b, c, d} | 2.3 ^{b,c,d} | 2.2 ^{b,c,d} |
| Pasture | 0.1 | 0.4 | 0.2 | 0.6 | 0.2 | 0.3 |
| Feeding | 0.3 | 0.7 | 0.4 | 0.5 | 0.1 | 0.4 |
| Littering/Cleaning | 0.2 | 0.8 | 0.5 | 0.5 | 0.2 | 0.2 |
| Other | 1 | 1 | 1 | 1 | 1 | 1 |
| Total, min/cow*day | 2.1 | 3.6 | 2.6 | 6.6 | 3.7 | 4.1 |
| Hours/cow and year | 12.8 | 22 | 16 | 40 | 23 | 25 |

^a Difference A1 and A2: A1 has few “fetched” cows and they fetch them 2-3 times/day.
A2 has a lot of “fetched” cows and fetching them 4-5 times/day.

^b no collecting pen + 0.5 min/cow*day

^c Milking 3 times/day + 0.5 min/ cow*day

^d No rational cleaning of collecting pen + 0.15 min/ cow*day

Economic consequences

Considering the differences in working time demand due to differences in planning of lay out and equipment you easily can make economic calculations of best profitability. Social fees 18 €/h, life time 20 year and interest rate 5% you will get 12.5 as an investment factor for break even. As exemple to invest in a collecting pen (1.5 m²/cow ; cost 500€/m²) for 80 cows in a 240 cow herd will save 13000€/yr in labour cost with invested 4800 €. According to Johansson (2008) additional cost to build a barn for AMS instead of traditional parlour is 1700€, this means that you must save at least 8 hrs per cow and year to get break even.

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10 ■ Farm buildings and working conditions on goat farms: the current situation in Trás-os-Montes (Portugal) and future developments

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In the region of Trás-os-Montes (Portugal) goat breeding is a fairly significant activity, not only in terms of meat and milk production, but also because breeders operate within an underdeveloped region where agriculture is the main activity and alternative economic activities are extremely scarce. Goats are raised in extensive systems; flocks are small and sourced mainly from local breeds. Generally, buildings and facilities are simple, supplying shelter and meeting the basic needs of the animals.

Breeders' association and producers are keen to develop goat raising and improve goat products. We worked with these stakeholders to carry out studies to characterize farm buildings used in goat farms; to identify the constraints and deficiencies of these buildings; to study the work and tasks performed by the breeders inside these buildings; and to improve milking and working conditions on goat farms.

Many buildings have limiting features and lack adequate facilities or equipment. In future, it is advisable to provide technical support to breeders in order to improve buildings and goat housing conditions.

Introduction

Situated in the northeast of Portugal, and bordered to the north and east by Spain, the region of Trás-os-Montes is a mountainous region, composed of several plateaus above 700 m and several mountains with peaks between 1000 m and 1500 m. It is one of the most disadvantaged Portuguese regions and has been subject to a rural exodus to urban centers in recent decades.

In Trás-os-Montes, small ruminants (goat and sheep breeding) have long played a major socio-economic role. This fact is particularly due to the scarcity of alternative economic activities, both at a local and a regional level. Over the last few decades, small ruminants have continued to be the main source of income for many families in the region, and have increased in importance due to the decline of other agricultural activities (cereal crops and cattle, for instance) and the scarcity of alternative economic activities.

Flocks are small and the main breeds that make up the flocks of Trás-os-Montes are local ones. Animals are raised in extensive systems, using traditional farming techniques. Most sheep farms have between 100 and 200 animals and goat farms between 80 and 120 animals. These small flocks provide the main source of economic support for many families in this region, where rural areas have gone through dramatic depopulation and exodus. The income provided by the flock is important in preventing these families from leaving rural areas.

Sheep are used mainly for slaughter production (lamb) whereas goats are raised both for meat and milk production. The kids are exclusively fed on maternal milk and they are slaughtered when they are between four and eight weeks old. Milk production, for cheese-making, is more profitable and has better prospects in terms of production.

Dairy goats in Trás-os-Montes are mainly from a local Portuguese breed, the Serrana. Closely linked to the Serrana breed, there are two PDOs (Protected Designation of Origin): the Transmontano goat cheese PDO; and the Transmontano kid (young goat) PDO. The cheese produced is easily sold due to demand, so an increase in production is likely to occur. The breeders' and producers' associations (mainly ANCRAS, the national Serrana breeders association) intend to improve milk production and milk quality for cheese.

In order to identify the current conditions of buildings and other facilities used in goat farms in this region, we have carried out works designed to: identify the constraints and deficiencies of farm goat buildings, in the region of Trás-os-Montes; study the building plans and internal layout of goat housing; and identify the work and tasks performed by breeders inside buildings.

This paper intends to make a brief presentation and summary of some work carried out in recent years, together with the breeders' associations, bearing in mind the specific conditions of these breeders; it aims to improve and to develop goat raising in this region.

Goat raising in Trás-os-Montes

Like other livestock raised in extensive systems, the basic needs of goat housing are simple and the organization and management of a goat house is mainly determined by the breeding system and the type of production and feeding system (Slade and Stubbings, 1994). Buildings for goat housing have a number of requisites, in order to meet the conditions of animal well-being; they must allow an advanced level of mechanization; have a positive effect on the organization of work performed; make management and equipment costs compatible with livestock-breeding investments; and make the building compatible with the environment and the surrounding area (Mennella, 1999). Moreover, buildings and equipment have a major impact on production quality, and mainly on milk production. The building must provide the breeder with good working conditions and ensure that all of the animals' needs are properly met (Martyn and Astley-Cooper, 1992).

In order to develop goat raising in the region of Trás-os-Montes, it is necessary to improve working and production conditions on farms. For that purpose, it is necessary to introduce changes to the housing and equipment presently used by breeders, since buildings and equipment play an important role in the improvement of working and production conditions and the quality of products (Barbosa et al, 2005). In addition, the development of goat raising may potentially help prevent the population from leaving rural areas; increase the income of rural populations; and improve the production of quality regional products (cheese and goat kids).

It is necessary to propose models and solutions that fit the local goat farming system, so as to encourage breeders to adopt more up-to-date techniques. However, it will be difficult to make breeders change their production system or introduce improvements in buildings for goat housing, unless the solutions can be afforded by the region's breeders (Barbosa et al, 2006).

Farm buildings on goat farms in Trás-os-Montes

As stated before, goats are raised in extensive systems and breeders scarcely make use of buildings to handle flocks. In the future, due to the growth in cheese and milk demand, it is expected that breeders will increase the use of goat housing and facilities. It is therefore important to identify the current conditions of buildings used for goat farms in the region and if these buildings have all the requisites to handle these animals. In addition, more than other farms, those dedicated to milk production need facilities or equipment to handle lactating goats and for milking.

The study of goat housing and the identification of the deficiencies of farm buildings is a good way to understand current conditions and, as a result, to carry out important works to improve goat housing conditions and equipment use. It will also contribute to finding building designs and equipment appropriate to goat farms in the region of Trás-os-Montes.

We selected 74 goat farms from across the region, to study breeding systems and to collect data about buildings, facilities and equipment. Breeders were asked about the work they carry out inside buildings and the procedures, techniques and equipment they use to perform their work (Fitas da Cruz and Barbosa, 2007).

In considering the information collected, eleven variables relating to the layout plan, function and materials were selected to characterize farm goat buildings in this region. Since these variables have different scales of measurement, all were established as categorical variables. The data collected allows us to analyze the buildings from several points of view. This presentation will focus on functionality and working conditions.

In our analysis of functionality, we chose four variables: building plan; internal layout; width of the entrance; and the height of the walls. We also took into account a fifth variable - the age of the building - in order to identify changes or improvements to building construction over time. Table 1 shows the frequencies of the categories for each of these variables, considering the 74 goat buildings studied. Concerning the building plan, the majority are enclosed buildings. A large number have a park outside, attached to the housing, which makes it easier to manage the flock.

Concerning the internal layout, there are many buildings with a single space inside, without any division, pen or fencing. The whole flock (animals with different ages, growth, sex and production) stays in the same area. This type of arrangement does not allow suitable supervision, organization or efficiency to perform work. When the inside space is divided into different pens and animals with different requirements are kept apart, or different areas are set apart and assigned to specific work (like feeding, milking, etc.), it may be assumed that these buildings offer better conditions to work and manage the flock.

Doors (or other types of entrances) and wall dimensions can pose some constraints. There are many buildings that have an entrance under 2 m wide. This dimension is insufficient for the transit of equipment or farm machinery (mainly for tractors and trailers) that could be useful to accomplish work inside. The size of the walls can be an obstacle to mechanization because low walls (under 2 m) represent an obstacle to the circulation of farm machinery. Moreover, low walls reduce the capacity for storage of hay, straw or other supplies.

Table 1 – Frequency tables of the categorical variables analyzed

| Variables | Categories | Frequencies | % |
|-----------------------|-----------------------------|-------------|----|
| Building plan | enclosed building | 41 | 55 |
| | open-fronted building | 2 | 3 |
| | enclosed building with park | 31 | 42 |
| Internal layout | single space | 28 | 38 |
| | pen layout | 46 | 62 |
| Width of the entrance | width under 2 m | 31 | 42 |
| | width over 2 m | 43 | 58 |
| Height of the walls | height under 2 m | 5 | 7 |
| | height between 2 m and 3 m | 46 | 62 |
| | height above 3 m | 23 | 31 |
| Age | built before 1950 | 18 | 24 |
| | built between 1950 and 1975 | 5 | 7 |
| | built after 1975 | 51 | 69 |

Some buildings used on goat farms were built over fifty years ago. These buildings are very old and generally not suitable for modern breeding techniques and present constraints mainly related to dimensions and materials.

Working conditions in goat farm buildings

When asked their personal opinion, goat breeders from the region consider milking and manure management as the most arduous work, mainly because it is performed manually and involves prolonged periods of physical effort.

At the time the study began, only two members of the ANCRAS association had a milking machine. For almost everyone, milking is an arduous task because it is manual and, while milking, the milker remains in an awkward posture that makes milking stressful and potentially debilitating. Goats are hand-milked in buildings or shelters where they are housed during the night and, usually, there are no places specifically designated for milking, which is done in the straw-bedding area. In these places, the cleaning and hygiene conditions are poor and they affect the quality of the milk and, consequently, of the cheese. To deal with the animals, the breeder uses fences to contain lactating goats, but he has to catch the animals by hand.

Manure management requires manual work on the majority of goat farms (Table 2). On a large number of goat farms, manure handling is entirely manual, where manure is gathered and carried outdoors manually. In other buildings, manure is loaded onto a trailer on which it is transported outdoors. A small number have a mechanical system to handle manure, generally a tractor equipped with a loader on the front. Only a few of the buildings have slatted floors for manure management.

Table 2 – Floor type and manure handling system used on goat farms

| Floor | Manure handling system | No. goat farms | % |
|---------------|----------------------------|----------------|----|
| Straw bedding | removal entirely by hand | 21 | 28 |
| | hand loaded onto a trailer | 31 | 42 |
| | front-loader | 19 | 26 |
| Slatted floor | | 3 | 4 |

The system and facilities used for manure management have improved over time. Table 3 shows the different manure management techniques on goat farms, according to the age of the building.

Table 3 – Manure handling system used in goat farms according to the age of the building

| Floor | Manure handling system | built before 1950 | built between 1950 and 1975 | built after 1975 |
|---------------|----------------------------|-------------------|-----------------------------|------------------|
| Straw bedding | removal entirely by hand | 16 | 3 | 2 |
| | hand loaded onto a trailer | 2 | 2 | 27 |
| | front-loader | 0 | 0 | 19 |
| Slatted floor | | 0 | 0 | 3 |

We found floors with slats only in goat housing built over the last few decades. Also, the only breeders using mechanical systems to handle manure have built goat housing recently. Removal entirely by hand is more frequent in old buildings, perhaps due to trailer access constraints and difficulties, or other equipment, inside the building.

Feeding is performed manually on all goat farms, but it is not hard work. In Trás-os-Montes, goats are raised according to traditional extensive farming systems and rangeland is the fundamental feeding source for goat flocks. A large number of goat buildings have hay feeders inside, generally along the walls, where fodder is supplied manually.

Final considerations and future developments

According to the data collected (and the summary presented here) it is possible to conclude that:

- many goat farm buildings have constraints and deficiencies in building features, mainly related to the dimension of doors and walls, which make the use of machines/equipment difficult or almost impossible;

- use of equipment or machines is scarce and a large number of goat farm buildings lack adequate facilities or equipment to perform work;
- in many buildings, the internal layout is not adequate to perform tasks in good conditions.

To develop goat raising in the region, it is necessary to improve building features, mainly those related to working conditions for milking and manure handling.

Our knowledge of the current conditions of buildings used in the region allows us to propose strategies to improve goat farm buildings, in order to improve working conditions and breeding practices with regard to the breeders' socio-economic conditions.

In terms of future goat housing, it is advisable to draw some templates of the internal layout, which would be made available to breeders. It is also important to provide technical support and information about the construction and equipment, mainly related to milking, feeding and manure removal.

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11 ■ Improving working conditions in the animal husbandry sector – Research example and extension services in France

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The evolution of the age pyramid in agriculture, productivity increases and successive CAP reforms have led to substantial restructuring in all segments. Work issues require a global multidisciplinary approach involving the technical and social sciences, as well as investments ranging from the accumulation of knowledge along with the development of references and consulting tools to concrete solutions. By placing the activities of people at the centre of this approach, research and development on work issues related to livestock operations address the third pillar of sustainability, which concerns the social and human dimensions that are essential for liveability, transmissibility and therefore employment in agricultural enterprises.

Challenges

Meeting the challenge of improving working conditions in animal husbandry is important in order to:

- facilitate productivity gains, which are still necessary in view of the increasing size of processing plants and farms,
- meet requirements aimed at improving the safety of production processes,
- respond to breeders' aspirations for a better quality of life.

Framework of the multi-partner project

Two main lines of research were dealt with in the framework of a research programme funded by the CasDar (Ministry of Agriculture) involving 25 research, education and agricultural development partners.

Mutualisation, capitalisation and transfer. This action resulted in the identification of approximately sixty experiments on work issues, the implementation of a thematic work section on the Institut de l'Elevage website, the preparation of bibliographical summaries and the organisation of technical seminars.

Work issues in the consulting and training processes: Five pilot operations were set up to incorporate work issues into technical and higher education programmes, as well as into the consulting process (for sheep farms, dairy cattle operations, building design and during whole-farm planning). Each of these approaches, co-constructed with future users, was adapted to their practices and available time, which are different for each activity.

Consideration of work issues in buildings

Objective

Key production processes such as parturition, milking and the fattening of young animals often take place in livestock buildings. A building investment is a long-term commitment and any design error remains a burden for many years. Furthermore, a review of Work Assessments conducted in livestock operations has shown that work issues in buildings not only concern the quantity and difficulty of the work performed, but also the mental stress generated by that work.

The objective is to improve the awareness of work issues by building consultants, animal husbandry consultants and regional consultants by offering them an operational methodology tool for existing buildings that can also be used during the building design process.

This operation was conducted in consultation with the project “Démarche Conseil Bâtiments d'Elevage (DCBé)” (Consulting Process for Livestock Buildings), which aims to formulate a standard method including tools that can be used during the consulting process for livestock buildings. It constitutes the project's work section.

Method

The first step consisted in setting up a technical national committee coordinated by the Institut de l'Elevage including building consultants and livestock technicians (for the sheep, beef and dairy cattle sectors).

During a second stage, a bibliography and a compendium of experience were used to draw up a summary memorandum of the methods used to deal with work issues in buildings.

Those parties involved in the agricultural building sector were then interviewed with the objective of contributing to a fuller understanding of these issues. Out of the 52 interviews conducted, four concerned livestock farmers, 24 concerned occasional users (inseminators, veterinarians, growth controllers etc.), and 24 concerned persons involved in the building consulting segment (livestock consultants, building consultants, ergonomists etc.). Thanks to their experience, it was possible to devise the most appropriate methodology and summarize the consulting approaches already put into practice.

Then, an interview guide was developed concerning work issues in buildings.

A three-step consulting process

The bibliographical summary shows that even though few formal methods exist for the diagnostic or consulting process, a number of pilot projects are being developed at local level and need to be described.

The interview guide constitutes a useful tool for building, livestock and regional consultants that can be used for both existing buildings and construction or expansion projects.

The tool is meant to be used in conjunction with a three-step consulting process:

Information collection: the goal is to review existing work issues, as well as points that need improvement in construction or remodelling projects. Project objectives are then prioritized at the end of the interview.

About half a day should be set aside for this step.

Data summary: a summary of the factors to be taken into account in the project is completed at the office, along with one (or two) outlines of a plan.

Reporting back: the technician verifies that the breeder's wishes are accurately reflected in the project outline and summary document, and that the outline responds to the issues raised during the information collection interview. The technician then completes the summary document and the breeder accepts the project on the basis of the outlines.

This step also requires a half-day with the breeder.

Le travail dans les bâtiments d'élevage COLLECTE DE L'INFORMATION

Groupe Travail & bâtiment CASMAR - 2005

Coordonnées de l'exploitant : Nom de la personne qui réalise l'entretien : Date :

Rappel du projet bâtiment – explicitation de l'enquête (voir fiche révisee) :

Qu'est-ce que vous attendez de ce bâtiment sur le plan du travail ? (gagner du temps, améliorer le confort, améliorer la sécurité du travail, améliorer la productivité du travail, diminuer la pénibilité, améliorer la capacité à être remplacé facilement...) :

Déroulé d'une journée type (matin + après-midi)

Faire préciser à l'éleveur la façon dont il va dérouler sa journée de travail dans les bâtiments soit :
• en indiquant les tâches principales et leur ordre de réalisation, ou
• en incluant le projet bâtiment pour refléter à la future organisation.

Déterminer avec l'éleveur la période à étudier (période utilisatrice de bâtiments, avec beaucoup d'animaux, des tâches particulières comme l'agriculture...):

Quantification de la journée type (voir guide de l'utilisateur).

Le travail dans les bâtiments d'élevage SYNTHESE

Groupe Travail & bâtiment CASMAR - 2005

Coordonnées de l'exploitant : Nom de la personne qui réalise l'entretien : Date :

Les objectifs du projets hiérarchisés

Adequation du projet avec les objectifs annoncés (adéquation totale ou partielle, points demeurés en suspens, difficultés rencontrées...)

Commentaires :

Pouvez-vous décrire le mode d'emploi de votre nouveau bâtiment ?

Three means of leverage

Work in buildings is organised around three means of leverage:

- streamlining of the layout of buildings and livestock equipment, as well as
- simplification of practices,
- reorganisation of the workforce on the basis of the objectives and workers' skills and versatility.

Practical experience with this tool shows that this approach encourages the breeder to reflect on the various tasks that need to be accomplished, including their implementation and organisation, as well as those who will perform them.

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Consult the thematic pages on the Institut de l'Elevage website:

Building and construction:

http://www.inst-elevage.asso.fr/html1/spip.php?page=un_espace&id_espace=927

Work issues in animal husbandry sector:

http://www.inst-elevage.asso.fr/html1/spip.php?page=un_espace&id_espace=958

12 ■ Work time and working environment in the fattening of young cattle in Sweden

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Background

In Sweden there are approximately 400.000 dairy cows and 200.000 beef cows. The beef production in Sweden is highly connected to the dairy production, and approximately 70% of the cattle slaughtered for red meat originate from dairy breeds (Strand & Salevid, 2007).

Red veal production

Swedish veal production is entirely of the red veal type, with an annual production of ~5000 tons (approx. 30.000 calves), constituting 0.6% of EU27 total production of ~800 000 tons in 2008 (carcass weight equivalents) (Eurostat, 2009). Red veal represents slightly less than 10% of Swedish beef cattle production (SJV, 2009). The production of red veal is characterized by a relatively intensive fattening of calves of dairy breed (*ad libitum* access to concentrates and hay or grass silage) to the age of 8 months and a carcass weight of 160 kg. The short rearing period and the young age of the calves require high demands on work organization and working routines with several systematic work tasks performed daily, weekly or monthly. At 1-10 weeks of age the calves are transported from the dairy farm to the specialist farm, often from several different herds. If more than 50 calves <4 months of age are bought from more than one farm, the calves must by law be kept separate from older calves for a minimum five-week quarantine period. In the quarantine building, calves are mainly grouped on straw litter, but single pens or outside group/single hutches are also used, depending on the age of the calf. The majority of quarantine houses are run according to an 'all in-all out' strategy for a maximum period of three weeks before the batch is closed off for a five additional weeks.

Young bull production

Production of young bulls make 45% of the total beef production with ~57.000 tons carcass weight (approx. 175.000 animals) (SJV, 2009). The production of young bulls is based on dairy and suckler calves reared to an average age of 15-17 months and carcass weight 310 and 350 kg, for dairy and beef breeds, respectively. The first months of rearing dairy calves for young bull production has management practices similar to red veal production. Rearing young bulls from beef breeds might be without the use of a quarantine area.

Introduction

Input costs in agriculture are increasing world-wide and labour costs are no exception. Additionally, the shortage of labour from outside the family is a large concern, intensifying the need of a work-efficient and attractive production. Despite of an increasing demand for feed, the self sufficiency of beef in Sweden is continuously decreasing. Agriculture is together with forestry the occupation with the highest risk of injuries and accidents, most commonly caused by handling of animals (70% of all accidents) or by machines and during construction work (Pinzke

& Lundqvist, 2007; SWEA, 2009). Work-related troubles other than injuries commonly seen in agriculture can even be respiratory diseases, disorders due to chemical handling, musculoskeletal disorders (MSD) due to awkward working postures, heavy loads and repeated strain during manual work (Walker-Bone & Palmer, 2002; Pinzke, 2003). The present study investigated the latter in relation to labour use in the fattening of young cattle. **Aim**

The aim of the present study was to investigate the current use of labour and the working environment in terms of hazard risks, the exposure of physical strain and prevalence of MSD in the production of red veal (RV) and young bulls (YB). Long term aims were to improve labour efficiency and working environment. A questionnaire was used to cover the production on a broad scale and field studies were used to investigate larger and more specialised farms.

Methods

Work time and work environmental factors during predefined work tasks were investigated through semi-structured questionnaires and field studies. Field studies were performed on 10 farms from each production line. Of red veal farms, 31 (67%) participated in the study and in the ongoing study of young bull farms producing ≥ 100 cattle per year, 96 farms (48%) have so far been involved. Predefined work tasks focus on the handling of animals, feed, litter and manure including cleaning procedures in quarantine (QS) - and fattening houses (FS), as well as labour use for administrative work. Farm facilities were recorded as well as strategies, performance frequency and techniques related to the different work tasks.

Work time

The labour use for every work task was given in time units per day and batch in quarantine and fattening houses, respectively, and total time for the whole rearing period until slaughter.

Labour efficiency was calculated as sec/calf/day or min/calf/batch. Calculation was based on the number of calves and total days in the quarantine area ($batch_{QS}$) or fattening unit ($batch_{FS}$), and the total number of days in the entire production period ($batch_{tot}$). Group size within the batch was not considered in the calculation of labour use.

Working environment

Perceived physical exertion in relation to each work tasks was assessed by the farmers using the Borg's CR-10 Scale (Borg, 1990) ranging from 0 (none at all) to 10 (extremely strong). From the general standardized Nordic questionnaire (Kourinka et al. 1987), perceived symptoms of musculoskeletal disorders (MSD) in different body parts were assessed. MSD was referred to as "pains, aches or discomfort" in the body parts.

The relationship between duration and repetitiveness of different work tasks influences the impact of physical exertion level (Borg's scale) and the risk of developing MSD. This impact can be determined by use of a Physical Work Strain index (PWS), according to the equation (Kolstrup et al. 2006):

$$PWS_i = t_{ixp_i}/t_i$$

Where t is the number of work hours per week working with a specific work task, i and p is the level of physical exertion (Borg's CR-10 scale) related to the work task.

Incidents of accidents was addressed through closed questions regarding where the accident took place, under which circumstances and how serious the accident was in terms of medical examinations and days absent from work.

The farmers' perceptions on a 1-4 scale (1=bad, 4=very good) of eight different physical and psychosocial work factors (Lundqvist, 1988) such as work climate, social network, teamwork and stress related to the production line was addressed through closed questions in the survey. A finalizing set of questions inquired whether the respondent was planning to make investments or improvements in his beef cattle enterprise to: a) reduce the work hours; b) improve the physical work environment; c) Improve the psychosocial working environment or; d) Reduce work-related hazard risks.

Results and discussion

Preliminary results show that the average labour use per calf and batch during the pre-defined work tasks was 6.4 hours on young bull farms (100-500 bulls/year) and 7.0 and 2.1 hours for medium (100-500 calves/year) and large sized (500-1150 calves/year) red veal farms, respectively. Overall, labour use was highly diverse between farms. Housing systems, level of mechanisation, ages and group sizes of calves during the production period differed not only between farms, but even within farms. Labour use per calf in the red veal production was not significantly more efficient when farm size increased from 500 to 1150 calves per year, indicating that the trend towards high mechanisation and effectiveness has not been as noticeable in beef cattle production as in the dairy, pig and poultry industry. This might illustrate the limit of the farming facilities used at present, with a minimum amount of time per calf that can be put into production. Utilization of former buildings was typically leaving manual feeding and strewing techniques as the only option.

Feeding comprised averagely 57% and 65% of the total work time in red veal and young bull fattening, respectively. Example of the distribution of work time on 11 large red veal farms rearing weaned calves is shown in.

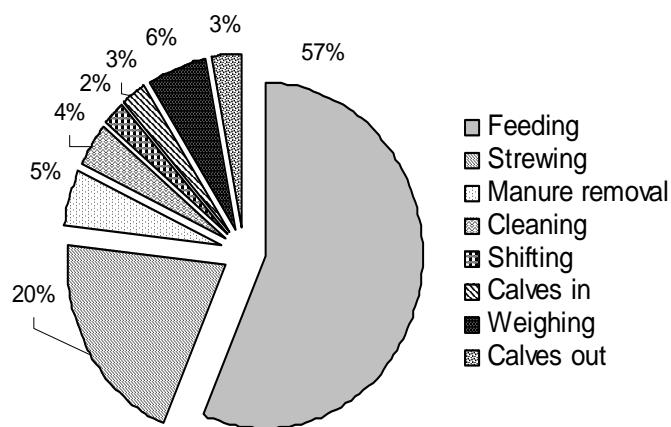


Figure 1: Distribution of average labour use for work tasks on 11 farms producing 500-1150 calves/year from 8 weeks of age (weaned calves). n=11.

Physical exertion and PWS

Cleaning was estimated as the most physically demanding work task, average scores ranging from 3.6 to 4.1 on Borg's scale (4 = strong strain). Overall, the perceived physical strain and PWS-index was negatively correlated with cattle operation size, however not significant. Further, work in quarantine houses was more strenuous than in the fattening houses, presumably due to a higher level of manual work in the quarantine building. Feeding tasks were the most frequent and time consuming (6.5 to 7.6 h/week) and were also the tasks with highest PWS (up to 1.3). The feeding frequency and time spent on this work task could be dramatically lowered by the use of automatic feeders, but up to 80% of the farmers in the study opted to have daily feeding routines, either once or twice daily.

Perceived musculoskeletal problems

Perceived MSD in any part of the body during the past 12 months period was reported by 52% and 65% of red veal and young bull producers, respectively. The prevalence of MSD was highest in the upper extremities, followed by the back, particularly the lower back. Effect of sex on the prevalence of MSD was not found, presumably due to the low representation of females in the study (12% and 7% of RV and YB respondents, respectively). The prevalence of pain, ache and discomfort in different body parts was by more than 50% of the respondents assumed to be related to the work in the beef cattle production.

Work related injuries

Work related injuries or accidents were reported by 28% of the respondents from RV farms, and 39% of the respondents on YB farms. Accidents were 89% of the cases of young bull farming related to the handling of animals, i.e. during strewing, weighing and shifting of animals between boxes or from box to transport vehicle. Although recommended, around 50% of the young cattle farmers in this study chose not to weigh the animals during the fattening period, which might reduce the possibility to optimize the production

Conclusion

Labour use and strategies for work on beef cattle farms is highly variable and is not simply dependent on farm size. The level of mechanisation, frequency and technique implemented for each work task play a major role for efficient labour use and a healthy working environment, particularly in quarantine houses where number of animals are low and batch period is short. Awareness of these factors is crucial during planning and designing for rebuilding or construction of new houses for young cattle production.

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13 ■ Design of walkway floors for dairy heifers and cows in loose housing systems

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Walkway floors have a significant effect on cattle locomotion and claw health, as well as on animal behaviour and general cattle house hygiene; and affected both animals' welfare and dairy farmers' profit. There are several qualities floors should fulfil, which contemporary walkway floors do not completely do. From an animal point of view, the most favourable of present passageway floorings in dairy cow cubicle housing systems seems frequently scraped solid rubber flooring to be, but should be improved further. Among other floor evaluation key factors, interaction between flooring systems of replacement heifers and lactating cows is to be considered.

Introduction

Floors in animal houses are the building elements animals will come into closest physical contact when they are walking, standing and lying. When they are standing and walking, floors in passageways in cubicle houses and straw bedding in straw yards interact with the animals' feet; and will affect the claw health of cows and young stock. Claw lesions of dairy cows lead to enhanced cost as well as lessen income for dairy farmers. Treatment of the lesions itself is costly; additionally, there arise mostly indirect costs mainly because of yield reduction, increased work load, illness complication, diminished fertility, increased replacement rate, lameness and altered behaviour. In addition, the lesions are most often painful indeed; and foot health is just as much an animal welfare issue as question of business economics. Laminitis is the cause of the most common, most severe and most costly claw diseases, which have both metabolic and traumatic components. Traumatic challenges can be moderated; and one risk of trauma of the sole corium is exposure of inadequate floor design.

Additionally, unsatisfactory hygiene owing to dirty and wet floors can contribute in infectious or hygiene related claw lesions such as dermatitis and heel horn erosion. Insufficient hygiene in walkways can as well contribute in mastitis and lack of milk quality. Consequently, the floor design is important and especially of the animal point of view, the floor should promote the possibility to keep the surface clean and dry, give an appropriate grip but do not be too abrasive, and be sufficiently soft. However, it is hard to find floors with optimum design satisfying all demands enough.

Other factors such as environmental policies must also be considered, e.g. the necessity to control ammonia emissions from livestock houses; but will not be paid any attention in this paper.

Hygiene and drainage capacity

Floor hygiene is often a scraper issue or/and slatted floor. It has been shown [7] scraping slatted floor ameliorates the floor hygiene; and in particular scraping passageways along cubicle rows reduces transfer of dung from passageway to cubicle. Also enough high cubicle rear end kerb has the same effect [3]. The result is enhanced cleanliness of cubicle base, udder and teat [7]. Slatted floor, in particular with wide gaps, great void ratio and uneven surface, is however not animal friendly because of unfavourable pressure on the sole [8] and risk of claw injuries. If

scraping of slatted floors is advocated, there should not be any want to preserve the current slatted floor design. There is consequently a need of floor development combining solid floors' animal friendly design and slatted floors' drainage capacity; a process that is started for instance in Denmark and Sweden.

Feed-stalls could be looked upon as a special design of feeding alleys in cubicle houses, but feed-stalls are possible as well in two area straw yards (straw-bedded pen with unbedded feed stands). Feed-stalls are just feed stands but including partitions between every animal feed place, and seen for instance in Germany, Denmark and Sweden. The original reason for developing feed-stalls was to get a hygienic surface to stand on meanwhile cows eating. It has been shown that feed-stalls reduce the stress and displacement at the feeding table [2], especially for the low ranked animals, and reduce the bad consequences of too abrasive passageway flooring [4].

Skid resistance and claw wearing

The difficulties to obtain and to preserve the right balance between skid resistance and abrasiveness of walkway floor surface is well known. Required coefficient of friction (i.e. providing against slipping) for moving cows is dependent on the cow behaviour; i.e. if the animal is walking straight ahead, turning, fleeing (accelerating) or stopping (decelerating), etc., as well as dependent on stance phase (i.e. from claws hits the footing to push-off). The maximum required coefficient of friction, mostly required at the hitting and push-off stance phase, ranges from 0.3 to 0.85 for various behaviours according to van der Tol et al.. [18]. For dry and clean solid (concrete) floors in walking areas (kinetic) coefficient of friction 0.35 – 0.45 is recommended [19]; if the solid floor has greater friction the surface will be too abrasive. Additionally, the real slip resistance will be dependent on several factors such as slurry coating [15] on the floor and wearing of the floor material caused over time by grinding and polishing action of mechanical cleaning equipment and animal movements.

Grooving does not improve slip resistance of the surface between grooves but can help the claw to get grip, in particular when a foot is sliding. Some studies have given results that grooves *per se* do not ameliorate locomotion of cows indicating cows do not have any trust in just grooved floors' gait security [12].

Softness/hardness

The cows' preference and comfort of rubber compared to concrete alley flooring is indisputable [13, 16]. Experience in practice [11] and early study by Jungbluth et al. [5] indicated improved locomotion, behaviour and claw health.

Own study

In our recently concluded study [1], about 150 heifers were followed from one year before expected calving throughout their first lactation. The study was carried out in a commercial dairy farm with 300 cows and own replacement heifers of Swedish Red and Swedish Holstein breed. The cows were housed in cubicles with soft mattresses, rubber equipped feed stalls and slatted passageways. After calving, the first calvers were blocked to breed and calving time, housed in cubicles and randomly allocated either to a section with pure concrete slats representing hard flooring or in a section equipped with slatted rubber mats representing soft flooring. All other management and feeding routines were identical.

Methods and materials

All claws were investigated and trimmed at calving and after four months of lactation. Locomotion and leg injuries were scored monthly during the housing periods. A logistic multivariable regression analysis (JMP 5, SAS Inst) was used for leg lesions and locomotion. In the statistical model used, correction was made for animal and managemental traits as well as for interactions in between them. The logistic regression coefficients were transferred to Odds Ratio (OR). Likelihood ratio test was done and the probability result is given (P_{LR}). Only the most frequent claw lesions were analysed and sole haemorrhage were analysed together with sole ulcer.

Results

The odds ratio for sole haemorrhages and sole ulcer, and for white line haemorrhages in first calvers on slatted concrete flooring compared to slatted rubber flooring was about 2 and 3 times higher, respectively. A tendency to more heel horn erosion was observed in animals with slatted rubber mats (Table 1). The odds ratio for lameness was even greater, 3.64 (Table 2). Surprisingly, also leg lesions (hock injures) differed between flooring systems, despite identical comfortable cubicles, probably because of more animal activity and less lying time with rubber flooring [10].

Table 1 – Effect on claw diseases in first calvers on slatted concrete floor compared to slatted rubber. Odds Ratio (OR) and results of likelihood ratio test (P_{LR}). N=118

| Claw disease | OR | P_{LR} |
|---|------|----------|
| Heel horn erosion | 0.49 | 0.08 |
| Dermatitis | 1.06 | 0.89 |
| Haemorrhages of sole including sole ulcer | 2.19 | 0.05 |
| Haemorrhages of white line | 2.82 | 0.01 |

Table 2 – Effect on leg injures and lameness in first calvers housed on slatted concrete flooring compared to slatted rubber. Odds Ratio (OR) and results of likelihood ratio test (P_{LR}). N=118

| Leg injures | OR | P_{LR} |
|--------------|------|----------|
| Hairlessness | 2.37 | 0.21 |
| Swellings | 2.45 | 0.15 |
| Sore | 2.57 | 0.02 |
| Lameness | 3.64 | 0.01 |

Discussion and conclusion

Leg and claw health, in particular concerning the more serious claw illness as laminitis related sole ulcer, haemorrhages of sole and white line, was mainly better among first calvers on soft floor. Soft passageways in cubicle housing systems reduce significantly painful claw diseases; consequently, soft passageways for dairy cows are recommended indeed.

Soft floor, skid resistance and abrasiveness

Beside improved claw health, soft floor gives increased skid resistance [9], and as mentioned above, improved animal locomotion [15]. Current rubber mats have however too less abrasiveness resulting in claw overgrowth and need for more frequent trimming [17]. On the other hand, rubber mats in walkways give more natural shaped claws and possibilities to correct defective claw conformation [17]. New rubber mats launched on the market are told to increase claw wearing. An alternative is to use different flooring with different abrasiveness in different areas of the cow house, e.g. rubber mats in the feeding alley and concrete in the passageway between cubicle rows.

Interactions between flooring systems of replacement heifers and lactating cows

In our own study mentioned above, soft flooring for heifers gave the same effect on leg and claw health compared to hard flooring as for first calvers. However, soft flooring meant in this case two area straw yards (deep straw-bedded pack and unbedded feeding alley/feeding stand). Notwithstanding, in cubicle systems for heifers rubber covered concrete walkways might be recommendable; even if investment in rubber mats for heifers probably is not profitable, or has less cost-benefit outcome in short run than for cows.

There is an additional aspect. Within advisory service, at any rate in Sweden, one means that heifers should be kept in same housing systems as they will be kept as adults, as lactating cows. The arguments are mainly animals' need of learning the system used for the cows, as well as adaptation of legs and feet; i.e. to inure heifers' extremities to most often hard walkway floors in the cows' housing system. One might however raise additional questions; when, how and how long should or needs the adaptation be done? Accordingly, the training might not be only to the system *per se*, but also, or especially, to the footing used such as hard or soft flooring.

Our study mentioned above resulted in differences in prevalence and severity of claw diseases among the first calvers due to differences in flooring system during the heifer period. Especially the more serious diseases such as sole and white line haemorrhages were more often observed, but the differences were not significant. First calvers coming from soft floor had more severe and a greater prevalence of sole lesions if they had been moved to concrete than to rubber floor, whilst first calvers coming from hard floor and allocated to rubber flooring had least lesions.

The result indicated that softness/hardness of floors could have a long lasting effect. If the passageways in the lactating cow cubicle section have hard floor, which is still the common situation in practice, one should consider indeed not having soft floor for the heifers. At least, the changeover from soft to hard flooring should occur in good time, perhaps 3 – 6 month before calving. Another alternative to reduce leg and claw ill-health is to avoid shifting surface for calving heifers until several weeks or months after calving as shown by Laven & Livesey [6]. Anyhow, to take into consideration the interaction between heifers' and the cows' floor system regarding lameness and laminitis related claw diseases will give consequences in many dairy farm planning.

Hopefully, many more cubicle houses with soft, as well as skid resistant, just enough abrasive, clean and dry walkway flooring for both cows and replacement heifers, at least heifers in late pregnancy, will be realised in the near future.

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14 ■ A simulation model to evaluate the performance of robotized milking parlours

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A feasibility study was carried out to check the convenience of applying a simple robotic arm to common parlour layouts (tandem and rotary type). For this purpose a simulating computer program was developed to calculate the performance of various functional parlour schemes. In this model, based on data taken from real observations of commercial systems, some input parameters can be varied and the effect on milking capacity evaluated.

Among the outputs of the model, the number of cows milked per hour and the corresponding milk production are the most important considered.

The work demonstrates not only the possibility of a convenient employment of robotized systems in traditional parlours, even under the restrictive limits of some typical productions, but also the decisive influence of the key technical elements.

Introduction

Robotized milking represents an important technological advance in the management of dairy cow herds. But such technology, which is commercially available mainly as units with single milking stalls, is not always adequate. For example, in Parmesan cheese production, where regulation requires two milkings per day, with each milking lasting a maximum of four hours, a single robotized station only enables thirty cows to be milked. It is for this reason that multi-stall stations should once again be considered for their greater efficiency.

Multi-stall technology could be adapted to traditional (existing) milking parlours, which would be less expensive than the sophisticated stand-alone stations currently on the market.

For these reasons, this paper sets out a feasibility study on the possibility of using a robotized arm in multi-stall milking systems, in a similar way to traditional milking parlours.

Materials and Methods

Several multi-stall solutions were simulated during this research, but only the most important are presented here: 1) a tandem configuration (linear layout), with a moving arm serving several stalls on a single line; 2) a tandem configuration on two lines; 3) a rotary tandem with a fixed or moving arm (circular layout).

The model developed here is dynamic, with a stochastic basis, and event-driven. The cow herd is simulated taking into consideration different average milk yields, according to the number of lactations and days from calving, by using distribution curves observed in real farm conditions.

A simulation was then conducted based on half of the daily milk production being obtained at each milking (s1). The main parameters considered in the simulation model are the following:

number of cows; average daily milk yield of the herd (25, 30, and 35 kg); total teatcup attachment time; individual milking time.

Other minor parameters not presented here have been included to complete the model.

For tandem configuration, the following parameters have also been considered: the number of stall lines (1 or 2); the number of stalls per line (from 1 to 6); the number of arms (1 or 2 for two-line configuration); the velocity of displacement of the arm (three levels: 0.4, 1.0, and 1.8 m/p second). For the rotary tandem, a discontinuous advancement has been imposed (fixed arm) or a continuous but modulated velocity of rotation for the moving arm. In this case, the arm can follow the cow in the box to which the attachment is to be made for only the first quarter of the rotation; after this, if the attachment is not terminated, the rotary parlour is stopped until the attachment is completed. For the circular layout, only two parameters have been considered: the number of stalls and the peripheral velocity (0.1 and 0.2 m/per second)

Results

Results presented here are averaged values relating to eight simulated milkings, and refer to Parmesan cheese production, where regulation imposes two milkings per day, with each milking lasting a maximum of four hours.

Linear configuration

Production capacity (milked cows) appears to be high (90-110 cows). Differences in milked heads with respect to the different configurations are not so significant, but become notable when considering milk yield. With certain solutions, we can therefore obtain a higher global milk throughput with fewer cows but with a higher individual milk yield (fig. 1).

Furthermore, we demonstrate that it is not convenient to use more than four stalls, because of the reduced marginal productivity of additional stalls. The arm displacement velocity is very important, while increasing the number of the served stalls.

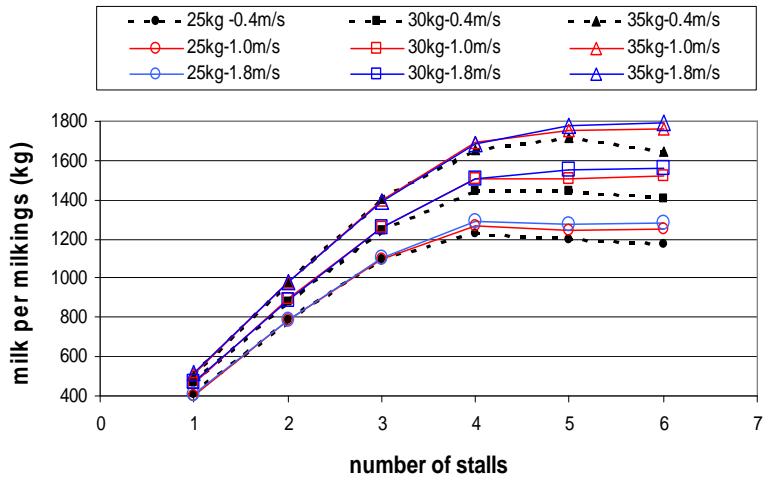
With one arm and two lines, the result is near to that of the single line in terms of total stalls served. Configurations with two arms allow roughly the doubling of the production obtained with a single arm.

Rotary configuration

A) Discontinuous advancement. During the stop of the rotation, the following events can happen: 1. cow exit/entrance from/to the milking stall; 2. teatcup attachment by the arm.

As shown in fig. 2, increasing the number of stalls over 4-5 does not improve the performance of the rotary tandem. This is because the determining parameters are 1) the time for the cow to enter/exit the stall, and 2) the time to skip to the next stall, but not the number of stalls.

Figure 1. Linear configuration, 1 line, 1 arm: milk yield in 4 hours milking as function of the number of stalls, arm displacement velocity, and herd production level.

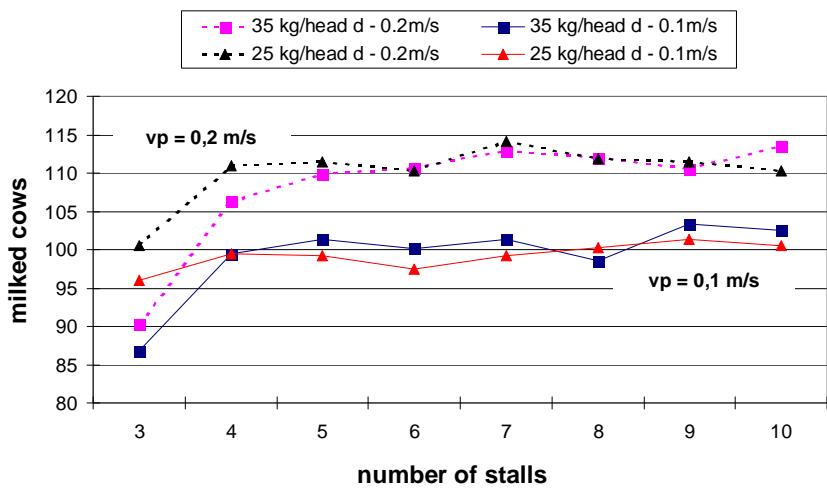


For the two peripheral tested velocities, 0.1 and 0.2 m/per sec., the number of milked heads is, respectively, 100 and 112 per milking.

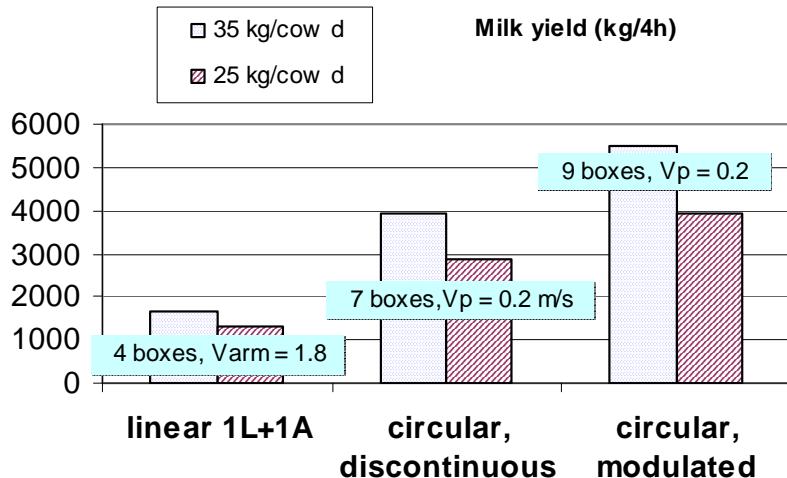
The simulation also enables us to conclude that the only parameter we can modify to increase productivity is the peripheral velocity. The reduction of the attachment time could also improve global productivity, but it is arduous with current technology.

For example, with 112 cows milked in 4 hours and an average yield of 35 kg/per head/per day we obtain 1960 kg of milk per milking, about 10% more than with the best linear configuration.

Figure 2. Rotary tandem parlour. Milked cows in 4 hours as function of the number of stalls, peripheral velocity (0.1 to 0.2 m/per sec), and average milk yield (25 to 35 kg/per head/ per day).



B) Continuous modulated advancement. This solution enables the milking of more than 150 heads, but the major difference is in milk production as shown in the figure above.



Conclusion

Our results show that, on a simulating basis, the robotization of milking parlours can be feasible and convenient especially in production areas with very restrictive regulations governing the production process, as in the case of Parmesan cheese.

Among the solutions and layouts examined the most efficient and productive would be a rotary arrangement with modulated continuous movement and a moving arm to follow the stall during the attachment.

To complete the whole system, parlour robotization should be integrated into an animal conveyance subsystem, to gather the cows to be milked. Such a system is already commercially available.

On the other hand, considering that the maximum capacity of milking configurations evaluated here is higher than the mean size of the heard in the typical Parmesan cheese area (herds with fewer than 100 cows), the economic sustainability of parlour robotization can also be hypothesized for a reduced use time, covering also possible teatcup attachment failures or/and re-attachment (about 3% of total attachments).

From an economic point of view, we hypothesize that a robotized system as proposed here, since it differs from a traditional milking parlour only in terms of the addition of an automated arm, could be less expensive than the commercial stand-alone robotized stations.

15 ■ A simulation model to predict the internal climatic conditions in livestock houses as a tool for improving building design and management

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Summary

A model simulating the transient environmental conditions inside livestock houses has been created for building design. The software can be applied to any type of building, animal or climatic situation and gives as outputs the heat exchange through all building components and the internal air temperature and humidity values. From these values some parameters are calculated that are useful in evaluating the building's thermal behaviour: Temperature Humidity Index, the duration of exposure to heat stress, the possibility of recovery through nocturnal refreshment, and the benefits of mechanical ventilation or evaporative cooling. Its application to three study cases (a piggery, a veal barn and a shelter for cows) is presented, along with possible ways of improving building design and management.

Introduction

Optimizing the thermal behaviour of buildings is a very important element in animal housing design in terms of maximizing production results. But it is fairly difficult to achieve this objective for two main reasons: the wide range of available building solutions and climatic variability, especially when very high (from winter to summer and from night and day).

To discover the optimal solutions, not only for design but also for management, reliable theoretical models capable of predicting the internal climatic conditions for a variety of climatic external parameters (air temperature and humidity, wind speed and direction, solar radiation) and building characteristics (materials, geometry, orientation, openings) are required.

Many authors have worked on modeling the internal environment of animal houses, but some aspects are always neglected or underestimated: i.e. the solar load, the transient thermal condition due to the thermo-inertial characteristics of the building envelope, the effect of the floor and slurry evaporation. All of these aspects become very important in a hot climate.

In order to include previous research, we developed a dynamic model that accurately includes all the factors influencing the thermal behaviour of buildings.

Materials and Methods

The model developed is dynamic and takes into account the following inputs: building geometry, building orientation, vent openings (size and position), the thermal-inertial characteristics of the construction materials (thermal conductivity, density, specific heat capacity, heat transfer coefficients), terrestrial coordinates (longitude, latitude), type of animal; as well as the local climatic conditions (direct and diffuse solar radiation, wind velocity and direction, air temperature and humidity). The outputs are: internal air temperature and humidity, surface temperatures, and

ventilation volume, calculated per minute. Some parameters relevant to design are derived from these values: heat exchanges through all building components, Temperature Humidity Index, duration of the exposure to heat stress, possibility of recovery by nocturnal refreshment, benefit from mechanical ventilation or evaporative cooling. The model also accounts for evaporation from wet floors, feeding management (i.e. hour of feed distribution for fattening pigs), mechanical and natural ventilation (combining thermal buoyancy and wind effects), wall shadowing and evaporative cooling.

The model is composed of sub-models that can work separately in order to evaluate partial aspects of the thermal exchange, i.e. the roofing effect - indirect on internal climate and direct on animals - can be specifically analysed for a better choice of geometric characteristics and the insulation degree. Moreover, the benefit of introducing, in a hot climate, mechanical ventilation and/or evaporative cooling can be estimated for different climatic conditions.

Results

The applications of the model to some study cases of animal housing, focused on hot climate conditions, are presented and discussed.

One case, the most complete, considers a house for fattening pigs on slatted floors. The other two cases are: a house for veal calves on a littered floor and a simple shelter for cows.

In the first two cases, the results are expressed in terms of exposure to different THI values and the solutions capable of reducing the duration and the intensity of the heat stress and, as an alternative, capable of compensating diurnal heat stress with nocturnal refreshment are highlighted. In addition, the contribution of the various heat transfer components is quantified showing their contribution to the heat exchange and the possibility of modifying it through construction contrivances.

In Tab. 1, the main results from the application of the model to the pig house are reported as parametric values, which are useful to compare the performance of the different solutions. The first column shows the integral of the THI values over the assumed acceptable threshold (75) to the time of their occurrence in the house. The last two columns show respectively the same integral for the very stressful THI values (> 85) and the duration of the exposure. The duration of the heat stress (THI over 75) is reported in *tstress*; the duration of the nocturnal recovery (temperature below 19 °C) is reported in *trec*. The analysis of these values would take too much space, but some results are self evident, especially the large difference in the internal climatic conditions among the best and the worst solutions for the two building types examined.

In addition to highlighting better design solutions for different housing arrangements, some particular aspects of the building's thermal behaviour, useful in informing design choices, are revealed.

The analysis of the pig house highlights the relevant positive effects of a concrete floor in reducing the internal air temperature and absorbing heat from recumbent animals.

The convenience of introducing supplementary mechanical ventilation to increase nocturnal benefit in closed barns is estimated in the examples for pigs and veal calves, along with an assessment of the optimal working conditions of the system.

In the latter case (with cows), the radiative action of the roof on the animals is quantified for various geometric characteristics and insulation degrees and the solutions with the least impact are revealed (Fig. 1; tab. 2,3). Finally, for the first two examples, the benefit of adopting an evaporation cooling system to reduce heat stress is evaluated and the optimal working conditions are assessed.

Conclusion

The simulation models capable of predicting a building's thermal behaviour can be a very useful tool for improving the design and management of livestock houses in order to achieve optimal conditions, whatever the external climate. This goal is practically impossible to achieve without such tools, due to the unlimited number of the possible different solutions and, in addition, the lack of parametric methods to perform a precise evaluation.

Overall, this requires a very accurate and complete model that takes into consideration all the variables that may influence the internal climatic parameters and the animal response.

In perspective, this kind of model, integrated with a model simulating the animal response, can produce an even more global and precise optimization of the interrelated animal/building/management system.

Table 1.

| Best results for each type of building (in order of Intgr. value) | | | | | | | |
|---|---|--------------|--------------|--------------|-------------|-------------------------|--------------------------|
| Intgr. value THI >75 | Building code | max THI | min THI | t stress (h) | t rec. (h) | Intgr.value THI > 85 | THI > 85 duration (h) |
| 82.30 | 1227 | 85.16 | 64.66 | 12.63 | 1.37 | 7.90 | 1.33 |
| 84.94 | 2222 | 85.41 | 64.49 | 13.32 | 1.70 | 34.55 | 2.20 |
| 87.25 | 12*7 | 86.09 | 64.32 | 12.68 | 2.32 | 96.83 | 3.03 |
| 90.09 | 22*3 | 85.93 | 64.29 | 13.02 | 2.00 | 114.34 | 3.15 |
| worst results for each type of building | | | | | | | |
| 133.23 | 11*1 | 89.26 | 68.07 | 14.42 | 0.00 | 1281.68 | 7.55 |
| 126.62 | 1111 | 88.58 | 68.40 | 14.50 | 0.00 | 1008.69 | 7.07 |
| 113.01 | 21*1 | 87.88 | 66.41 | 14.45 | 0.00 | 685.04 | 5.97 |
| 106.74 | 2111 | 87.08 | 66.73 | 14.57 | 0.00 | 438.98 | 5.23 |
| Building coding | | | | | | | |
| first numeral | 1 = one slope building ; 2 = two slope building | | | | | | |
| second numeral | 1 = standard window area ; 2 = larger window area (+25%) | | | | | | |
| third numeral | 1 = insulation layer 3 cm ; 2 = insulation layer 6 cm ; * = no insulation layer | | | | | | |
| fourth numeral | orientation 1=N ; 2=NE ; 3=E ; 4=SE ; 5=S ; 6=SW ; 7=W ; 8=NW | | | | | | |

Figure 1. Roof configurations: a) gabled roof; b) multiple shed roof. A and B, cow positions inside the barn. Three roof slopes (10, 30 and 45%), and two eaves heights (3.5 m and 4.5 m) were evaluated. R1 and R2 are the roofing pitches.

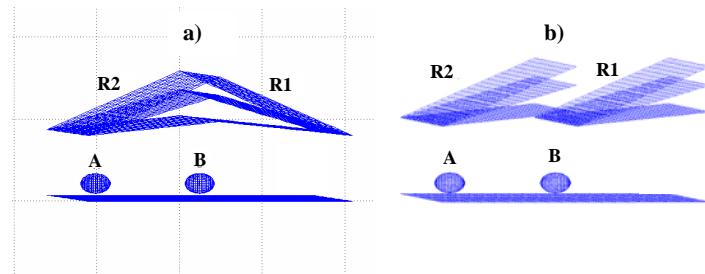


Figure 2. Gabled roof. Thermal power (peak values) exchanged by the cow with the roof (positive = gained, negative = lost), for different roof configurations.

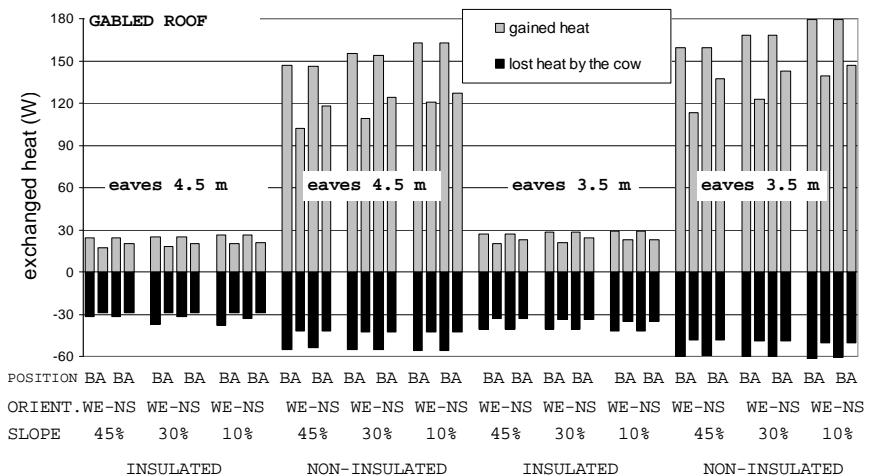
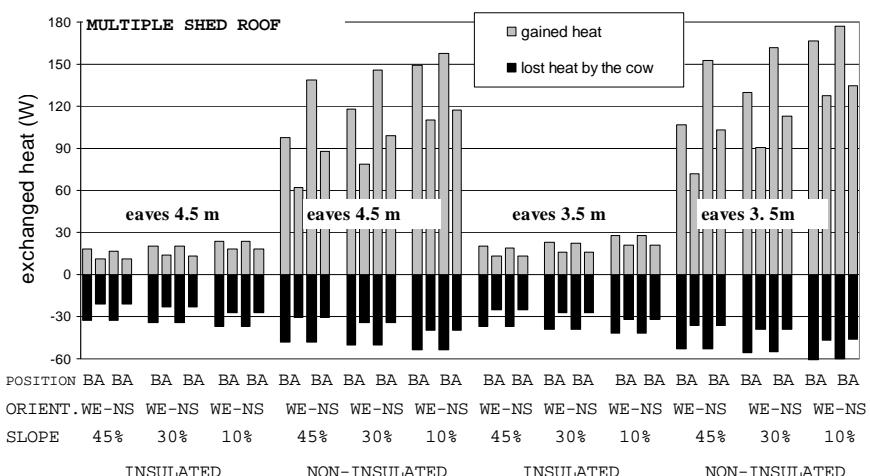


Figure 3. Multiple shed roof. Thermal power (peak values) exchanged by the cow with the roof (positive = gained, negative = lost), for different roof configurations.



16 ■ Alternative energy on poultry farms: study of a heat recovery system

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Introduction

As fossil fuels become increasingly rare and efforts are made to combat climate change, the poultry industry, like other sectors, must find ways of reducing its consumption of fossil fuels and identify and develop alternative energy sources. Starting a batch of birds to fatten on a poultry farm requires ambient temperatures of around 32 °C in order to ensure their thermal comfort. At the same time, a minimum air flow is required to remove toxic gases and allow fresh air to enter. Introducing cold air into the building and heating it to replace the air extracted consumes large amounts of energy. As a result there is some merit in examining the options for recovering the energy contained in the outgoing air to heat the incoming air.

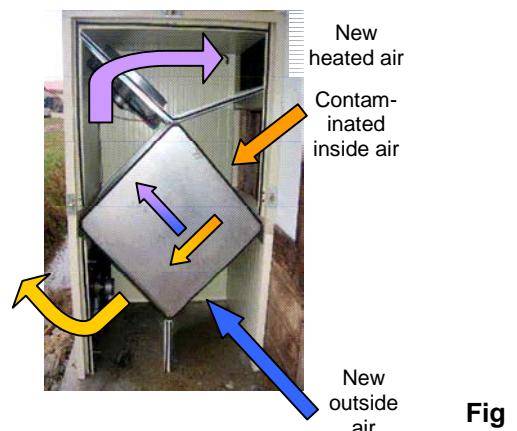
Methods and equipment

The ITAVI, the Pays de la Loire Regional Chamber of Agriculture, the Brittany Chambers of Agriculture and the INRA, in partnership with two equipment manufacturers, three installers and three breeders, agreed to set up a heat recovery trial in poultry houses for a period of one year. Table 1 gives details of the three farms involved.

The principle of the heat exchanger tested in these trials is based on a transfer of energy (calories) by convection: the warm contaminated outgoing air and the incoming fresh air cross as they pass through the heat exchanger (the two air flows remain separate in order not to contaminate the incoming "new" air).

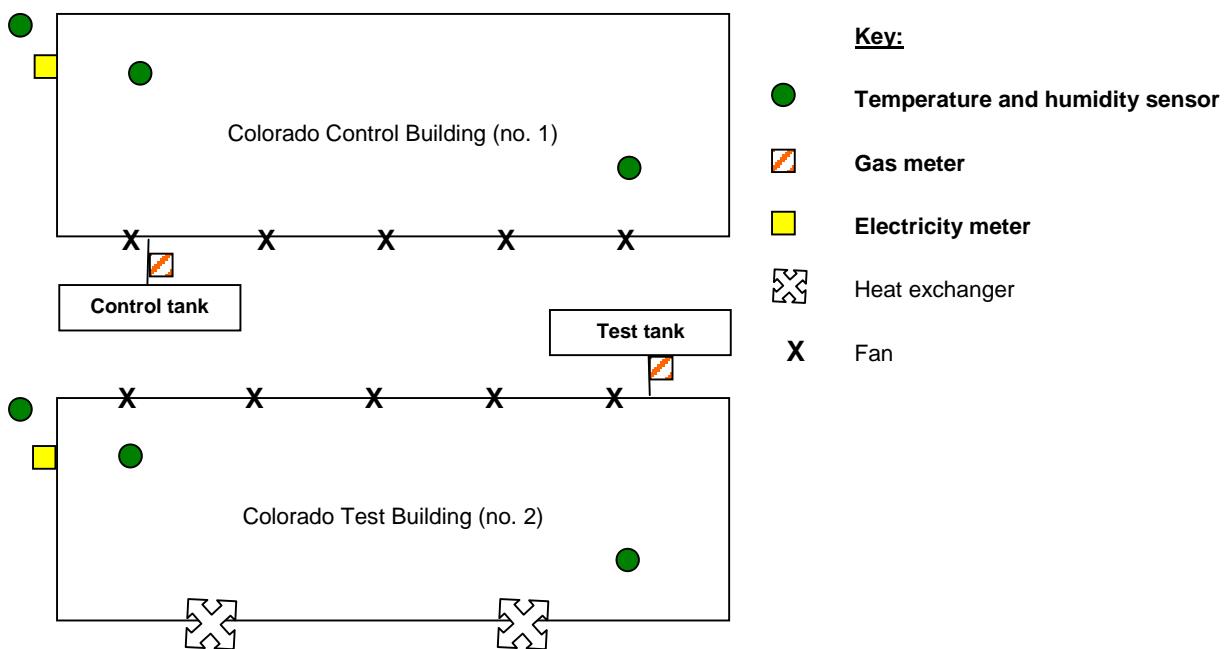
The heat recovery system prototypes studied were designed as follows:

- Heat exchanger with aluminium plates
- Gap between plates = 11.5 mm
- Heat exchange area = 37 m²
- 2 4,000 m³/h fans per chamber
- Chamber around heat exchanger creating a sandwich
- Chamber can be opened to remove the heat exchanger unit (not airtight).



Heat exchangers with plates were positioned on one of the cladded walls of the buildings. One device is considered adequate for a building with a surface area of approximately 500 to 600 m². Two identical buildings (shell, insulation, surface area, ventilation, performance, etc.) were monitored on each farm. One was fitted with a heat recovery system (test building) and the other run under standard conditions (control building). The prototypes, supplied by SYSTEL, were tested on units producing turkeys and chickens for meat in buildings with natural ventilation (with curtains) and mechanical ventilation with single-side extraction. Two different operating methods were used for the heat exchangers: one based on cyclical operation (for example, at 1 day old, the heat exchangers operated for 3 s in every 180 s, at 10 days old, 60/180 s and from the 19th day they operated continuously, with an identical flow all along the batch); the other operated continuously and progressively, using a frequency changer (increase in flow along the batch). Prior to the start of the trial at each site the equipment and settings for the control building and test building were adjusted to the same values. The following parameters were recorded on a continuous basis: gas and electricity consumption (meters), internal and external temperature and humidity (LogTag sensors), technical and economic results. Figure 2 shows the position of the measuring equipment and heat exchangers in each building.

Figure 2 – Equipment installed in farms studied: example of building with single-side mechanical ventilation (trial no. 1)



| Trial no. | Department | Ventilation | Surface area of building (m ²) | Production | No. of batches/year | Heating system | No. of heat exchangers installed | Heat exchanger operation |
|-----------|------------|------------------------|--|--------------------|---------------------|----------------------------|----------------------------------|--------------------------|
| 1 | 72 | mechanical single-side | 1,200 | turkey | 2.5 | adjustable radiant heaters | 2, on long wall opposite fans | cyclical |
| 2 | 85 | natural, with curtains | 1,300 | chicken for export | 7.5 | indoor space heaters | 3, on long wall | cyclical |
| 3 | 29 | natural, with curtains | 1,200 | chicken for export | 7.6 | adjustable radiant heaters | 2, on long wall | progressive |

Table 2 – Description of farms studied

Results and discussion

Ventilation during start-up

Air circulation is essential during the start-up period. During this phase, the heat exchangers installed in the buildings are sufficient to ensure a minimum level of air circulation on their own. The role of the heat exchangers observed in each type of building is as follows:

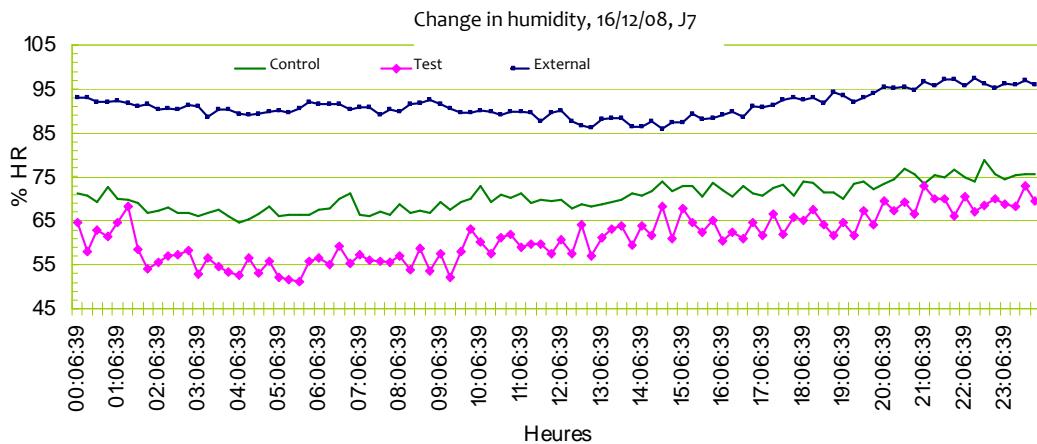
- In the case of buildings with mechanical ventilation (dynamic buildings), the heat exchangers act as a substitute for the ventilation system (1st group).
- For buildings with natural ventilation (static buildings), the heat exchangers act similarly to mechanical ventilation and thus make the buildings “dynamic”.

Reduction of ambient humidity

The temperature and humidity sensors installed on the inside and outside of the buildings were used to control the atmospheric conditions. Observation of all three buildings equipped with heat recovery systems showed:

- maintenance of the set temperature,
- lower humidity: 10% less on average (Cf. figure 3).

Figure 3: Trial no. 2
Humidity recorded on 16/12/08 (7 day-old birds)

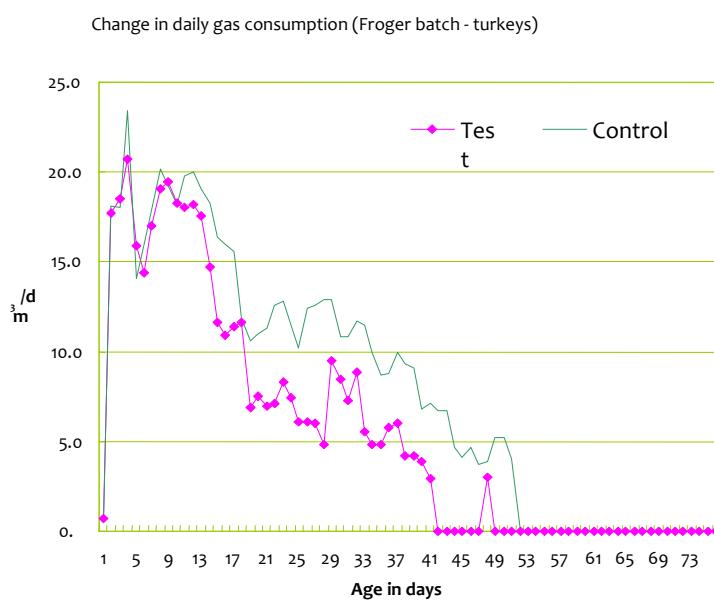


Reduction of energy consumption

In addition to a dryer atmosphere and minimum ventilation on start-up, the primary expectation for heat recovery systems is a reduction in propane consumption. An analysis of the results over one year of operation shows:

- a decrease in propane consumption for birds aged 6 days and over,
- radiant heaters were turned off 10 days earlier in the test building, for turkeys,
- slightly increased consumption of electricity in the test building because of the two fans in each of the chambers.

Figure 4: Trial no. 1
Daily propane consumption in m³ (batch from 21/01/08 to 21/05/08)



An assessment of propane and electricity consumption over the monitoring period of one year shows a reduction in propane consumption of 18 to 27% and an increase in electricity consumption. It should be noted that the buildings used in trial nos 1 and 3 already had low levels of propane consumption prior to the start of the trial (compared with the baseline figures in the Grand-Ouest Chambers of Agriculture poultry survey carried out in 2007-2008). Installing the prototypes helped to optimise consumption levels. These results are summarised in Table 2.

Table 3: Propane and electricity consumption

| Propane consumption (kg/m ² /year) | | | Propane saving achieved | | | Electricity consumption due to heat exchangers | | CO2 emissions avoided |
|---|---------|------|-------------------------|----|---------|--|--------|-----------------------|
| Trial | Control | Test | Kg/year | % | €/year* | kWh/year | €/year | Kg CO2 eq/year |
| 1 | 4.73 | 3.47 | 1,572 | 27 | 1,165 | 2,185 | 98 | 5,464 |
| 2 | 12.4 | 10.0 | 3,107 | 18 | 2,300 | 7,946 | 486 | 10,493 |
| 3 | 6.1 | 5.0 | 1,301 | 18 | 962 | 2,918 | 230 | 4,428.5 |

* Average price of propane paid by breeders in 2008 = €740/T

Note: CO2 emissions can be calculated based on the direct emission factors supplied by the ADEME and the indirect emission factors available from the ecoinvent 2.0 ® database. The figures shown in the table above have been calculated based on:

- emissions avoided by not burning the propane saved
- emissions caused by the additional consumption of electricity due to the operation of the heat exchangers.

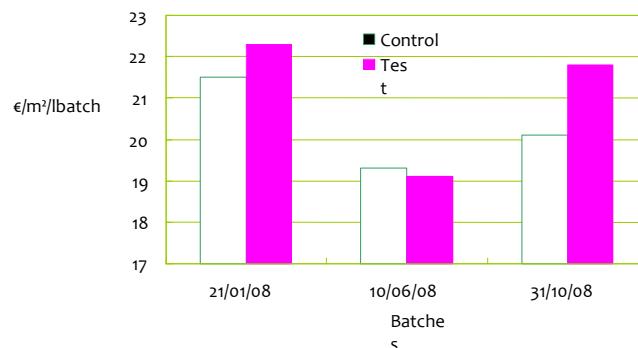
Impact on chick-feed margin

In trial no. 2, the presence of heat recovery systems had no impact on the chick-feed margin (CFM). Trials 1 and 3, however, showed a marked improvement in margin.

Trial no. 1: building with mechanical ventilation

A marked improvement in CFM was observed in this trial on batches started in cold weather. The benefits in terms of CFM are less marked in the summer (although the propane saving achieved is still 17%) because at this time of year the fans on the heat exchangers are no longer able to act as a substitute for the building's ventilation system. The average improvement in CFM is €0.76/m²/batch or €2,280/year.

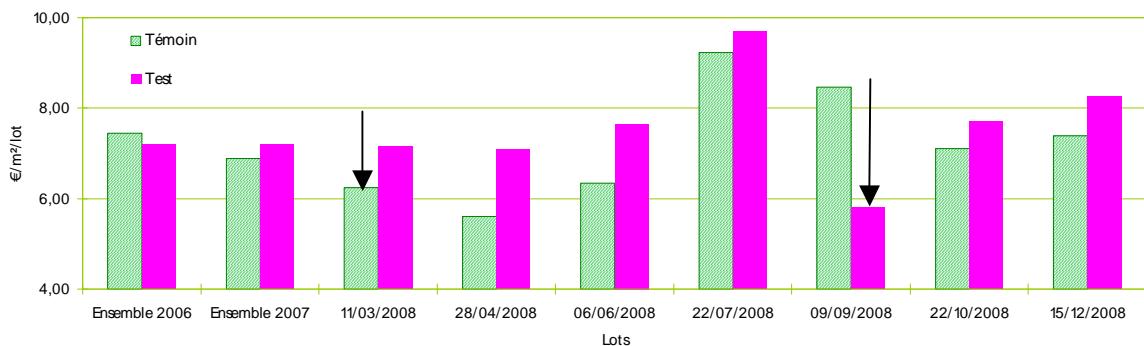
Figure 5: Change in turkey poult-feed margin



Trial no. 3: building with natural ventilation

CFMs improved on all batches from the start of the trial. The heat exchangers were in operation all year round, the benefit of which was to make the building "dynamic". The average improvement in CFM is €0.94/m²/batch or €8,570/year.

Figure 6: Annual change in chick-feed margin



Return on investment time

The return on investment time is calculated solely on the basis of the energy savings generated by the prototype heat exchangers. It was decided not to take account of the improvement in technical performance given that this varies from one trial to another. The return on investment time may therefore be up to nine years. Thanks to investment subsidies in the energy sector, for example through Energy Performance Plan subsidies, the return on investment time may be reduced to five years.

Table 4: Return on investment time

| | |
|--|-------------------------|
| Baseline propane consumption for a 1,200 m ² Colorado, turkey production (poultry survey by Grand-Ouest Chambers of Agriculture) | 7,800 kg/year |
| Propane savings: 25% | 1,950 kg/year |
| Reduction in annual energy expenditure (€740/T, €150 electricity/year) | €1,300/year |
| Investment (2 heat exchangers + installation) | €10,000 to €12,000 |
| Maximum return on investment time | 7.7 to 9.2 years |
| Return on investment time with 40% subsidy (EPP) | 4.6 to 5.5 years |

Conclusion and prospects

The results achieved with the prototypes are of some interest and go beyond the savings in propane, also helping to improve the atmosphere (reduction of atmospheric humidity, minimum ventilation on start-up). The trials have contributed to helping turn the prototypes into a product that can now be marketed:

- Heat exchangers with PVC plates and insulated polyester chamber
- Heat exchange area = 80 m² or 150 m²
- Chamber and heat exchanger with plates form a single unit
- More robust
- Ease of cleaning
- Better air circulation

The new heat exchanger versions as well as models produced by other equipment manufacturers will be monitored to provide a benchmark.

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17 ■ Innovative methods for pasture based poultry production systems

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The aim of this study is to describe field experiences and research results on innovative methods that capitalize on productive pastures. The technology of portable houses is described, ranging from crude shelters to well-constructed, insulated houses. Other pasture equipment is also introduced in order to attract birds in the pasture and improve their welfare status. The results of a research project conducted by the bilateral collaboration N.AG.RE.F.-British Council is presented on the use of composted vegetable waste as soil medium in free-range laying hens' production systems. The results of another study (still in progress) is also presented, showing that the enrichment of the pasture area with cultivated aromatic plants effectively promotes the foraging behavior of hens and has a positive effect in most of the egg quality characteristics.

Introduction

Pastured poultry refers to a poultry production system that is characterized by poultry being raised primarily on pasture. It represents a low-input, sustainable alternative for new farmers and a potential diversification of on-farm enterprise for established farmers. It does not require costly equipment or structures and it offers the flexibility of seasonal production during peak seasons of product demand.

The history of poultry production includes a long chapter on pastured poultry. In the past, even the conventional poultry industry raised the birds with outdoor access. Production moved indoors largely because of concerns of high feed intake, high mortality due to predators, endo-parasites and disease, poor winter egg output because of lack of light and climate control but also to allow production on an intensive scale with automated feeding and watering (FANATICO, 2006).

In France, pasture-raised poultry is the leading product in a program called *Label Rouge*. It began 40 years ago as a grassroots movement led by visionary farmers and now accounts for 30% of poultry sales to the public, in spite of its high price—twice the price of conventional poultry. This program provides premium products to consumers, increases farmer income, and strengthens rural development. It consists of many regional producer-oriented alliances, called *filières*, which produce and market their own branded products under a common label. A third-party certification program ensures that strict standards are being followed. Other countries are beginning to take note of the *Label Rouge* program.

Although pastured poultry is not a new concept, there is lack of suitable innovative solutions concerning crucial infrastructure and more humane production methods with less environmental impact available to producers. The aim of this paper is to describe field experiences and research results on innovative methods that capitalize on productive pastures.

Housing innovations for pasture based poultry production systems

There are a variety of housing designs used in pastured poultry production. Materials and construction may depend on the resources and skills of the farmer and are associated with a particular management style. Stocking density, weather conditions (heat and cold, winds), predator risk, turf destruction and parasite population have to be considered when design a housing system. Moreover, choosing a housing system involves considerations such as the flexibility and fertility of the system, the labor and management requirements and the birds' welfare.

From practical experience it is clear that there are a number of problems to be eliminated at the design stage (DEFRA, 2001; SOSSIDOU, 2009):

- *The position of the birds' house:* it will influence how well the birds range over the pasture.
- *The quality of the pasture:* it offers the ability to move the houses or pens regularly once they are on site.
- *Equipment and perches:* feeders, drinkers, nest-boxes and perches to compromise bird welfare and performance.
- *The ventilation system:* it needs to be such that air change rate is adequate for the removal of bird heat from the building during hot weather and also able to remove stale, smelly air and humidity during cold weather.
- *Lighting:* should be designed properly. Usually, natural lighting is used except when managing layers and pullets.
- *Fire precautions, alarms, generators:* statutory requirements at farm level.

Both fixed and mobile shedding is commonly used in range systems.

Fixed houses with yard can be used in dry climates where biological activity is low and pathogens do not survive or with a low density stocking density. Otherwise, it is critical to rest or rotate pastures to prevent these problems. One way to help rest or rotate pasture is "double yarding" subdividing the yard in two or more with fences and rotating the flock between the yards. This type of housing is popular with large free-range producers. It provides prior to good bird welfare and a year round seasonality.

Portable houses are designed to be moved with a tractor or four wheel vehicles. The design ranges from crude shelters to well-constructed insulated houses. Portable house main advantage is the possibility to be moved every few days or less frequently and so, prevents the pasture from damage and mud. This system is considered to be more flexible and welfare-friendly. Many attractive designs for small poultry houses used for pasture production are shown on the Forsham Cottage Arks, HENSPA, EGLU, ATTRA and other companies and organizations Web sites.

To give the birds outdoor access, the house needs pop-holes (bird-sized doorways)—in general, the more, the better (Figure 1). If the pop-holes are too narrow or too few in number, chickens who want to go in and out will be blocked by others lounging around in the doorway. Also, high-traffic areas lead to unnecessary mud and manure build-up.

Compared to hand-movable houses, machine-portable houses, if well-constructed, can be (PLAMONDON, 2003):

- Sturdier, surviving stronger winds, heavier snow loads, and more vigorous towing.
- More weatherproof, making them suitable for year-round production, including winter brooding.
- Longer-lived, by being built with the same materials and techniques used in permanent agricultural buildings.
- Larger, holding more birds and equipment, making chores easier.
- More versatile, usable as a brooder house or for hens, broilers, turkeys, or ducks-and also for non-poultry uses.

Pasture pens are small floorless pens that are moved daily, usually by hand, to fresh pasture. They are favourable to small-scale producers due to their low cost and flexibility. This type of housing is highly associated with Joel Salatin, author of the popular book, 'Pastured Poultry Profits' (SALATIN, 2004). Salatin has developed a system of pasture rotation that produces nutrient-rich grass and maximizes the spreading and composting of animal waste. Floorless pens allow the broilers inside to graze the grass under their feet. The pens are dragged by hand to a new patch of grass once or twice a day. This leaves their manure behind and presents them with a new patch of grass to graze. Daily moves also eliminate the danger of coccidiosis and other disease and have a dramatic and almost immediate effect on plant growth, because the single day's worth of manure provides the plants with plenty of fertilizer, while a single day's grazing is not enough to harm the plants. Many producers have modified the pen size and configuration to better suit their own needs, but the basic method involved in raising 'pastured poultry' remains. An ideal pasture system with fixed house and 4 rotationally used grassed pens was described and illustrated by Elson (1995).

Plamondon (2003) suggest that a pen should:

- Be easy to move by hand.
- Not injure birds during moves.
- Remain in place during high winds.
- Be easy to build out of readily available materials.
- Have a low initial cost so the investment can be recovered quickly.
- Have a low maintenance cost.
- Provide reliable shelter from wind, rain, heat, cold, and predators.
- Allow daily chores to be performed quickly, efficiently, and safely.
- Provide easy access for the farmer, with either a roof high enough to stand under or walls low enough to step over.
- Support the changing needs of the birds as they grow.

In general, birds need the same services outside the house as inside. They should have access to feed and water, so that they do not have to return inside. Feeders should be protected from rain and wildlife with a shield or cover and should be easy to move to a new location.

Moreover, birds don't tend to like wide open spaces as they are fearful of the threat of predators. Trees, hedges and artificial shelters on the range area can help to encourage them to make better use of the pasture available (THEAR, 1997).

Innovative methods to pasture management

On-going research exist to investigate innovative solutions on the above issues such as the use of composted vegetable waste transformed into valuable added soil medium for free-range laying hens units (SOSSIDOU *et al.* 2006; SOSSIDOU *et al.*, 2008; SOSSIDOU *et al.*, 2010) or the cultivation of aromatic plants in the pasture area (KOSMIDOU *et al.*, 2006; KOSMIDOU *et al.*, 2008).

The use of vegetable waste as soil medium in free-range laying hens' production systems

When applying a pasture poultry production system, good pasture management is essential in order to keep a high status of bird health and welfare. The ground has to be kept in good condition in order to provide some forage for the birds at range, to prevent the area from becoming muddy and avoid the problems of poaching and the build-up of parasitic populations. A good quality sward is important in that it provides some forage for the birds at range and it avoids the area becoming muddy. Mud can increase fly breeding areas, transmit diseases, create unsafe footing and increase polluted runoff. Even with a good quality sward, the areas close to the entrances of houses frequently become denuded (SOSSIDOU *et al.*, 2008). To prevent the area becoming muddy from excess bird activity, a large number of farms have some removable material (small rocks, gravel, wood chips, wood shavings) along the length of the shed sides for about 5-10 metres away from the sed (GLATZ *et al.*, 2005).

Moreover, flocks raised in pasture are more likely to be infected by parasites than caged birds (PENNYCOTT and STEEL, 2001). The parasites are mostly nematode worms and their incidence is higher than in other loose-housing systems (PERMIN *et al.*, 1999). The nematode worms survive in the soil and this allows them to complete their life-cycle successfully.

Recent studies provided information on the potential value of composted recycled vegetable waste as a soil medium for commercial free-range laying hens units, in order to improve soil structure and grass cover and assess if its use is practicable, without introducing any health and behavioural problems for the birds. The soil media compared were either a mixture of 90% recycled composted vegetable waste and 10% sand or un-sterilised topsoil obtained from the same site. The comparisons have been based on behavioural observations, grass cover, soil structure and nematodes' population measurements. The experiments were contacted at Harper Adams University College and at the Animal Research Institute of the National Agricultural Research Foundation within the project "*Improvement of the welfare of free-range laying hens by innovative changes in range management*" (Figure 2).

The results suggest that composted vegetable waste can be transformed into valuable added soil medium for free-range laying hens units and its use is in accordance to the health and behavioural needs of the birds.

Nowadays, composted recycled vegetable waste is readily available and inexpensive. The use of vegetable waste compost as a soil medium for the whole range area maybe uneconomic, however it is possible for the managers of commercial egg production units to consider using it to seed areas that are close to the entrances of the fixed housing and that probably have the greatest bird use. The use of composted vegetable waste also reflects environmental considerations into CAP rules and deals with the development of agricultural practices that preserve the environment and safeguard the countryside.

The effect of an enriched pasture with aromatic plants on birds' behaviour and egg quality of free-range laying hens

Over the past few years, aromatic plants (herbs) and their extracts have been used in animals' diets as feed additives in order to improve their performance and health and the quality of their products. This use of aromatic plants is based on the wide range of their antimicrobial (SIVROPOULOU *et al.*, 1996) antioxidant (BOTSOGLOU *et al.*, 1997) or even on their appetitive and digestion stimulation properties (KAMEL, 2001). In poultry, there are studies on the use of aromatic plants and/or their extracts as feed additives in which the antioxidant (BOTSOGLOU *et al.*, 1997; GALOBART *et al.*, 2001) and performance improving (NARAHARI *et al.*, 2004) effects have been reported. However, very little has been documented for the use of these plants as a part of the pasture area in free-range systems.

The objective of a PhD thesis, still in progress, is to evaluate the effect of the enrichment of a pasture area with cultivated aromatic plants on the behaviour and the egg quality of free-range laying hens.

First, a pilot study has been contacted to determine free-range laying hens' preference for four different cultivated aromatic plants: *Ocimum basilicum*, *Origanum vulgare*, *Petroselinum crispum* and *Anethum graveolens*. The results of this study showed that the enrichment of the pasture area with cultivated aromatic plants has a promoting effect on the foraging behavior of hens.

A second study has been contacted to access birds' behaviour and to evaluate the egg quality and the antioxidant effect in egg yolk of *Ocimum basilicum* (Group B) and *Mentha spicata* (Group SP) when are cultivated in the pasture area of free-range laying hens' system. Observations on hens' preferences (foraging behavior) were made from outside the free-range area, using the scan sampling procedure (ALTMAN, 1974). The malondialdehyde (MDA) assay was used for determining the extent of yolks' lipid oxidation. Traits measured consisted of egg weight, albumen weight, yolk weight, yolk colour, shell deformation, shell thickness, egg specific gravity and Haugh units.

The results of this study showed –as in the previous pilot study- that the enrichment of the pasture area with cultivated aromatic plants has a promoting effect on the foraging behaviour of hens. Furthermore, within treatment of aromatic plants, hens showed a clear preference for basil in comparison to spearmint (Figure 3). Moreover, results revealed a positive effect of the aromatic plants treatment in most of the egg characteristics. MDA concentration differed between treatments and was higher in the control group in all time periods, while such differences between groups B and SP were not evident.

Future development

While a number of innovative methods and practices have been already under study, the bird health and welfare and the environmental and product hygiene risks associated with pasture based poultry production systems should be further examined to develop effective control programmes.

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Figure 1: The house needs pop-holes to give the birds outdoor acces

(N.AG.RE.F., Experimental Poultry Farm, Greece)



Figure 2: The preferences of free-range laying hens for grass swards grown on different soil media and particularly for those that utilise the beneficial effects of composted recycled municipal waste



Figure 3: Hens showed a clear preference for basil in comparison to spearmint



18 ■ How can value be derived from incorporating open-air poultry ranges into the landscape?

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A poultry range is an integral part of an open-air poultry breeding operation. These ranges are generally examined from the standpoint of the animal's welfare, the sanitary management of both groups of animals and the finished products, and manure management. The purpose of this study is to propose methods for adapting poultry ranges to the landscape that comply with breeding needs (welfare, the environment) and, moreover, yield value in terms of the landscape, environmental concerns and cost, with recovery of wood products in the form of lumber. This presentation is based on two case studies involving farms located in northern Provence.

Introduction

The poultry range is an important component of the breeding process and quickly becoming more so as a result of product quality specifications including the Label Rouge, Organic, PGI (Protected Geographical Indication), AOC and open-air. It also plays an increasingly important role in terms of product image (Magdelaine and Mirabito, 2001). Several studies have been conducted to examine the welfare of the animals, sanitary control and environmental management of the manure deposited in the range (Faure, 1992; Keeling et al, 1988; Lubac et al, 2003; Lubac, 2006; Mirabito and Lubac, 2000). Poultry range management has also been addressed in studies on integrating agricultural operations into the landscape (Ambroise et al, 2009).

However, these various factors give rise to requirements that can sometimes be contradictory. The purpose of this study was to suggest a planting approach that can most effectively reconcile the majority of these requirements and at the same time provide for economic development of the range in the form of lumber.

Method

ITAVI (the French Technical Institute for Poultry Production) and AGROOF, a research organization that specializes in agroforestry (Dupraz and Liagre, 2009; Liagre, 2006), pooled their expertise to adopt the following requirements for the development of a poultry range:

- the welfare of the poultry: provide shade, which is especially welcome in strong heat; protect the poultry from birds of prey and wind; offer reference points for moving through the range, etc.;
- the environment: promote proper distribution of the chickens around the range in order to limit the accumulation of manure in particular areas. This can also be valuable for managing living pathogens, depending on the fecal-oral cycle of the poultry. Plants are also useful for absorbing minerals, creating buffer areas and slowing seepage and soil erosion;

- economic development of the range: the choice of species that can be harvested for lumber and that are suitable for the soil type and climate;
- integration into the landscape and the surrounding environment: siting with respect to neighbours, the view from nearby locations, the choice of local species.

These points have been addressed by proposing that free-standing trees, guide hedging and border hedging be planted. Each case study was accompanied by precise specifications for preparing the ground based on its makeup, planting plants and protecting their roots and trunks (using square woven fabric on the ground and protective tubing or wire mesh). This essential point is specific to poultry ranges, to ensure the plants survive (in the face of damage by the hens, competition with vegetation in the range) and thrive, and to ensure that they can be appropriately harvested as timber (proper tree size, shortened cultivation period).

The research focused on two pilot studies: two laying hen farms, located in the Drôme des Collines area of the Provence region. The researchers visited the site and spoke with the breeder, and also performed auger probes and a physicochemical analysis of the soil, following on previous work carried out by ITAVI (Lubac, 2006).

Results

Case study at Farm A

The study focused on an open-air laying hen farm comprising 3 ha of meadow and including a row of previously planted mulberry bushes parallel to the buildings.

- ⌚ The farm is clearly visible from the local secondary road, so improvements to the landscape would offer a valuable benefit.
- ⌚ The range has a slight downward slope from the building hatches to the bottom of the range. One end of the plot consists of a wet ditch with reeds at the surface. Runoff to this area needs to be limited by planting trees and a hedge.
- ⌚ A fair number of the hens use the range, enough to satisfy the breeder. Guide hedges are not needed. On the first portion of the enclosure, individual trees will be planted with spacing of 20 x 10 metres, to ensure they can grow properly and at the same time prevent overly uniform shade, which would discourage the poultry from exploring the area.
- ⌚ The lack of reference points at the far end of this extensive enclosure means that few chickens advance to the centre of the range, so reference points are needed. The recommended hedge will be planted along the length of the area at the midway point. It will consist of rural species, with standard trees every 10 metres, coppiced trees every five metres and shrubs and creepers (hawthorn, currant bush, lilac, dogwood, sloe, common privet, common hazel, honeysuckle, viburnum) every metre.
- ⌚ The hens visit the area at the far end of the pen only rarely, and it is mowed only once a year. It would be interesting to derive value from this area by planting cherry trees, whitebeams, pubescent oak, wild apple trees and maple, as well as a few poplars and ash trees in the wetter sections, spaced at 10 x 10 metres.
- ⌚ The soil type is favourable for trees to take hold and grow.

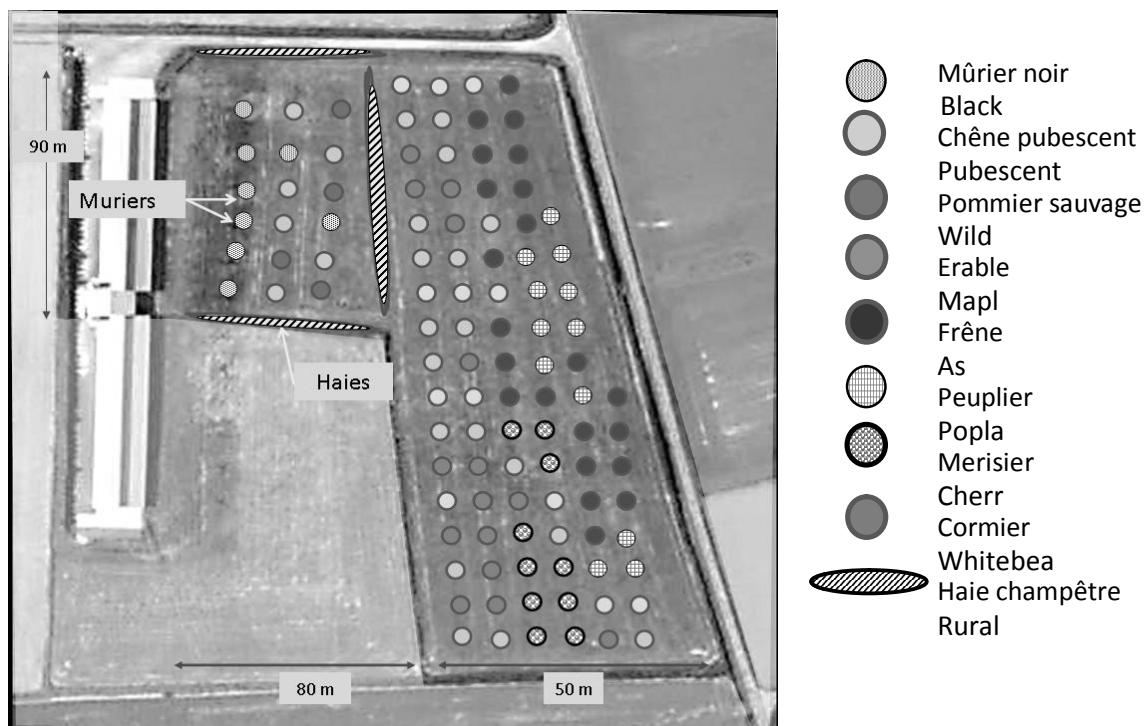
The estimated cost, including the acquisition of the plants, protection with square woven fabric at the foot of each tree and along the length of the hedge, protective tubing, stakes, and labour for planting, is as follows:

- €114 (excluding tax) for planting 12 trees in the area close to the building;
- €1,200 (excluding tax) for the back hedge, or €3,053 (excluding tax) for 330 metres of hedges (side and back);
- €909 (excluding tax) for planting 101 trees intended for lumber.

Upkeep would then consist of cutting and pruning the trees and hedge shrubbery, one day a year. This could be done by the breeder.

If the trees are properly maintained, they could yield significant revenue at harvesting that could ultimately total €21,100 (see Table 1). In financial terms, the profitability study should be based on discounted income, taking into account all revenues and expenditures over the 50 years of the project. In this case, the discounted income is positive, since it amounts to just over €1,500 for the breeder. This notable result indicates that harvesting of the trees more than offsets the initial investment, which is nonetheless quite significant with poultry given the high cost of the protective equipment. Given this revenue, it would be helpful to evaluate the external factors, both positive, such as the benefits provided (carbon, biodiversity, water quality, breeding system performance, etc.) and negative (predators, dietary balance).

Figure 1 - Proposed upgrades for Farm A7



Muriers = Mulberry; Haies = Hedges

Table 1 - Growing period and commercial value at the site as lumber

| Species | Growing period | Price per cu.m (2009) | Usable area in cu.m | Estimated value, uncut |
|---------------|----------------|--------------------------|------------------------|---------------------------|
| Cherry | 40-50 years | €100 - €350 | 19 | €3,800 |
| Whitebeam | 50 years | €300 - €1,000 | 5 | €2,000 |
| Wild apple | 50 years | €100 - €350 | 12 | €2,400 |
| Ash | 40-50 years | €80 - €250 | 30 | €4,500 |
| Pubescent oak | 50-60 years | €120 - €200 | 44 | €6,600 |
| Maple | 40-50 years | €90 - €120 | 10 | €1,000 |
| Poplar | 15-20 years | €40 - €50 | 18 | €810 |
| TOTAL | | | | €21,110 |

Case study at Farm B

The study focused on a poultry range operated by a breeder of organic laying hens, consisting of 1.2 ha of meadow. An initial tree-planting project had been carried out but had failed despite irrigation (owing to the selection of exotic species that were unsuited to the sandy soil).

- ⌚ The plot is relatively hidden from nearby roadways as a result of housing and buildings.
- ⌚ It sits on a steep upward slope from the exit openings, resulting in substantial soil erosion given the soil type, the movement of the poultry and significant runoff in the direction of the building. The soil very quickly deteriorates in the summer. Planting would help to limit this deterioration.
- ⌚ The breeder's objective is to plant the maximum number of trees so that the hens can explore as much of the area as possible. As they face the hill, they have no reference points. Guide hedges have been proposed in the upward direction for the first few metres, and then parallel to the building thereafter, to create a formal potential stopping point for the hens. The guide hedges are about 10 metres long, with a plant every metre. These plants are fast-growing shrubs, low in height, with flexible branches (shrubs and creepers: ivy, vines, sloe, flowering currant, broom, bladder senna, wild rose bush, hawthorn).
- ⌚ The soil is very sandy (more than 85% sand, silt and clay in equal proportions). Less than 50 cm underground, there is a slab (probably a layer of marl) of irregular thickness that tree roots are unable to penetrate.

For this range, the complexity is technical in nature. It will be necessary to perforate the slab so that the trees can take root deep in the ground. Some very well established walnut trees surrounding the area appear to be able to collect a portion of the water that runs off the slab surface or is able to penetrate the slab. The use of a mechanical drill or shovel will be required for planting purposes, but it is not guaranteed to succeed. The proposal is to plant mulberry and walnut trees (replaced with more rustic acacias or oaks if the slab proves impenetrable), acacias, honey-locust, pubescent oaks and red oaks.

➡ Despite the difficult nature of the terrain, the irrigation option is not being adopted, since it does not encourage the trees to establish deep roots and does not ensure the plants' survival over the medium term.

Figure 2 - Proposed upgrades for Farm B



The estimated cost, including the acquisition of the plants, protection with square woven fabric at the foot of each tree and along the length of the hedge, protective tubing, stakes, and labour for planting, is as follows:

- €385 (excluding tax) for 35 individual trees;
- €1,210 (excluding tax) for eight 10-metre guide hedges;
- €1,174 (excluding tax) for a 90-metre border hedge.

Depending on whether the plants successfully grow and survive over time, the 35 standard trees could be harvested as lumber, but this objective should be viewed as a bonus benefit and not likely to be an option for some fifty years. The sole aim in this case is to enhance the landscape and the welfare of the hens. If the plants die, they will be replaced with the trees that have survived best, most likely the acacias.

Conclusion

The presentation of these two case studies indicates some avenues to consider and a method that can be applied to other poultry ranges. However, the proposals put forth for the farms that were monitored are not universally applicable. They have been adapted to the agro-pedoclimatic conditions at each site; in addition, they vary with the breeder's preferred approach and wishes. The poultry range may also have other economic benefits, such as the production of wood for dendro energy or crops.

The poultry range is an important factor in blending the farm into the landscape. It can also be addressed from a green standpoint, in terms of planting as a means of reducing the farm's ecological footprint, or the stockpiling of carbon permits. Moreover, it can limit the fragmentation of natural areas and encourage a form of biodiversity, so as to combat the image of intensive husbandry.

Nonetheless, greater research is needed into managing the range at a poultry farming operation, since the choice of enhancements can vary depending on the preferred direction to be taken, and these options may sometimes be contradictory. In this light, no evaluation has been made here of the other positive effects that trees can have on a pen (preventing death from heat, for example) as well as the negative effects (the possible increase in predation by birds of prey or foxes, supplemental food consumption). Similarly, health regulations must also be taken into account. In our two case studies, for example, a decision was made not to plant fruit trees, in accordance with regulations governing salmonella and the proposed biosafety measures contained in decrees on bird flu.

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19 ■ A New Prefabricated 3,200 Sow Pig Unit and its Environmental Impact Assessment

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A new 3,200 sow prefabricated pig unit was built this year near Vendas Novas, south of Lisbon, which corresponds to 1% of the Portuguese pig herd. The main objectives of this work are to present and discuss the different aspects and technical solutions that were chosen regarding: a) location, dimensions and main units; b) animal management, building layouts, materials and equipment for the different main units, which include mating, gestation, farrowing and lactation, growing, fattening and finishing.

Environmental control equipment in animal buildings is discussed and the differences between several types of buildings are highlighted.

Finally, attention is given to slurry management and its application on farms. Measures to monitor the environmental impact on the soil, water and air are described.

Pig farm: localization, size and main units

The firm Extrinvest Agropecuária bought a 456-hectare farm near Vendas Novas, Portugal, to set up a new prefabricated 3,200 sow pig unit in 2009, in total confinement. The farm is covered by PIGS (integrated program for piggeries management) in the Montemor-o-Novo area and is placed inside the Tejo river hydrographical basin.

The pig farm has three independent main animal housing units: breeding, growing, and fattening. They were designed on the basis of a multi-site layout to reduce disease contamination. The other buildings on the farmstead include a quarantine, an infirmary, residences, office, cloakrooms, laundry, dining hall, a dangerous waste store and, further away, a waste treatment and slurry storage unit. The farmstead is 2.5 km from the main national road giving access to the farm.

Animal housing: buildings and equipment

Access to the breeding unit is through the cloakroom, which has three independent shower rooms, one for its animal unit. Any person entering the unit takes a shower and puts on washed overalls, boots and, if necessary, gloves.

The buildings were designed based on an American model. They are prefabricated with wooden structures. The roof is made of white PVC corrugated panels and is supported by trusses that reach up to 26 m long. A ceiling runs underneath the roof at a height of 2.4 m. The walls are made of double PVC panels. Concrete is used on most floors, either solid or slats over the slurry channels.

The feedstuff is kept in metal silos outside the animal buildings. There are two silos for each main feeding line, working in parallel, to avoid the mixing of different foods and to allow for proper cleaning.

Breeding unit

The breeding unit includes five buildings, one for mating, two for gestation and two for farrowing and lactation. It is localized in the northeast area of the farmstead (figure 1).



Figure 1. Breeding unit showing, from left, the buildings for mating, gestation (two) and farrowing.

Mating

During the first stage of the unit the sows F1 Large White x Land Race are bought from selected pig units at six months of age, in static groups. Later on, the selected sows born in the unit will be managed in dynamic groups. The boars are housed near the dry sows and are used to stimulate the sows and detect oestrus. The steel partitions in stalls and pens allow visual contact between the animals. Two groups of 80 sows are artificially inseminated per week with Pietran semen. The sows are kept in individual stalls during the first 3-4 weeks to ensure that they are in gestation and then kept in groups until 42 days after insemination (figure 2). These pens have individual feeding stalls. The individual sow stalls are exited at the front. The boars may be kept in individual stalls adjacent to the sows or in groups in pens at one end of the building. Controlled automatic feeding is used. Concrete linear drinkers run at the front of the pens.



Figure 2. Sow stalls and pens for dry sows and served sows before and after insemination.

Gestation

Two buildings are used to house 800 sows in ten groups of 80 sows during 11 weeks. The pens are 18 m long by 10 m wide. Half of the floor is of solid concrete and the other half of concrete slats. The pens have several opaque partitions that allow some sows to hide from others and so reduce tension and conflicts.

Automatic individual feeding is achieved with two feeding stations per pen (figure 3). The amount of food given depends on each defined feeding curve. Only one sow is allowed in at a time and the feeding period is also controlled. After the programmed feeding time has elapsed, the plate with the food is removed and another sow is allowed in. The central processing unit controls all the sows' cycles and automatic feeding.



Figure 3. Gestation building with a feeding unit showing the entrance door.

Later on, when the piggery starts to handle the dynamic groups of sows, the feeding stations will have two ways out, to separate the primiparous sows from the other sows and to allow for individual handling.

Farrowing and lactation

The two identical farrowing buildings have 10 rooms each, with 36 farrowing pens per room, split into four parallel rows. Each building has a main lateral corridor giving access to the rooms and acting as an antechamber for the external incoming air.

The sows are brought in 4 days before farrowing and are dried within 4 weeks of lactation, then returned to the gestation buildings. The weaned piglets weighing around 7 kg are transferred to the growing unit.



Figure 4. Farrowing pen with crate and piglets' nest at the far left.

The pens are 2.44 m x 1.5 m, have removable PVC partitions, allowing them to be converted into collective farrowing pens at a later date. The galvanized steel farrowing crates enable the sows to exit through the front and were designed to reduce injury to the piglets. The sows' feeding is automatically controlled. The cast iron mesh floor is an appropriate size for the piglets and sow (figure 4). The piglets' solid nest at one side of the pen is warmed with hot water coming from a central boiler. One week is reserved for the cleaning and disinfection of the rooms between batches.

Growing

The growing unit is located after and separate from the breeding unit. At present they are separated by a eucalyptus wood, which acts as a natural barrier. It comprises two buildings and has toilets at the entrance like the fattening unit. Each building has 8 rooms for 750 weaned piglets each, which stay until they reach 11 weeks of age, with a live weight of approximately 28 kg. The rooms are 18.5 m x 14 m, corresponding to 0.345 m² per animal. The layout is similar to the farrowing units, with a lateral corridor running along the building, and the external walls are fitted with evaporative cooling panels. The floor is made of white PVC mesh that stimulates feed intake and covers the whole slurry pit.

Automatic controlled stainless steel hopper troughs for six pigs and drinkers for 10 weaners are used throughout the rooms. The room's sanitary period is also one week between batches.

Fattening and finishing

The fattening and finishing unit is placed after the growing unit, at the southwest end of the animal area. It includes 8 similar pavilions, each 90 m long by 24 m wide, divided into two rooms for 750 pigs. With this layout, no mixing of pigs occurs from growing to fattening, avoiding fights and animal injuries, in accordance with animal welfare. They are equipped with *ad libitum* automatic filled troughs and bow drinkers. The pigs stay until reaching 25 weeks of age with approximately 110 kg live weight. The entire floor is made of concrete slats laid over a slurry pit, with 0.75 m² per pig (figure 5).



Figure 5. A fattening and finishing building during construction, showing the roof and ceiling structures, slatted floor and slurry pit.

Environmental control

Environmental control, namely of air temperature and relative humidity in all buildings, is achieved through heating, forced ventilation and evaporative cooling, due to the external climatic conditions. In the buildings for mating (figure 1), gestation and fattening, tunnel ventilation is used. Buildings for farrowing and growing have crossed forced ventilation, also with evaporative cooling when required. Air inlets are adjusted independently for each room.

Fattening and finishing buildings have a second set of fans that extract the polluted air and gases under the slats and guarantee a minimum air flow rate.

A plastic curtain automatic safety system allows natural ventilation in case of power failure, dropping the curtains at the lateral walls.

Slurry management and environmental impact assessment

In such a large pig unit, environmental issues are of paramount importance. The private firm that wanted to build a new pig farm had to submit the project and show to the local and national authorities that the project complied with Portuguese legislation in relation to air, soil and water pollution, in order to get the necessary permission to start construction. It was a long process.

Slurry management

The treatment of the slurry produced in the farm includes solid separation, sedimentation and lagoon anaerobic decomposition of the liquid fraction.

The slurry treatment unit receives the slurry which flows by gravity from all the animal buildings. It comprises a reception pit, pumping system, solid separators, concrete platform for mud, two sedimentation lagoons working in parallel each six months, three anaerobic lagoons working in series and a surplus lagoon for any breakdown. All lagoons are lined with a geotextile membrane and a geo-membrane of high density polyethylene to avoid any soil infiltration and pollution. According to national legislation, the unit has to guarantee a minimum slurry storage period of 210 days. Not including the slurry pits in the animal buildings, the installed total capacity of storage is over 400 days.



Figure 6. Partial view of the anaerobic lagoons.

Environmental impact assessment

The environmental impact declaration is valid for 6 years and includes many procedures.

Building phase

The procedures include reducing the risks of soil erosion, the protection and maintenance of natural water lines, and the construction of two lagoons to store rain water collected from the building roofs, among many others. The water must be used during the production phase for washing down the buildings and for evaporative cooling.

Production phase

The effluents must present an 80% reduction in total nitrogen after treatment. They are used for the ferti-irrigation of the farm, mainly occupied by eucalyptus forest, but which will start to produce corn to be used to produce concentrates to feed the pigs. The amount applied to the soil cannot exceed 170 kg ammoniacal nitrogen per hectare, and slurry can only be spread between May and September to avoid surface flow off.

Effluent characteristics are measured monthly at the entrance to the reception pit, as well as the effluent to be applied to the soil. They include pH, BOD₅, QOD, TSS, P, N, and Cu. The mud produced will be used by other farms for soil enrichment.

Surface water quality is tested annually in a small river that crosses the farm, upstream and downstream of the farmstead. TSS, pH, BOD₅ and faecal coliforms are determined. Underground water is controlled by annual sampling from two artesian wells and includes organoleptic parameters, physico-chemical parameters and microbiological parameters. The consumption of water, electricity, diesel and propane is monitored all year round.

Air quality procedures include the reduction of odours and a ban on slurry spreading at weekends. Inside the animal buildings, CO₂ and ammonia concentrations are monitored and controlled through forced ventilation.

Carcasses of dead animals are cold stored in plastic bags and delivered to a specialized, licensed disposal company. In the future, an incinerator will be built to burn the carcasses and the energy collected will be used for water heating of the farrowing rooms.

Deactivation phase

After closing down the piggery, the terrain morphology must be restored and proper natural water drainage ensured. All lagoons will be cleaned and must be filled with soil or used as artificial humid areas. All buildings have to be dismantled.

This set of procedures should minimize the risk of an environmental impact and ensure a more sustainable agriculture and animal production activity, for the benefit of future generations.

20 ▀ Noise in pig housings

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Noise may be a potential stressor in intensive animal rearing because of high number of noise-producing animals, needs for more intensive ventilation system and feeding and excrement removal lines. All this may result in relatively high level of noise that affects not only animals but also the tending personnel. High sensitivity to noise levels has been observed in pigs with some potential impact on their behaviour. In our study we measured exposure of pigs to noise in 3 houses for three categories of pigs, farrowing house, house for weanlings and house for sows before mating and after confirmation of gravidity. Although our measurements failed to identify high exposure of pigs to noise, this issue should be monitored further to avoid unnecessary stress in this very sensitive species of animals.

Key words: noise, pig housing

Introduction

Animals in intensive rearing systems, are increasingly exposed to various stressful situations arising from animal rearing practices. Handling of animals, confined housing conditions or social stress in group housing are strong stressors throughout the life of farm animals causing acute or chronic activation of the hypothalamo-pituitary-adrenocortical (HPA) axis and the sympathoadrenomedullary (SAM) system (Otten et al., 2004).

Noise has also been identified as an aversive stimulus during animal housing. Animals are exposed to greater noise by the mechanization of many husbandry procedures. The noise produced in animal production affects the tending personnel and veterinarians and may even lead to damaged hearing (Jackson 2002). The damage to hearing is insidious in its nature because it occurs over some time and when the levels are sufficiently high this damage can be irreversible. The damage occurs when the hair like cells (cilia) that receive the sound waves are repeatedly or very violently flattened. Initially, given enough quiet time for regeneration, the damage may be reversible. Because of that the maximum noise level allowable over an eight hour period is 85 dB. Longer exposure to higher levels may result in damage.

Reports regarding the influence of noise on the physiological, behavioral and productive traits of animals are contrasting especially because response to sound stimulation are species-specific and largely depend on the nature, loudness and familiarity of the noise.

Farm animals are exposed to noise not only in housings (Talling et al., 1998a; Schäffer et al., 2001) but also during the transport and at the abattoir (Geverink et al., 1998). Noise experienced during housing of farm animals can be short-term and acute (e.g. screaming before feeding times) or uniform and chronic or chronic intermittent (e.g. basal sound levels caused by crowded animals, mechanical ventilation). Average sound pressure levels ranging between 69 and 78 dB were recorded in fattening units of pig farms, between 88 and 96 dB during transport and between 85 and 97 dB at the abattoir (Talling et al., 1998a). Behaviour of piglets and sows during suckling in relation to sound levels were investigated by Bo Algers et al. (1985). The external noise changed the vocalisation feeding pattern so that the noise-exposed piglets gained

less milk and their weight gains were affected. The aim of our study was to measure and evaluate the noise level on two different farms in houses for fattening pigs.

Material and methods

Measurements were carried out on 2 typical farms for fattening pigs with ad libitum feeding by dry mixed feed. Pigs were housed in pens without litter. Air exchange in the houses was ensured by forced ventilation system. The measurements were carried out with an integrated noise measurement apparatus NORSONIC 118, accuracy class 1, with 1/3 frequency analysis.

Results and discussion

Results obtained in our study are presented in Fig.1. – 4.and Tables 1 – 2.

**Table 5 – Pig farm 1
Noise level**

| Parameter | Level [dB] | Parameter | Level [dB] | Percentile | Level [dB] |
|-------------------|------------|--------------------|------------|------------------|------------|
| L _{Aeq} | 74,8 | L _{Ceq} | 75,8 | L _{0,1} | 98,8 |
| L _{Amax} | 103,7 | L _{CFmax} | 102,6 | L ₁ | 82,6 |
| L _{Amin} | 53,7 | L _{Cpeak} | 113,4 | L ₅ | 76,0 |
| | | | | L ₁₀ | 73,4 |
| | | | | L ₅₀ | 65,4 |
| | | | | L ₉₀ | 59,7 |
| | | | | L ₉₅ | 58,3 |
| | | | | L ₉₉ | 56,2 |

**Figure 8 – Pig farm 1
1/3 octave spectrum (dB)**

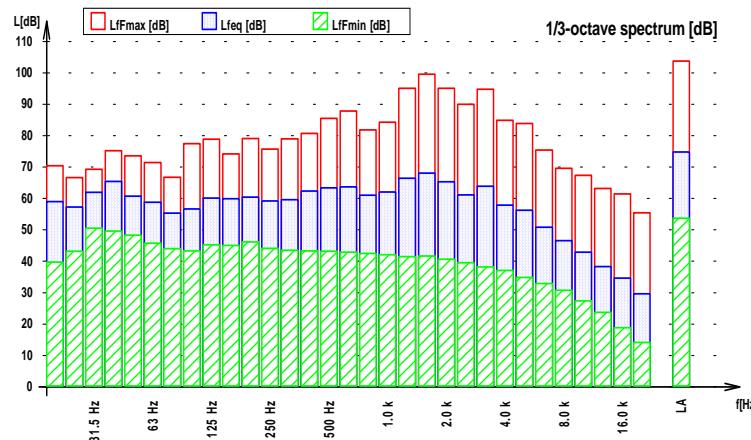


Figure 2 – Pig farm 1
Time overview

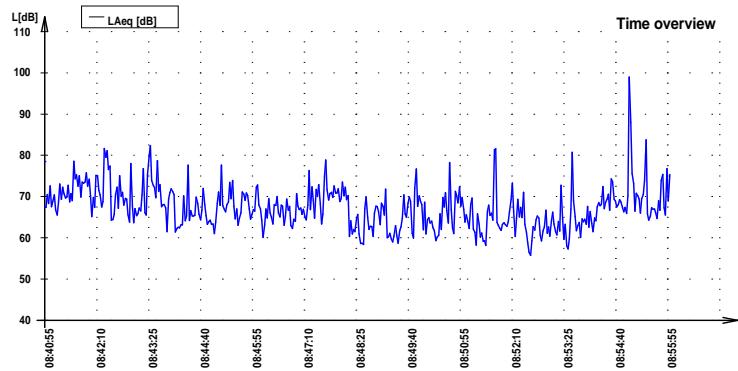


Table 2 – Pig farm 2
Noise level

| Parameter | Level [dB] | Parameter | Level [dB] | Percentile | Level [dB] |
|-------------------|------------|--------------------|------------|------------------|------------|
| L _{Aeq} | 76,5 | L _{Ceq} | 79,1 | L _{0,1} | 94,2 |
| L _{Amax} | 96,0 | L _{CFmax} | 98,6 | L ₁ | 85,6 |
| L _{Amin} | 69,5 | L _{Cpeak} | 112,4 | L ₅ | 80,8 |
| | | | | L ₁₀ | 78,6 |
| | | | | L ₅₀ | 73,6 |
| | | | | L ₉₀ | 71,4 |
| | | | | L ₉₅ | 71,0 |
| | | | | L ₉₉ | 70,4 |

Figure 3 – Pig farm 2
1/3 octave spectrum (dB)

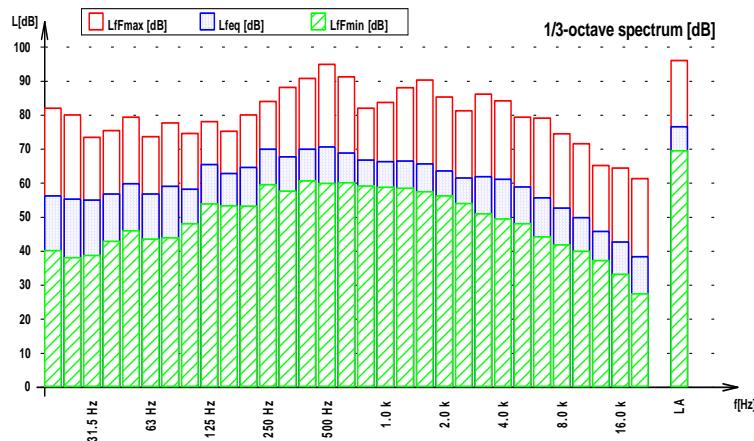
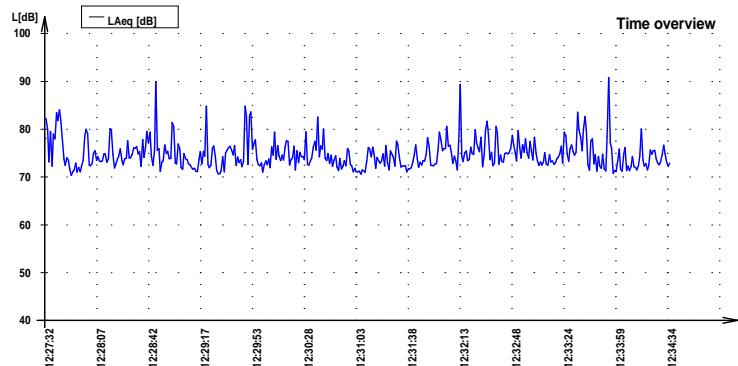


Figure 4 – Pig farm 2
Time overview



Different species were observed for the effects of acute and chronic noise exposure on the behaviour as well as on the neuroendocrine and immune system (Segal et al., 1989; Raaij et al., 1996). Very little information is available about acute or chronic noise effects on pigs. Acute sound exposure was found to increase active behaviour and heart rate (Talling et al., 1998b). A single and short-term noise exposure of pigs at 120 dB was found to increase plasma glucocorticoid concentrations, but had no effect on plasma catecholamines (Kemper et al., 1976).

Harmful noise in animal production originates from various sources: feeding 104-115 dB, mating 94-115 dB, high-pressure cleaning 105 dB, feed mixing 88-93 dB. However, these values are only orientational and may differ according to the technologies used. There are respective regulations which set the minimum requirements on protection of herds for individual categories of animals. For pigs, which are very sensitive to changes in noise levels, these requirements are specified by the Statutory Order of SR No. 325/2003 that amends and supplements the Statutory Order of SR No. 735/2002 of the Civil Code specifying minimum standards for protection of pigs. In the part of a building where pigs are reared the noise level must not exceed 85 dB and there are also limits on background or sudden noise.

Various levels of noise were observed in pigs in relation to the type of ventilation. The sound level measured in mechanically ventilated pig buildings was 73 db but naturally ventilated buildings were on average 10 dB quieter. The frequency of sound on farms is also important and ranges between 20 to 6300 Hz.

Our results did not indicate high exposure to noise of fattening pigs on two observed farms. However, with regard to the fact that even short-lasting but intensive noise can have harmful effect not only on animals but also on personnel further monitoring of its level is justified.

Conclusion

Noise in intensive animal houses has recently attracted considerable attention with regard to both animal well-being and working conditions of animal tenders. High sensitivity to noise levels has been observed in pigs with some potential impact on their behaviour. Some sources of noise (ventilation system) result in almost constant exposure while others can produce short-lasting but intensive noise (feeding and manure removal lines).

In the examined pig houses we did not measure such a high levels as reported by some authors for ad libitum fed pigs. Although we detected high levels of Lpeak , the equivalent levels obtained by long-term measurements did not exceed the limit LAeq = 85 dB.

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21 ■ Fresh slurry: The frequent removal of pig house slurry

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Since 1993, a process for frequent removal of slurry in pig houses has been tested and refined at the pig experimental station in Guernévez, in France's Brittany region. Various systems are being studied for removing and treating manure for subsequent recycling. Four piggeries without a dung grid have been compared with two pig houses with slatted floors for collecting manure. The comparison is focusing on zootechnical performance, respiratory indicators and nitrogenous gas emissions. At the same time, an innovative system is currently being developed for complete recycling of pig excreta within pig houses for the purpose of washing pit floors.

Introduction / Bibliography

A large majority of pigs in France are raised on slatted floors. The collection of slurry underneath the animals leads to volatilization of some of the nitrogen, creating ammonia (NH_3) and nitrous oxide (N_2O). In all, the nitrogen that is lost in this manner accounts for 25% of the nitrogen excreted by the pigs in faeces and urine (CORPEN, 2003). In addition, environmental regulations call for limiting the application of nitrogen and phosphorus on agricultural land. As a result, in some cases pig farmers are forced to treat the excreta produced in the course of pig breeding.

Regular drainage of faeces from piggeries, combined with early phase separation, limits the formation of ammonia. In particular, it prevents hydrolysis of the urea, which changes to ammonia and carbon dioxide in the presence of water through the catalytic effect of urease (Aarnink, 1997). Research carried out in the Netherlands and Canada suggests that the use of systems for frequent drainage of excreta reduces ammonia emissions at pig houses by 50% to 70% (Hendriks and Van de Weerdhof, 1999; Belzile et al, 2006). Numerous systems, both mechanical and hydraulic, are available (Ramonet et al, 2007).

Buildings of this type are significant from a zootechnical standpoint, since they improve sanitary conditions as well as the breeding environment. Madec et al (1999) recommend that the grids be drained and the barns washed and disinfected at farms where severe wasting disease has become a problem among piglets. The viruses, bacteria and parasites excreted by the animals can survive in the slurry for several weeks (Strauch, 1987). Regular removal of excreta can therefore lead to more effective medicinal treatment and shorter periods of poor health.

The Agricultural Chambers of Brittany are developing and testing both mechanical and hydraulic systems at the Guernévez pig experimental station. A variety of methods are being used to process manure in combination with hydraulic systems: simple gridding, vermicfiltration, macrophyte ponds, biological and membrane treatment. Over the past two years, the results in terms of zootechnical and sanitary effectiveness and environmental performance have been recorded and analysed.

Material and methods

Buildings and equipment

The Guernévez experimental station develops, tests and offers demonstrations of innovative pig house buildings and equipment. To that end, for over ten years the station has focused its research on piggery systems with regular drainage of excreta versus piggeries without a grid.

Four pig fattening houses are operating with this system, as well as a house for gestating pigs. They are all mounted on built-in slatted floors.

The first fattening house equipped with such a system includes 60 spots for meat-type pigs fed with soup, distributed among five pens with 12 pigs each. It operates on the principle of mechanical removal of the excreta, with a V-shaped scraper system (Prolap® separator) used for solid and liquid phase separation directly underneath the animals. The scraping is performed three to 13 times a day (increasing once a day for each week of fattening). Excess pressure is dynamically vented within the piggery, with air intake via a ceiling diffuser made of perforated aluminium and glass wool.

The second fattening house includes 72 spots for meat-type pigs fed with soup, distributed among six pens with 12 pigs each. It operates on the principle of hydraulic drainage of excreta on a draining lying box (Caliclean® process). Large excreta are separated at one end of the pig house using a screening system (1-mm mesh). The most liquid portion is returned to the start of the piggery, where it carries excreta that falls into drains built into the concrete floor. The drains are cleaned six times a day for a period of three minutes. The pig house is dynamically vented for negative pressure and upper extraction; air intake is via a tank made of aluminium and glass wool.

The third fattening house includes 72 spots for meat-type pigs, also fed with soup and distributed among six pens containing 12 pigs each. It operates on the principle of hydraulic evacuation of excreta using dump buckets over a corrugated pit floor (Igimax® process). The flushing liquid comes from excreta subjected to phase separation via a vibrating screen followed by vermicfiltration. The flushing is performed six times a day at a rate of 600 litres per flush, i.e., 150 litres per metre over a 12-metre-long space. The piggery is dynamically vented for negative pressure and upper extraction, with air intake via a vent over each channel.

The fourth pig fattening house is an existing piggery that was redesigned to allow for removal of waste by flushing. It has 72 spots, with four pens housing 18 pigs each. The pigs are fed with soup. The flushing is performed with a flush valve (200 mm in diameter) over a pit floor equipped with flushing channels. The flushing liquid comes from excreta subjected to centrifugation, biological treatment using activated sludge and membrane filtration (BIOSEP® process). A flush is performed six times daily, at a volume of 400 litres per flush, i.e., 100 litres per metre over a 16-metre-long space. The pig house is dynamically vented for negative pressure and upper extraction; air intake is via a vent directed towards the channel.

The redesigned house for gestating pigs, with regular removal of excreta, was intended for 30 sows. Manure is removed by flushing six times a day at a rate of 800 litres per flush, i.e., 100 litres per metre over a 12-metre-long space. The liquid used for each flush comes from the treatment of excreta via screening, vermiculture and macrophyte ponds. The pig house is dynamically vented for negative pressure and lower extraction.

Test plan and analysis of the results

The results presented here reflect an analysis of zootechnical performance (growth, feed conversion ratio, muscle content in each cut, loss percentage) among animals raised in fattening houses with regular removal of excreta as compared with animals raised in buildings with floor slats below each station during the same period.

The analysis is also intended to compare the results obtained for two known respiratory

indicators (percentage of coughing and sneezing and pneumonia score on a scale of 28) across four bands between the four fattening houses without a grid and two control piggeries with slatted floors below each station.

In addition, continuous measurements (every 12 minutes) of ammonia and nitrous oxide were taken in the four test fattening barns and the two control barns, again across four bands and during four periods of 14 days per band (from Day 7 to Day 21 of fattening, Day 28 to Day 42, Day 56 to Day 70 and Day 84 to Day 98). These measurements were taken using a photoacoustic infrared analyser connected to the six test and control pig houses. The measurements were coupled with an estimate of simultaneous air flows, calculated on the basis of the hydrobalance within the pig house (using the equations from the CIGR, 1984). This can be used to calculate ammonia and nitrous oxide emissions by pig house, band and period. When excreta could be collected in full by period and analysed, assessments of nitrogen, phosphorus, potassium, copper and zinc could be made in order to validate the method used, specifically the measurement of nitrogenous gas emissions. In the gestation pig house, the same measurements could be taken over the course of a week, using the same analyser, to compare the pig house with regular removal of excreta with a control gestation pig house built above slatted floors. The various treatments have been assessed over the course of a range of experiments. This article offers a summary of the results rather than a detailed description.

Results and discussion

Zootechnical and sanitary performance during fattening

There was a significant difference in the results for pig growth between buildings with slatted floors and those without such a grid (liquid manure): pigs in buildings without a grid had added growth of 30 g/d ($p<0.05$) (Table 1). However, there was also a significant difference in pig growth ($p<0.05$) among buildings without a grid: those with a draining lying box and a V-shaped scraper system yielded the best growth rates (781 g/d and 80 g/d respectively, vs. 750 g/d). Feed conversion rates showed a similar result, with a significant difference of 0.12 points ($p<0.05$). By contrast, buildings without slatted floors have no impact on muscle content in cuts, which showed very little variation among buildings. The percentage of losses during fattening varied widely from one building to another but also from one band to another, without any major impact from the system adopted (slatted floors or slurry removal).

The respiratory indicators observed show no significant difference between buildings with fresh slurry (12.5%) and those where slurry is captured (15.1%) with regard to coughing and sneezing percentages and the pneumonia scale assigned at the slaughterhouse (1.63 vs. 2.09 respectively). There are notable differences among buildings without slatted floors, but the variations are not meaningful given the small volume of data recorded.

Table 1 – Zootechnical performance by type of pig fattening house (comparison based on data recorded over a three-year period)

| Building | Total number of animals observed | Average daily gain (g/d) | Feed conversion rate | Muscle content of cuts (%) | Loss rate (%) |
|----------------------|----------------------------------|--------------------------|----------------------|----------------------------|---------------|
| Slurry grid | 4,897 | 746+54 a | 2.97+0.22 a | 59.8+1.1 | 3.97+3.10 |
| Fresh slurry | 2,155 | 776+45 b | 2.85+0.24 b | 59.5+0.9 | 3.61+2.71 |
| Draining lying box | 647 | 781+50 a | 2.83+0.21 ab | 59.3+1.1 | 2.63+2.13 |
| Channels | 430 | 754+45 b | 2.96+0.19 a | 59.4+0.7 | 3.71+2.72 |
| Corrugated pit floor | 614 | 750+34 b | 2.86+0.35 ab | 59.6+1.2 | 4.59+2.35 |
| V-shaped scraping | 464 | 807+45 a | 2.78+0.24 b | 59.6+0.9 | 3.53+2.71 |

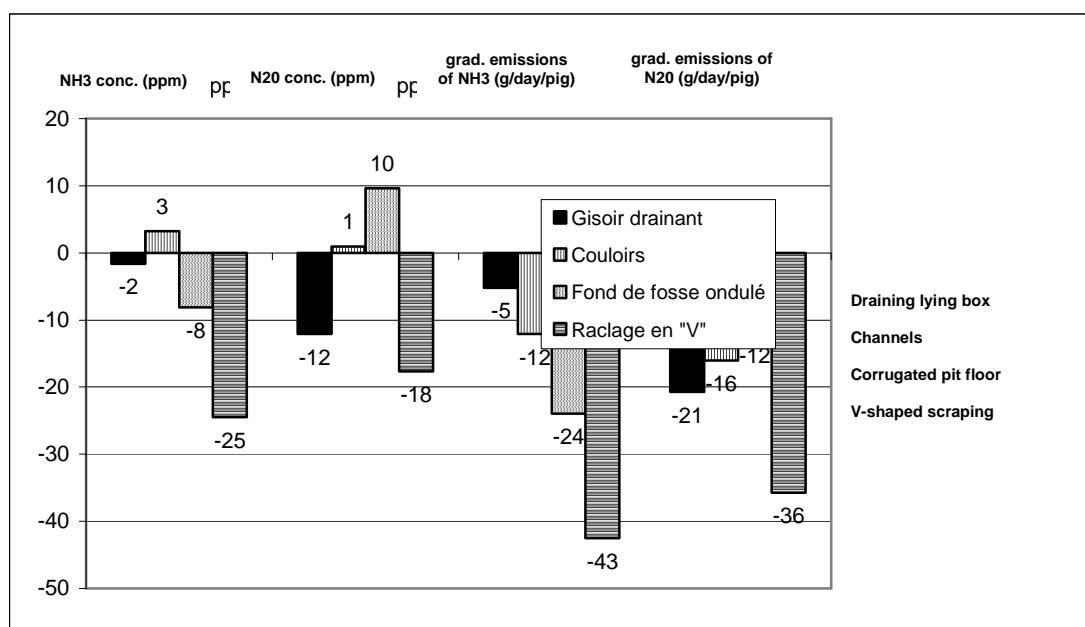
The values assigned with various letters showed a significant difference.

Environment in the barns and gas emissions

For the fattening houses, ammonia concentration in the barns did not differ significantly between the houses with slatted floors and those where slurry is removed (Figure 1). Nonetheless, the house with a V-shaped scraping system stood out from the other buildings, with an average concentration across four bands of 15.5 ppm in this test and 12 ppm in a previous test (Landrain et al, 2009), compared with 20.5 ppm in the buildings with slatted floors.

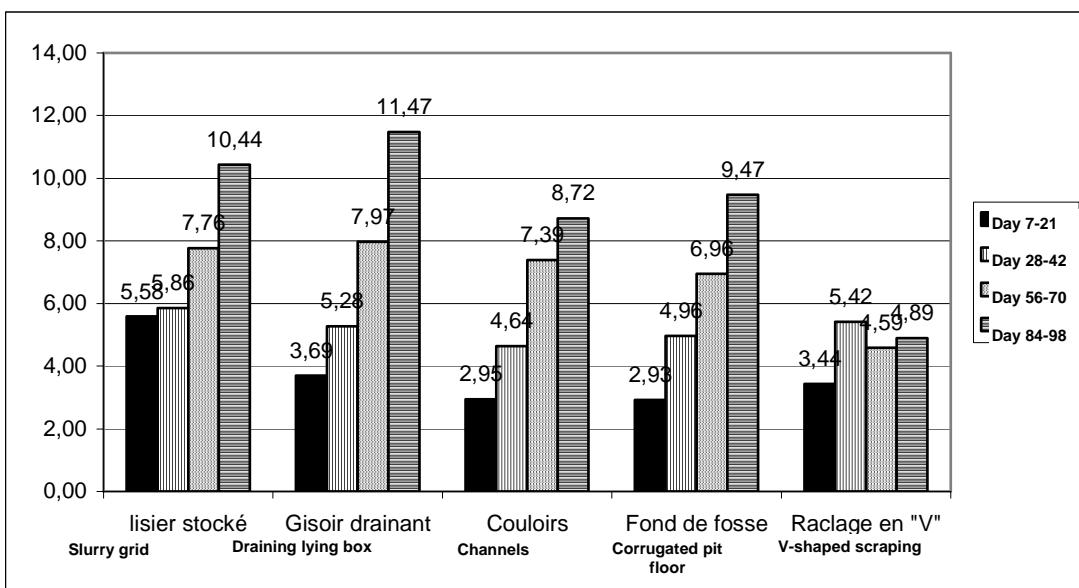
A similar trend was found with nitrogenous gas emissions: buildings where slurry is removed were significantly lower in ammonia and nitrous oxide emissions, by an average of 25% and 24% ($p<0.05$), in comparison with buildings with slatted floors. The building with V-shaped scraping performed notably better than the others in terms of reducing the production of gases that have a major impact on the environment. In this test, ammonia emissions were an average 43% lower, while nitrous oxide emissions averaged 36% lower in the building with the scraper system. These results are a slight drop from those recorded in the 2009 test (54% and 49% respectively) but still significant.

Figure 9 – Average reduction (in %) in concentrations and emissions of nitrogenous gases (ammonia and nitrous oxide) in pig houses where slurry is removed compared with houses where slurry collects under slatted floors



An analysis of the results by fattening period (Figure 2) shows that the buildings where slurry is removed are particularly effective at the start of the fattening period with regard to nitrogenous emissions, but these results show a decline over the course of the fattening process, except in the building with V-shaped scraping. The deterioration is especially marked from about the midpoint of the fattening period for the building with draining lying boxes, which generated much higher emissions by the end of fattening than the buildings with slatted floors for capturing slurry.

Figure 2 - Ammonia emissions (g/pig/d) by building type and fattening period



For the gestation pig house with slurry flushing, the preliminary results from measurements taken in October 2008 are highly encouraging: ammonia concentrations in the gestation sow hall were reduced by 74% with the flushing system, while emissions also fell by 74% (11 g/sow/day versus 44 g in the building with slatted floors).

Results from phase separation and effluent treatment

Each system for removing slurry in pig houses without a grid is coupled with a fairly thorough manure treatment system.

The phase separation made possible with the V-shaped scraping system under the animals ensures that 38% of solid excreta is captured (Landrain et al, 2009). This solid consists of 29% dry material and contains 91% of the phosphorus produced, 55% of the nitrogen and 45% of the potassium. It can be exported after composting in order to comply with mandatory hygienization standards. For this purpose, it is essential to add a straw-type structuring material and turn it over several times. A straw content of approximately 1% to 2% appears to be adequate (testing is underway).

The screening provided in the draining lying box is not notably effective. The liquid portion that is recirculated within the pig house contains 5.3% dry material, compared with 8.7% for the portion caught in the screen (Ramonet et al, 2007).

The vermicfiltration used after the screening to treat excreta from the Igimax® pig house reduced total nitrogen by 85%, phosphorus by 62% and potassium by 54%. This system contributes to the production of two products for export: solids after screening and vermicompost that consists of decomposed wood chips, organic matter from pig excreta and earthworms.

The centrifugation system, biological treatment and membranic filtration used with the flushing treatment in the piggery with flushing channels reduces total nitrogen by 94% and phosphorus by 84%.

Lastly, the system installed for the flushing treatment in the gestation house, which combines a vibrating screen, vermicfiltering and macrophyte ponds, reduced total nitrogen by 95%, phosphorus by 76% and potassium by 71%, while also providing microbial purification of 6Log_{10} for E. Coli and 5Log_{10} for Enterococcus (Morand et al, 2008). This system is especially innovative, since it is the only one that provides for complete recycling of effluent from the pig house with no exterior discharge. It can be used to recover products for export, such as the solids captured in the screen, vermicompost and also the plants found in the lagoons (for energy recovery, for example).

Conclusion

Systems for regular removal of excreta help to improve the pig house environment, so long as the removal is complete and effective throughout the fattening period. This results in enhanced performance that is undoubtedly the result of better sanitary conditions for the animals and, in particular, a reduction in nitrogenous emissions into the atmosphere. Among the buildings that were analysed at the Guernévez station, we should emphasize the marked effect on the gestation building and, above all, the exceptionally good results seen in the building with the V-shaped scraping system during fattening. The other systems appear to be less effective, often as a result of a deterioration in cleaning quality towards the end of the fattening period.

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22 ■ Manure management, hygienic conditions and greenhouse gas emissions in dairy farms using recycled manure solids as bedding for cows

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Twelve cowsheds representative for different manure management were compared to evaluate the suitability and cost efficiency of recycled separated manure solids as bedding for loose housed dairy cows. Housing systems, equipment, machines, labour and litter usage were analysed and compared as well as skin dirtiness, locomotion scores and milk quality. Greenhouse gas emission of cubicles bedded with manure solids were also measured. The survey showed acceptable hygienic conditions of cows housed in cubicle with manure solids. Cost savings related to the recycle of manure solids amounted to 43.6 € cow¹year⁻¹ with reference to labour, machine and litter costs. Emission factors of cubicles bedded with recycled manure solids resulted 6.98 mg · h⁻¹ of NH₃, 44.39 mg · h⁻¹ of N₂O, 32586 mg · h⁻¹ of CO₂ and 145.5 mg · h⁻¹ of CH₄.

Introduction

Manure management affects hygiene, animal welfare, work organization and costs on dairy farms (Barbari and Ferrari 2006; Barbari et al. 2008). The use of recycled separated manure solids (RSMS) as bedding for loose housed dairy cows is considered cost-effective because avoiding the purchase of bedding material. Actually this practice is applied by several dairy farms in USA and by a few modern dairy farms in Italy, although there is some resistance from farm advisors and veterinarians because high bacterial populations in bedding material would influence the level of bacterial counts on udder surface, particularly on teat ends, and increase the risk of mastitis.

Researches carried out in USA to assess the hygienic feasibility of this practice found that properly composted and dried manure solids, with more than 60% dry matter and no or few coliforms, may be used as free stall bedding in conjunction with stringent mastitis control measures without increasing incidence of coliform mastitis (Allen et al., 1980). Composting manure solids effectively reduces coliform counts to few or to zero but coliform counts can increase if the compost in the barn becomes moist or is contaminated by external factors, such as faeces or urine (Carroll and Jasper, 1978). Thus dried composting manure was found satisfactory material for bedding of free stalls if it was dried properly before application.

Zehner et al., (1986) compared various bedding materials and demonstrated that clean, damp bedding may support bacterial growth; they also suggest that high bacterial counts under barn conditions are influenced by factors more complex than type of bedding used. High moisture levels of organic bedding materials will result in rapid growth of environmental bacteria in the bedding contributing to high populations of bacteria on teat ends. Thus the reduction of humidity in manure material is the main consideration of separating dairy manure; however when bedding materials become mixed with manure and urine, rapid growth of environmental mastitis pathogens start because of available nutrients (Novák et al. 2004).

Schrade et al. (2006) found that bedding material of compost and RSMS is comparable with straw mattresses from the point of view of cubicle maintenance, animal welfare and hygiene.

With regard to the effectiveness of chemical treatments of RSMS Hogan et al. (1999) compared bacterial counts of untreated recycled manure bedding and those of recycled manure bedding treated with either an alkaline commercial bedding conditioner, acidic commercial bedding conditioner or hydrated lime. The results of this study showed the use of acidic conditioner in recycled manure has little effect on bacteria in bedding and that alkaline conditioners initially reduce bacterial counts even if the antibacterial effects diminish two days after the treatment. However this kind of treatments may be suggested for herds affected by high rate of mastitis in order to control the fast bacterial growth during the first 2-3 days after bedding.

The main aim of this study is to improve loose housing systems and waste management in dairy farms in order to improve welfare and hygiene of cows and to reduce costs for dairy farms.

Materials and Methods

Twelve dairy farms were considered in this study in order to compare hygienic conditions of milking cows in loose housing systems with different lying areas and manure management (Table 1).

Table 1 – Technical parameters of lying areas, bedding use, type of flooring and manure handling systems in twelve reference cowsheds able title

| Farm | Lying area | Type of bedding | Bedding use kg cow ⁻¹ d ⁻¹ | Type of flooring | Manure removal system |
|------|-----------------------|-----------------|---|------------------|-----------------------|
| 1 | Cubicles | Manure solids | 9.0 | Solid | Flushing |
| 2 | Cubicles | Manure solids | 9.0 | Solid | Scrapers |
| 3 | Cubicles | Manure solids | 9.0 | Solid | Flushing |
| 4 | Cubicles | Chopped straw | 2.0 | Solid | Flushing |
| 5 | Cubicles - mattresses | Wood shavings | 0.7 | Slatted | Flushing |
| 6 | Cubicles | Wood shavings | 0.4 | Slatted | Storage pit |
| 7 | Cubicles - mattresses | | 0.0 | Slatted | Storage pit |
| 8 | Cubicles | Straw | 3.3 | Solid | Scrapers |
| 9 | Cubicles | Straw | 0.9 | Solid | Scrapers |
| 10 | Cubicles | Straw | 2.3 | Solid | Scrapers |
| 11 | Sloped bedded floor | Straw | 3.0 | Solid | Scraper |
| 12 | Sloped bedded floor | Chopped straw | 2.4 | Solid | Scraper |

Three dairy farms using RSMS as bedding in cubicles have been surveyed; in these farms fresh manure solids are spread in cubicles every two weeks just next to mechanical separation without any previous chemical or physical treatments. The dry matter content of manure solids in the cubicles was analyzed two times per farm in summer and winter.

The other farms, except for farm 7, were used to spread organic bedding materials (chopped or whole straw or wood shavings) in cubicles or in sloped floor areas two or three times a week.

In each cowshed type of lying area, type of bedding, bedding consumption, manure removal system and type of flooring were considered. The following kind of lying areas were analyzed:

- cubicles bedded with RSMS;
- cubicles bedded with $2 \text{ kg} \cdot \text{cow}^{-1} \cdot \text{d}^{-1}$ or more of straw;
- cubicles bedded with less than $1 \text{ kg} \cdot \text{cow}^{-1} \cdot \text{d}^{-1}$ of straw or wood shavings;
- cubicles not bedded;
- sloped bedded floor.

Cubicles of farms 5 and 7 are provided with mattresses in order to improve cows' comfort and to avoid or minimize the use of bedding. Farms 1, 3, 4 and 5 are equipped with pumps for flushing; except for farm 5 they are provided with mechanical separator for processing manure in order to separate solids from the liquid manure used for flushing. Cowsheds of farms 8, 9, 10, 11 and 12 are equipped with automatic scraper conveyors.

In every cowshed skin dirtiness score (DS) and locomotion score (LS) of milking cows were tested and bulk milk somatic cell count (SCC) were recorded. SCC is one of the indicators of udder health and milk quality. The nine farms not using manure solids as bedding (from 4 to 12 in table 1) were selected among a sample of forty dairy farms already investigated within a survey on manure management in dairy farms in order to be representative for the most popular and the most modern loose housing systems for dairy cattle in the North of Italy.

The DS method was used to analyze five anatomical parts of cows' body: sacro-ischiatic part viewed from the back; back side of the udder viewed from the back; front side of the udder viewed from both sides; legs; feet. The score for each anatomical part varies from 0 to 2 within the following steps: 0 = clean; 0.5 = a few small dirty areas; 1 = less than 50% covered with dirt; 1.5 = more than 50% covered with dirt; 2 = totally covered with dirt. Therefore the total score for each cow ranges from 0 to 10. The number of total scores to be collected in each farm are more than 50% of the number of milking cows in the herd; choice of cows to be scored is random. The mean value of the dirtiness total scores of cows tested in each cowshed expresses the cows' dirtiness score of that cowshed (Houdoy, 1992).

LS is a qualitative index of cows' ability to walk normally (Berry, 1997); it is visually scored on a scale of 1 to 5, where a score 1 reflects a cow that walks normally and a score of 5 reflects a cow that is three-legged lame. LS can also be used to determine the expected milk revenue losses due to lameness.

Four cowsheds in which RSMS are used (including the first three of Table 1) were subjected to the measurement of emissions of ammonia and other greenhouse gases (dinitrogen oxide, carbon dioxide and methane) from the cubicles. Two subsequent sessions of measurements had been carried out in each cowshed in winter and in summer; in each session five cubicles representative of the all cubicles of the barn were measured in the front and in the back part. The measurement technique is based on the possibility to measure the increase in concentration of the gasses in a space consequent to the emission from the surface and collected into an enclosed gasproof air chambers, "static chamber method" (Brewer et al., 1999; Denmers et al., 1998; Hornig et al., 1999; Pedersen et al., 2001). Gas concentration was measured by pumping the headspace air of the containers through the Multi-Gas monitor (Brüel & Kjaer, Type 1302) and back to the chamber in a closed loop.

Results and Discussion

Dirtiness scores were collected from 1284 milking cows and lameness score on 1183 heads; the number of cows tested per farm varies from 30 to 431.

SCC analysis of bulk milk were collected for every farm from August 2004 till July 2007, except for farms 1 and 2 (from January 2005 till July 2007), for farm 3 (from June 2006 till July 2007) and for farm 4 (from September 2006 till July 2007).

Table 2 shows different values of DS, LS and SCC of milking cows in the surveyed cowsheds with different housing systems and with different type and amount of bedding. Significant differences were found among mean values of DS, LS and SCC (ANOVA one-way) of the three cowsheds where RSMS are used and the other categories of cowsheds (tables 3 and 4).

Table 2 – DS, LS and bulk milk SCC in the surveyed reference cowsheds.

| Shed | Lying area | Bedding use kg cow ⁻¹ d ⁻¹ | DS | LS | SCC ¹ |
|------|-----------------------|---|-----------|------------|------------------|
| | | | Mean±SD | Mean±SD | Mean±SD |
| 1 | Cubicles | 9.0 | 3.46±1.08 | 1.36±0.76 | 328±65 |
| 2 | Cubicles | 9.0 | 3.59±0.74 | 1.30±0.54 | 319±68 |
| 3 | Cubicles | 9.0 | 2.70±0.93 | 1.36±0.75 | 327±112 |
| 4 | Cubicles | 2.0 | 1.83±0.51 | 1.17±0.48 | 333±133 |
| 5 | Cubicles - mattresses | 0.7 | 2.46±0.53 | 1.41 ±0.79 | 248±85 |
| 6 | Cubicles | 0.4 | 4.77±0.76 | 1.45±0.74 | 143±89 |
| 7 | Cubicles - mattresses | 0.0 | 4.81±0.76 | 1.68±0.80 | 515±177 |
| 8 | Cubicles | 3.3 | 1.41±0.33 | 1.15±0.41 | 147±44 |
| 9 | Cubicles | 0.9 | 2.14±0.68 | 1.25±0.55 | 136±29 |
| 10 | Cubicles | 2.3 | 1.88±0.52 | 1.16±0.44 | 190±76 |
| 11 | Sloped bedded floor | 3.0 | 5.32±0.88 | 1.18±0.45 | 489±125 |
| 12 | Sloped bedded floor | 2.4 | 4.77±0.98 | 1.41±0.83 | 359±189 |

¹) Nr. · ml⁻¹ · 1000

Table 3 – DS, LS and bulk milk SCC in cowsheds with cubicles in lying area.

| Sheds Nr. | Lying area | DS | LS | SCC ¹ |
|--------------|--|-------------------------|-------------------------|-----------------------|
| | | Mean±SD | Mean±SD | Mean±SD |
| 3 | Cubicles with RSMS | 3.38 ^B ±1.01 | 1.35 ^B ±0.72 | 323 ^B ±72 |
| 3 | Cubicles with litter ≥ 2 kg cow ⁻¹ d ⁻¹ | 1.68 ^D ±0.50 | 1.16 ^C ±0.44 | 231 ^C ±126 |
| 3 | Cubicles with litter < 1 kg cow ⁻¹ d ⁻¹ | 2.72 ^C ±1.12 | 1.35 ^B ±0.69 | 185 ^D ±92 |
| 1 | Cubicles without litter | 4.81 ^A ±0.77 | 1.68 ^A ±0.80 | 514 ^A ±177 |

¹) Nr. · ml⁻¹ · 1000

A, B, C, D) P < 0.01

Table 4 – DS, LS and bulk milk SCC in cowsheds with cubicles bedded with RSMS and in cowsheds with sloped bedded floor.

| Nr. sheds | Lying area | DS | LS | SCC1 |
|-----------|---------------------|-------------------------|-----------|-----------------------|
| | | Mean±SD | Mean±SD | Mean±SD |
| 3 | Cubicles RSMS | 3.38 ^B ±1.01 | 1.35±0.72 | 323 ^B ±72 |
| 2 | Sloped bedded floor | 5.12 ^A ±0.95 | 1.26±0.62 | 428 ^A ±170 |

¹⁾ Nr. . ml-1 . 1000

^{A, B}) P < 0.01

The average DS of surveyed cowsheds in which RSMS are used was found relatively higher (3.38) than cowsheds provided with bedded cubicles (1.68 and 2.72) but lower than cowsheds provided with not bedded cubicles (4.81) or sloped bedded floor (5.12) in the lying area. The results of this study suggests that the practice of using fresh not treated separated manure solids would not improve cleanliness of cows in comparison with the use of traditional bedding materials like straw and wood shaving. Anyway the relatively high value of DS for cows bedded with RSMS could be affected by the relatively high water content of this bedding material which was used in the surveyed farms next after mechanical separation without any previous chemical or physical treatments.

LS of farms using manure solids was found higher (1.35) than LS of farms with cubicles bedded with 2 kg cow⁻¹d⁻¹ or more of straw (1.16) but lower than farms with cubicles non bedded (4.81) while was not found significantly different from cowsheds provided with cubicles and less than 1 kg cow⁻¹ d⁻¹. Although LS of cows is affected by various factors such as the type of flooring, feeding programs and hooves health and care, these results didn't show any negative effects of using RSMS as bedding on the health of cows' hooves.

Bulk milk SCC of cowsheds in which RSMS are used (323000) was found higher on average than cowsheds with bedded cubicles (231000 and 185000) even if lower than cowsheds with not bedded cubicles (514000) and cowsheds with sloped bedded floor (428000). These data showed acceptable health conditions of udders for surveyed cows housed in free stalls bedded with RSMS even though worse than those of cows housed in free stalls bedded with straw or wood shavings. Nevertheless SCC may be affected by other factors which play an important role in the health of udders such as the feeding program, the climate, the milking routine and the maintenance and settings of the milking machine.

The average dry matter content (DM) of RSMS inside the cubicles resulted 43.6% (SD 5.46) whereas the average total Kjeldahl nitrogen (TKN) was 2.23 % of the DM (SD 0.41) and the ammonia nitrogen was 1.17 of DM (SD 2.42). No significant differences were found between these concentration in winter and in summer. The average emission factors of cubicles bedded with recycled manure solids resulted 6.98 mg · h⁻¹ of NH₃, 44.39 mg · h⁻¹ N₂O, 32586 mg · h⁻¹ of CO₂ and 145.5 mg · h⁻¹ of CH₄, with reference to an emissive surface of 2.88 m²/cubicle.

Conclusion

The survey showed acceptable hygienic conditions of dairy cows housed in cubicle barns using RSMS but the assessment of milk quality pointed out relatively high content of somatic cells even if not directly correlated to the use of such bedding. However, as bedding may play a role in the cleanliness of the udder, a careful pre milking hygiene routine may be advisable to control mastitis when using RSMS.

Generally the research highlights the importance of housing systems to keep milking cows in acceptable hygienic conditions. Best hygienic conditions have been assessed in cubicle cowsheds using plenty of straw. Sloped bedded floor in lying area would not be not advisable because of the high levels of cows' skin dirtiness and SCC even if LS management cost of cowsheds with sloped bedded floor was found relatively low.

The main advantage of RSMS for bedding is the low material cost which is zero if free available on farm; in this case the estimation of cost savings is 43.6 € cow¹year⁻¹ with reference to labour, machine and material average costs in Emilia Romagna. The drawback of this practice is the high capital spending on mechanical separator. For these reasons the purchase of a liquid manure separator for producing manure solids as bedding is only worthwhile for relatively large farms or for collective use.

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23 ■ Reduction of Odor and Odorant Emissions from Slurry Stores by Means of Straw Covers

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Swine slurry stored in open storages is a source of airborne contaminants. A customary practice for ammonia and odor control consists of covering the surface of the slurry with floating materials, such as straw. Although straw covers have been proven to generally reduce gaseous emissions, more knowledge is needed regarding how age, moisture content, and microbiological development of the straw cover affect the emissions of odor and odorants to develop recommendations for the practical use of straw covers. This paper provides new information on this topic.

Introduction

Rural areas face specific air quality challenges, such as the emission of gases, odors, dust and microorganisms from intensive livestock production systems. Among them, the largest public concern is the emission of odors from manure storage units, animal housing, and land application of manure, which has become an important social problem in many areas due to its negative impact on the local economy, human health and the quality of rural life. Moreover, in recent times citizen complaints of odor nuisance from livestock operations have become more frequent because of the concentration and increased size of livestock operations, the new residential development in some historically rural areas, and the change in the willingness of the neighboring communities to accept livestock odors. Concerns have been directed at a wide spectrum of livestock production operations. However, the swine industry has received the highest attention from both a public health and public policy standpoint (Blanes-Vidal et al., 2009a).

Covering of open slurry storage facilities is the most widely used ammonia and odor control method in Europe. Covers are usually classified depending on the materials used, into degradable (e.g., straw, silage, oil) or nondegradable (e.g., concrete, plastic). Floating covers are flexible covers made up of degradable or nondegradeble materials (e.g., straw, geotextile materials); that float on the surface of the slurry.

Although organic solid materials originally present in the swine slurry can float on the top of the stored swine slurry, forming a natural crust that lowers gas escape, the formation of an effective layer of floating materials on swine slurry often requires the addition of materials (e.g., straw) on the slurry surface to abate gas emissions (Misselbrook et al., 2005; Blanes-Vidal et al., 2008). Addition of straw is a low cost covering method in comparison to rigid slurry covering systems of concrete or plastic, as straw is a cheap and readily available agricultural material. It has not been completely determined whether the gas emission reduction caused by the covers is mainly the result of physical, chemical, or biological processes (Hudson et al., 2008).

The objectives of this study (Blanes-Vidal et al., 2009b) were to evaluate the effect of the moisture content of straw covers (rainfall) on the reduction of emissions of odor and odorants from stored swine slurry, and to evaluate the contribution of the biological mechanism on the odor reduction effect of straw covers.

Materials and methods

This study compiles data on odor concentration and odorants above swine slurry stored in 15 dynamic flux chambers (Figure 1), covered by straw of different ages and moisture contents, during a 9 wk laboratory scale study (Figure 2). More information can be found in the article by Blanes-Vidal et al., 2009b.

Figure 10 – Experimental set-up



Figure 2 – Slurry stored in flux chambers : A, Uncovered slurry, and B, Slurry covered by straw



A

B

Results

The results showed that aged straw covers significantly reduced emissions of ammonia (by 99%), dimethyl sulfide (by 81%), phenol (82%), *p*-cresol (by 95%), skatole (by 98%), and benzylalcohol (by 97%), while no significant differences were found between uncovered and covered slurry for emission of odor, hydrogen sulfide, volatile fatty acids, dimethyl disulfide, and indole. The moisture content of the straw cover neither affected emissions of odor nor odorants.

Conclusion

This study suggests that the main mechanism for odor and odorants emission reduction from straw covered slurry is as a physical barrier and not as a biofilter. However, the reduction in emissions of specific gases (such as ammonia, dimethyl sulfide, *p*-cresol, and benzyl alcohol) appears to be also caused by the straw cover acting as a biofilter.

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24 ■ Increasing milk yield by improving cow comfort

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A scoring system for cow comfort in freestall barns for dairy cows is developed that results in a single score for a farm. This system has a variable weight for all parameters, depending on their score. The system has been tested in the Netherlands and Mexico and the score has a positive correlation with milk yield.

Introduction

Cow comfort receives substantial attention in modern dairy farming. Many farmers try to provide their cows with a comfortable environment in order to increase production. So far, there is no report, however, about the relation between the general level of cow comfort and milk yield. Of these parameters, milk yield is objectively measurable in an easy way. Cow comfort, however, is not as easy to assess. Certainly if one wants an overall score ¹. In the design of a scoring system for cow comfort several approaches can be chosen. One can look at the cows individually or as a herd, at one moment or over a certain time period, and one can include the environment as well. Also of importance is the health status of the cows. The health status can be influenced by the cow-comfort level, but it is also of major importance for the well-being of a cow. Furthermore, the time needed for the assessment should not be too long. In this paper a scoring system is described that provides an overall score for cow comfort and its relation with milk yield is presented.

Materials and Methods

Farms have been visited in two countries: The Netherlands (27) and Mexico (55). The farms were visited by trained investigators. A scoring system was developed that included both cow- and environment related parameters ². Health status was included as well. The scoring is based on available reports and experience of the authors and was evaluated extensively in practice over two years. The system is constructed out of several chapters. Each chapter needs to score a certain minimum number of points. If not, the difference between the score and the minimum is subtracted from the total score. In the analysis, the level of milk production is correlated with the total score and with each chapter (Pearson correlation in SPSS). Because of the different climatic conditions in Mexico and the Netherlands, the data from both countries are treated separately.

Results

The results are presented in figures 1-4. Mexican farms scored higher than the Dutch farms 227 ± 57 vs 127 ± 87 points resp. (Mean \pm SD). There was a substantial variation between farms as represented by the SD. Therefore, not all the correlations are statistically significant at the $p = 0.05$ level. However, a trend is visible for the Dutch farms in the correlation between milk yield and total score (Fig 1). The Mexican farms gave similar results, but with a larger variation (Fig 2).

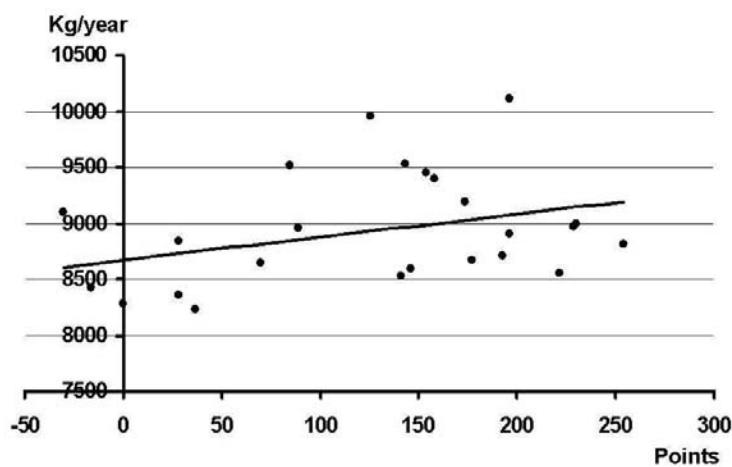


Figure 1: Results of 27 farms in the Netherlands. The milk yield (305 day rolling herd average) is correlated with the cow comfort score ($r = 0.35$; $p = 0.08$)

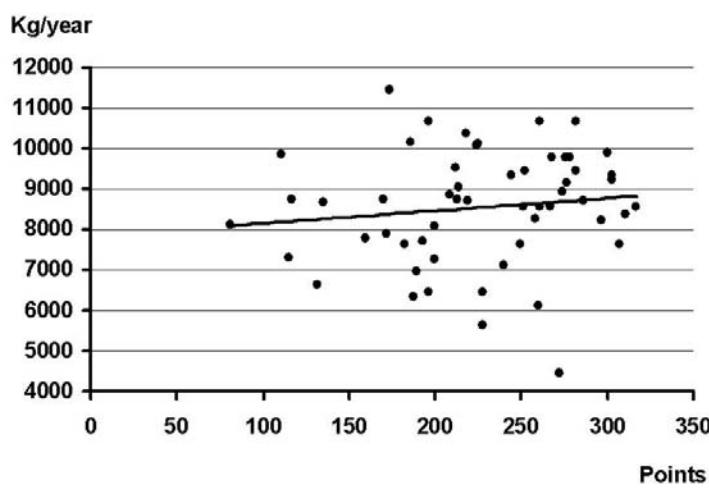


Figure 2: Results of 55 farms in Mexico. The milk yield (305 day rolling herd average) is correlated with the cow comfort score ($r = 0.13$; $p = 0.35$).

Several chapters in the scoring system did have a significant correlation with the milk yield level. Examples are presented in fig 3 and fig 4.

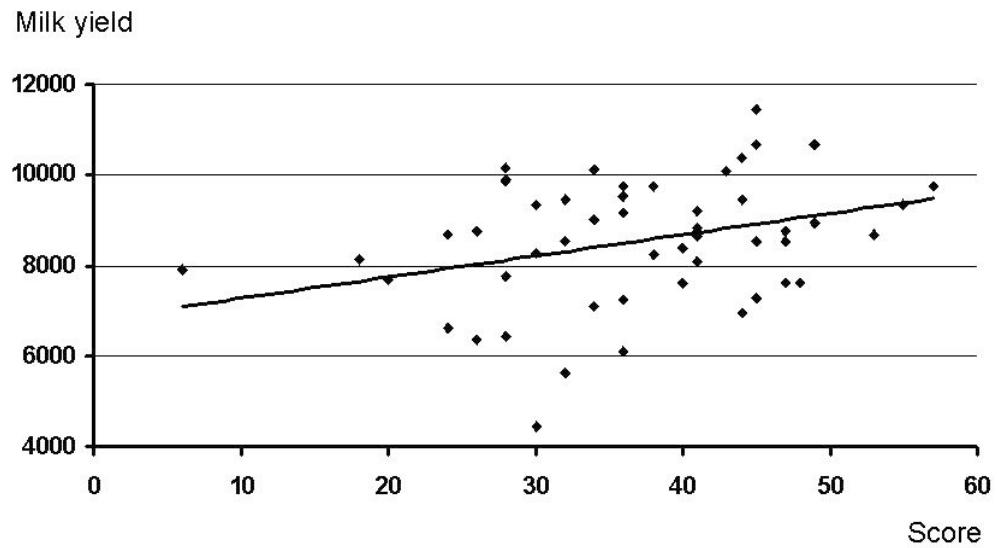


Figure 3: Correlation between freestall comfort and milk yield in the Mexican farms ($r = 0.33$; $p = 0.014$).

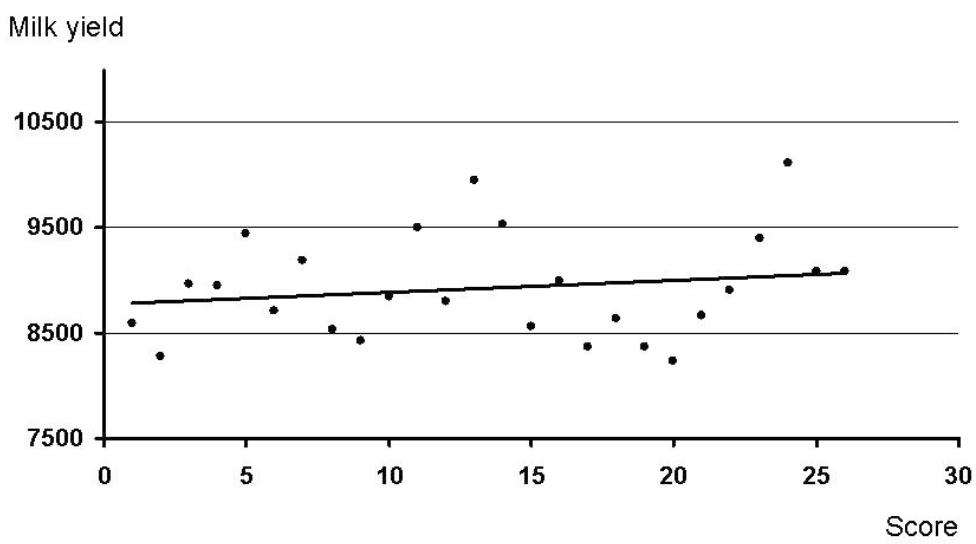


Figure 4: Correlation between floor comfort and milk yield in the Dutch farms ($r = 0.39$; $p = 0.05$).

Remarkably, the health status of the farms had no correlation with production in the Mexican farms and a low, not significant one, in the Dutch farms ($r = 0.03$; $p = 0.82$ and $r = 0.21$; $p = 0.30$, resp.).

Discussion

Since there was no general scoring system reported for cow-comfort, so far, it had to be developed from scratch. This implies that there is nothing to compare it with. However, after using and adjusting the system in the ambulatory clinic of the Veterinary Faculty of Utrecht for more than two years, it was decided to start the present study. It is a system with limitations, but in the current form these are minimal.

The fact that the Mexican farms scored higher than the Dutch farms (227 ± 57 vs 127 ± 87 resp.) (Mean \pm SD), can be explained by the fact that the Mexican farms were selected on the basis that they had to keep records of all diseases and production data. Only the "better" farmers do so, whereas the Dutch farms were selected completely random.

Health parameters were not correlated with the milk yield level at the farms, both in Mexico and the Netherlands. This is surprising because it was expected that these would have a substantial impact³⁻⁶. An explanation for this result is not available yet.

Cows are highly motivated to maintain lying times of 12 to 13 h/d⁷. Lying time can, therefore, be a good indicator for animal welfare or cow comfort⁸, but it takes a major time investment to measure it. It is therefore that in this system is chosen to evaluate the conditions that are required for lying and known to promote lying in cattle. This is much more practical. Overstocking is one of the known factors that will reduce lying time⁹. A comfortable bedding will increase lying time¹⁰⁻¹⁵, but also the size of the free stalls and type of divider are of importance¹⁶⁻²⁶. An indication for the lying time can be derived from the number of cows standing idle. This is, however, depending on the time of the day and other factors as well. During lying the blood flow through the udder is 25 – 50 % higher and this will result in a higher milk yield²⁷. In the present study, a positive correlation was observed between the cubicle parameters and milk yield (fig 3).

The scoring system was used by many persons and on many farms. After a short training all observers could evaluate a farm in less than 1 hour, if the farmer had the historical health data ready. So it is a system that can be implemented in the routine of herd health consultants. Because it is numerical, one can compare the comfort level between farms, world wide.

The fact that negative scores weigh more than positive ones is unique for this system. Other systems that evaluate animal welfare status, such as the Animal Needs Index²⁸, weigh certain parameters more than another, but never depending on the score of that parameter. However, if a certain aspect of welfare, e.g. food, is negatively scored, this implies that there is a need for that particular aspect. If an animal is hungry, food is the main thing that occupies his/her mind at that moment. The search for food is dominating other needs, like proper bedding or social contact. With a full belly, proper bedding and social contact become, relatively, more important. If a cow has mastitis, she will feel bad. Having access to pasture is then less important. She just wants to get rid of the disease. It is therefore that in the presented system a minimum score needs to be acquired for each paragraph. If the minimum score is not reached, the difference between the score for that chapter and the minimum is subtracted from the total. Thus increasing the importance (weight) of this parameter for the total score.

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25 ■ The Challenges Ahead for Animal Buildings Faced with the Emergence of Hot Climate Conditions in Portugal

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Portugal has a Mediterranean climate characterized by hot, dry summers. According to data from the Portuguese IM (Instituto de Meteorologia), over the last decade, summer temperatures have tended to be higher, with a greater incidence of heat waves, temperatures above 40 °C, and periods of consecutive warm nights (daily minimum air temperature above 20°C).

During the summer, very high temperatures and heat waves are becoming increasingly common in Portugal. The summers of 2003, 2004, 2005 and 2006 were among the hottest ever recorded.

These frequently hot climatic conditions can cause problems in intensive animal production, or even to livestock in extensive systems. In most cases, livestock buildings are not designed for animal production under high temperatures and most of them do not have environmental control equipment suitable for controlling the indoor climate under such conditions.

An analysis of climatic data revealed the existence of two regions (Alentejo and Trás-os-Montes) where high temperatures are more usual and summers tend to be hot. In these two regions, livestock numbers are high and play a major role in the regional economy. The occurrence of hot climate conditions was identified and its impact on the environmental conditions in animal housing discussed.

Introduction

Portugal is located in south-western Europe (37° to 42° N and 9.5° to 6.5° W). Despite the fact that it has a large Atlantic coast, its climate is mainly Mediterranean. In general, summers are hot and dry; winters are cold and wet. In littoral areas, the climate is milder and the rain is more frequent. The climate varies significantly from region to region, which has an effect on agricultural activity and also on animal production. In addition to other factors, these climatic conditions have a major influence on the geographical distribution of domestic animal species. Briefly, dairy cattle are more common in the littoral north, and beef cattle are more common in the Alentejo region, in the south. Pigs are mainly raised in the central littoral areas of the country and in Alentejo. Sheep and goats are more common in Alentejo, and in the inland regions of the centre and north (INE, 2005).

Based on developments over the last few decades, it is now possible to identify the emergence of hot climate conditions in Portugal, which may be having a gradual impact on animal production, especially in summer. According to data from IM (2006) over the last decade, summer temperatures tend to be high (mainly in June, July and August) and have tended to be

above the average of the reference period 1961-1990, according to the Climatological Standard Normals (WMO, 1983). Likewise, days with significantly high temperatures have become more frequent; there has also been an increase in the number of days with a minimum air temperature (generally at night) of over 20 °C; and the incidence of heat waves (several consecutive days of high temperatures) in recent years.

These frequently hot climate conditions (very high temperatures, warm nights and heat waves) can cause problems in animal housing production. It is recognized that these adverse hot climate conditions, primarily heat stress, have a number of negative effects on animal behaviour and production, causing livestock damage with losses to the farmer. Heat stress decreases voluntary feed intake (Fuquay, 1997; Nienaber et al, 2004); retards animal growth (Cruz et al, 2000); affects carcass composition and meat quality (Nienaber et al, 1987); decreases milk production while reducing milk quality (West et al, 2003; Perissinotto et al, 2005); and disturbs animal activity and interactive social behaviour (Frazzi et al, 1998; Hahn, 1989).

In Portugal, emerging hot climate conditions are posing a new challenge to animal housing and also to livestock in extensive systems. Breeders are not usually familiar with this situation and they have difficulties dealing with this problem. In addition, in most cases, buildings for livestock are not suitable for animal housing under high temperatures and they lack appropriate equipment to control the indoor environment under such conditions.

High temperatures combined with a lack of necessary equipment to control environmental conditions inside buildings and deficient acclimatization of animal housing can increase this problem. In addition, livestock in extensive systems, or raised outdoors, can be affected by high temperatures associated with humidity, as well as by the absence of shade, airflow or wind. The risk increases when these conditions persist for several consecutive days (Nienaber et al, 2004).

A review of climatic data from recent years assumes that, periodically, problems related with hot climate conditions have affected animal production in some regions.

The occurrence of hot climate conditions in Portugal is a concern that we have been analysing over the last few years and it was our intention to set up a project with several institutions in order to identify practical solutions designed to help and prepare breeders to deal with hot climate conditions and to minimize the impact on livestock. For several reasons this has not yet been possible (shortage of time and financial resources).

Objective

The main objectives of this work were, 1. to identify the occurrence of hot climate conditions in some regions of Portugal, 2. to discuss the impact of these conditions on livestock production, and 3. to outline our concerns about the procedures required to manage this problem.

Data, results and discussion

Climatic data over the last few decades show that hot climate conditions have been more frequent in recent years.

Table 1 shows the five hottest summers since 1931 considering the variation over the average of the reference period. The summer of 2005 was the hottest since 1931 and presents an anomaly of +2,4 °C in mean air temperature. Between 2003 and 2006, four summers were exceptionally warm and among the hottest since 1931.

Table 1. The five hottest summers since 1931, in Portugal (source: IM, 2006).

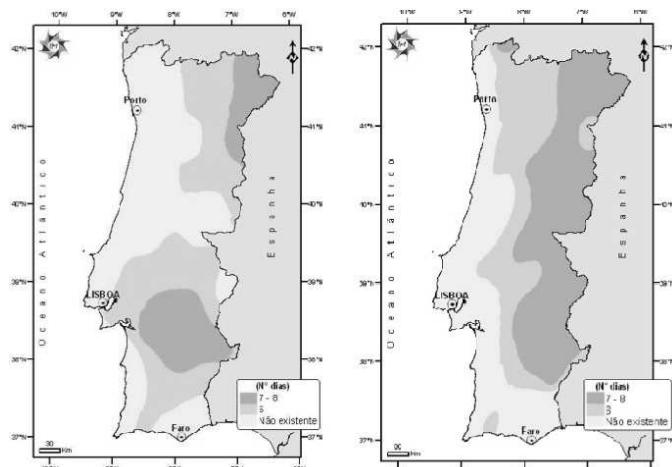
| Year | Variation in Mean Air Temperature (°C) |
|------|--|
| 1949 | + 2.0 °C |
| 2003 | + 1.9 °C |
| 2004 | + 1.9 °C |
| 2005 | + 2.4 °C |
| 2006 | + 1.8 °C |

As presented in Table 1, the years from 2003 to 2006 had very hot summers. In 2007 and 2008, summer temperatures were normal, according to the average of the reference period. Preliminary data from summer 2009 point to another very hot summer, with temperatures above the average of the reference period.

Another consequence of emerging hot climate conditions is the regular occurrence of heat waves. Considering a heat wave as defined by the Heat Wave Duration Index (WMO, 2001) the Portuguese IM registered heat waves in 1981 and 1991. In recent years, however, several heat waves have occurred in Portugal. During one heat wave in 2003, temperatures were over 40°C for eleven day in some places and there were two heat waves in 2005 with temperatures over 40°C degrees in several regions.

Similarly, in summer 2006, five heat waves occurred in the period from May to September. These five heat waves affected different regions for several days. It is interesting to note that the heat wave that began on 7 July had the greatest territorial extension ever registered and that from 27 August to 9 September marked the longest heat wave ever registered, with a duration of 14 days in some places.

Recently, during summer 2009, at least four heat waves occurred: from 2 to 8 May and from 27 May to 3 June (Fig. 1); and between 10 and 22 June. Again, during August several regions were affected by heat waves. Generally, the most intense heat waves affect mainly inland regions in the north and the south.

**Figure 1. Heat waves that began in May 2009 (source: IM, 2009).**

Another problem is the occurrence of high temperatures. Days with values higher than 40º C for maximum air temperature, sometimes associated with high values of minimum air temperature, above 20 ºC, increases the risk for animals since night time recovery is difficult. Again, the occurrence of high temperatures is more probable in some regions, generally in the south and inland regions.

According to data that we recorded in Vilariça (in the northeast of Portugal), during the summers of 2005, 2006 and 2007, some days presented very high temperatures, above 40 ºC. Table 2 shows the number of days with maximum air temperature (Tmax) ≥ 35 ºC; and the higher value of temperature recorded in this location.

Table 2. The hottest days (Tmax) registered in Vilariça, from 2005 to 2007

| Year | No. days with Tmax ≥ 35 ºC | Tmax recorded |
|------|---------------------------------|---------------|
| 2005 | 58 | 42.1 |
| 2006 | 62 | 41.3 |
| 2007 | 21 | 41.8 |

In Vilariça, several periods of consecutive days with minimum air temperature (Tmin) ≥ 20 ºC were recorded, representing conditions of consecutive warm nights. Table 3 shows the longest period: twelve days in summer 2006, from 7 to 18 July.

Table 3. Longest period of consecutive days with Tmin ≥ 20 ºC.

| Date | Tmax | Tmin |
|------------|------|------|
| 2006.07.07 | 35.7 | 20.7 |
| 2006.07.08 | 37.8 | 20.5 |
| 2006.07.09 | 40.2 | 19.8 |
| 2006.07.10 | 39.6 | 21.5 |
| 2006.07.11 | 40.3 | 22.5 |
| 2006.07.12 | 40.1 | 23.1 |
| 2006.07.13 | 38.2 | 23.4 |
| 2006.07.14 | 37.8 | 20.9 |
| 2006.07.15 | 37.8 | 21.1 |
| 2006.07.16 | 39.9 | 22.2 |
| 2006.07.17 | 41.3 | 22.3 |
| 2006.07.18 | 30.1 | 20.4 |

This period of consecutive hot days (high values of Tmax and Tmin) coincided with one heat wave registered in July 2006. It is notable that, during this period, 10 days of Tmax higher than 37 ºC were recorded. Hot climate conditions, as shown in Table 3, could present risks that can affect animals mainly in intensive systems.

The regions of Alentejo (in the south) and Trás-os-Montes (in the northeast) have a higher risk of high temperatures or extended heat waves. In these two regions, livestock numbers are very high and animal production is fairly important to the regional economy. This suggests that farmers should be on alert for a significant number of days, since heat stress-related problems may occur and some measures should be implemented in order to minimise any negative effects.

In fact, consecutive days with high temperatures increase the difficulty of controlling animal heat stress, which is aggravated if cooling is not possible during nocturnal periods. These risks can be heightened due to the fact that most breeders are not familiar with these problems and most of the time buildings are not equipped with preventive and mitigatory systems. Evaporation cooling systems can be a solution for solving or at least minimising these problems. Also, in extensive production, some problems may occur due to heat only in nocturnal housing and again breeders should be prepared to solve the problem.

Final considerations

After analysing these climate data it is possible to conclude that:

- there seems to be a tendency for summers to be hotter than before;
- periods of consecutive days with temperatures higher than usual, classified as a heat wave, are now occurring;
- in Alentejo and Trás-os-Montes, where summer is usually hotter than in the rest of the country, temperatures higher than 40 °C occur with relatively high frequency;
- in these regions there are consecutive days with minimum air temperature higher than 20 °C;
- all these situations present heat-related risks for animals and it will be necessary to prepare animal housing and breeders to implement certain preventive and mitigatory measures.

It is our conviction that this problem could affect productivity indices/levels in the future and it will be necessary to alert farmers/breeders and to prepare them to deal with the problem and the impact of climate conditions on animal welfare and production.

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26 ■ Automatic On-line Monitoring of animal Health and welfare by Precision livestock farming

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Abstract

Livestock production today has become a very complex process since several requirements have to be combined such as: food safety, animal welfare, animal health, environmental impact and sustainability in a wider sense. The consequence is a growing need to balance many of these variables during the production process. In the past farmers were monitoring their animals in their daily work by normal audio-visual observation like ethologists still do in their research. Today however the number of animals per farm has increased so much that this has become impossible. Another problem is that visual observation never can be done continuously during 24 hours a day.

One of the objectives of Precision Livestock Farming (PLF) is to develop the technology and the tools for the on-line monitoring of farm animals and this continuously during their life and in a fully automatic way. This technology will never replace the farmer but can support him as a tool that automatically and continuously delivers him quantitative information about the status of his animals.

Like other living organisms farm animals are responding to their environment with several behavioural and physiological variables. Many sensors and sensing techniques are under development to measure such behavioural and biological responses of farm animals. This can be done by new sensors or by sound analysis, image analysis etc.

A major problem to monitor animals is the fact that animals themselves are complex systems that are individually different and that are so called time varying dynamic systems since their behaviour and health status can change at any time. Another challenge for PLF is to develop reliable monitoring tools for such Complex Individual Time varying Dynamic systems ("CITD" systems).

In this paper we will talk about what is PLF and what is the importance of PLF. Next we will explain the basic principles. Further we will show examples of monitoring tools by PLF such as on-line monitor for health status by analysing continuously the sound produced by pigs. Another example shows the on-line automatic identification of the behaviour of individual laying hens by continuous analysis of 2D images from a top view camera. Next we will demonstrate the potential of PLF for more efficient controlling of biological processes. Finally we will discuss how implementation might be realised and what risk and problems are.

The technology that is already available and that is under development today can be used for efficient and continuous monitoring if an engineering approach is combined with the expertise of ethologists, physiologist, veterinarians who are familiar with the animal as a living organism.

Keywords: automatic monitoring, welfare monitoring, livestock monitoring, technology for livestock, precision livestock farming.

Problem of modern livestock production

The worldwide demand for meat products is expected to increase significantly in the next 15 years. At the same time livestock production today is no longer limited to obtaining economic goals. There is much public and political concern about critical issues that relate to economic but also moral aspects of animal health and welfare. Modern society is concerned about food safety and quality, efficient and sustainable animal farming, healthy animals, guaranteed animal well being and acceptable environmental impact of livestock production. As a consequence, there is a growing need to monitor many variables during the entire production process in order to satisfy these targets. In the past, livestock management decisions have been based almost entirely on the observation, judgment and experience of the farmer (Frost et al., 2003). However, together with the increasing scale of the farms and the corresponding high number of animals, this evolution has resulted in an increasing administrative, technical, organisational and logistic workload for the farmer and has limited the possibilities of the same farmer to monitor his animals by himself.

An important question today is: how does the society ensure that farm animals are reared and treated in good welfare conditions and this with minimal environmental impact and that food from animals is safe while the demand for more meat is rising?

In Europe the Animal Welfare Quality project has spent a lot of time and money to come up with welfare quality measures that are collected from farm visit assessments during a farm visit by the assessor.

Observation by ethologists is needed for research purposes in animal welfare, but is very expensive for practical application and has the disadvantage of limited time period of observation.

A common problem with many of the proposed solutions to these contemporary problems of modern livestock farming is their reliance on vast streams of data to identify and manage the risks. Collection of the relevant data today nearly always relies on manual methods. While this might be acceptable in R&D projects, it is unrealistic when solutions are applied on the scale needed on commercial farms. Scoring of some animal-based information by human experts and manual methods remain difficult, time consuming and expensive when implemented at farm level. Both animal related researchers and technology related researchers have a high awareness of the existing problems. From limited existing collaborations it is clear that a multidisciplinary and integrated approach is needed to find solutions.

Objectives of Precision Livestock Farming in monitoring

Today, automatic monitoring and controlling techniques are becoming more and more important to support the farmer in managing the production process. Although biological processes involving living organisms have always been considered as too complex to be monitored and controlled in an automatic way, today new emerging technologies offer possibilities to develop full automatic on-line monitoring and control of many of these processes.

One of the objectives of Precision Livestock Farming (PLF) in the field of monitoring is to develop on-line tools to monitor farm animals continuously during their life, in a fully automatic way, with objective measures and criteria calculated on-line from collected data and without imposing additional stress to the animals. The aim of these technical tools is not to replace but to support the farmer who always remains the crucial factor in good animal management. Besides on-line automatic monitoring, PLF offers also interesting possibilities in automatic control for supporting the management of such complex biological production processes (e.g. feeding strategies, growth rate control, activity control, see Morag et al., 2001; Halachmi et al., 2002; Aerts et al., 2003a, b; Kristensen et al., accepted).

What is Precision Livestock Farming (PLF)?

Precision Livestock Farming is the use of modern technology in sensors, sensing systems (image, sound, and others) and real time modelling and software to realise the continuous automatic monitoring and management of livestock farming according to multiple objectives. Its technology is based upon recent advances in ICT and sensors in combination with mathematical and biological models. PLF takes advantage of technology developed in other industries like in the whole world of control engineering and the solutions in other sectors, which gives access to low-cost hardware and software through mass production. PLF includes the use of this technology at animal level and the use of collected information at level of the livestock house, the farm, the region, the country and Europe.

One current focus in PLF research is the development of sensors and sensing technologies to monitor and evaluate data from processes in real-time. Collecting data from livestock and their environment is now possible using innovative, simple, low-cost ICT systems, often pioneered in other fields of research and industry; the data are then integrated in real time by using knowledge-based computer models.

Sensing systems under development will monitor feeding times, feed intake, animal health and behaviour as well as conventional performance parameters; real time, on-line analysis of sounds, images, live weight, condition score, milk analysis and others is becoming feasible. The overall goal is complete, continuous assessment of the state of livestock and their environment in terms of health, welfare, performance and environmental related issues. Models for data evaluation are available for a few key processes. However, further research is needed to make efficient use of the vast stream of process information that will be provided by the next generation of ICT systems. The outputs from these models can then be used for management and production control on the farm. The information will provide an essential component of Farm Assurance Schemes throughout the food chain, helping to minimise risks to the consumer and guarantee product quality.

Basic principles of Precision Livestock Farming

The PLF approach starts from the observation that the animal is the most crucial part in the biological production process in an animal house. Despite this fact, in most modern livestock houses worldwide farmers use control equipment (e.g. climate control, feeding supply etc) that does not measure anything on the most important part of the process: the animal.

Animals, as all living organisms, are *complex*, individually *different* and *time-variant* (meaning that they respond differently at different moments of time) *dynamic* systems. Therefore, we say that animals are *CITD systems* (Complex, Individual and Time-variant, Dynamic).

A starting point in PLF is the recognition that each individual animal is such a CITD system. This contrasts with more classical approaches where animals are considered as “an average of a population and due to its complexity as a steady state system”.

For monitoring and control of livestock production processes, the PLF approach makes use of modern monitoring and control theory. To achieve favourable monitoring and control of such processes, three *conditions must be fulfilled*.

The *first condition* to be fulfilled is that *animal variables must be measured continuously* and this information is analysed continuously. “Animal variables” can be very different such as weight, activity, behaviour, drinking and feeding behaviour, feed intake, sound production, physiological variables (body temperature, respiration frequency, blood variables,). What “continuously” means is depending on the measured variable such as 25 times a second when monitoring on-line animal activity from video images or a sample every day when monitoring animal weight.

A *second condition* to realise accurate animal monitoring and management is that at every moment a *reliable prediction (expectation) must be available* on how the animal variables will vary or how the animal will respond to environmental changes. By environment we mean the whole of all variables that are not genetically defined. It is the continuous comparison between this prediction (in the past the experience of the farmer and now for example a mathematical model) and the actual measured values that allows to identify animal activities and to judge when something abnormal is happening.

The *third condition* is that this prediction together with the on-line measurements are integrated in an analysing algorithm (a number of mathematical equations implemented in a microchip) to monitor or manage the animals automatically and to achieve on-line monitoring of animal health, welfare, or take control actions (climate control, feeding strategies,). A schematic overview of the three conditions is shown in Figure 1.

Since the animal is acting as a complex, individual and time varying system we need to apply this PLF approach in an appropriate way. The best way to handle this time-variant character of all the complex individual animal responses is by applying continuous measurements and predictions and by using predictions and applying mathematical data-analyses in an on-line or real time way and, if possible, on individual animals. The required technology is available. The key to realise this application is novel and innovative multidisciplinary research.

Sensors and sensing techniques

The last years, many research and development efforts have been done all over the world to develop new sensors and sensing techniques to acquire on-line information from animals and to collect different animal variables. For cows, pigs and chicken several sensors, sensing principles and sensing techniques have been described in literature. As shown before (Berckmans, 2003) we have found in recent literature 11 papers to measure eating behaviour, respiration rate, non destructive chewing behaviour, stress responses, etc. for pigs (e.g. Eigenberg et al., 2000). For cows, 29 sensors are described in recent literature to measure deep body temperature, body weight, udder health, oestrus, breath emissions, biting rate in grazing cows and others (e.g. Velasco-Garcia and Mottram, 2001). For chicken's recent literature gives 9 papers describing sensors to measure body temperature with radio transmitters, biosensors to detect pathogenic bacteria at very low levels, heat stress and others (e.g. Lacy et al., 2000). Twenty papers were found about vocalisations of pigs to measure variables such as: pigs need for supplemental heat, peripheral endocrine stress responses,

behavioural responses to separation, on-line detection of infection of the respiration system (e.g. Merchant et al., 2001).

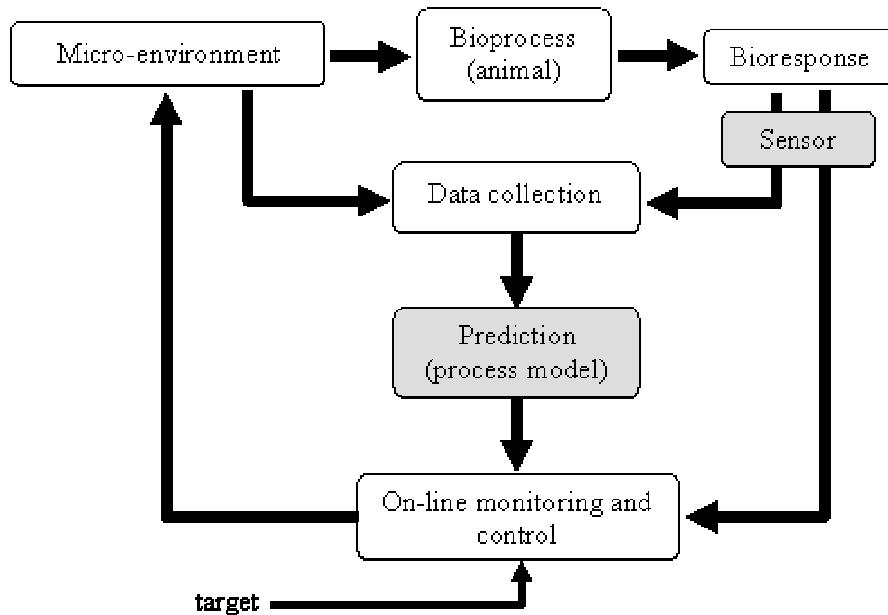


Figure 1. Precision livestock farming (PLF) by integration of measured Bioresponses together with a predictive process model into a model-based monitoring or control algorithm: a schematic overview (Aerts et al., 2003a).

Twelve papers were found about the vocalization of cow sounds to measure animal's condition, effects of separation on behavioural responses, milk production, and identification of individual cows (e.g. Weary and Chua, 2000). Eleven papers were found on vocalization of chicken describing: an increasing number of gakel-calls with an increasing hunger state, stress dependence of chicks call qualities, capacity to emit food calls and quantification of stress (e.g. Zimmerman et al., 2003). Nineteen papers describe image analysis of pigs to measure: location of pigs in scenes, stress conditions, tracking of piglets, relation of outside 3 dimensional body conformations and lean-fat ratio, on-line monitoring of pig weight (e.g. Onyango et al., 1995). Twenty seven papers describe image analysis of chicken for real time disease detection, behavioural responses, non-destructive prediction for yolk-albumen ratio in chicken eggs, feeding behaviour, animal distribution and activity and automatic identification of activities related to animal welfare, animal weight (e.g. De Wet et al., 2003).

It can be concluded that several efforts are done to develop sensors and sensing techniques for animal variables and this is just a beginning stage. Many new sensing systems will be developed in near future (sensors at the micro- and nano-scale, biosensors, telemetry, etc.).

A main problem however remains to use these sensors or sensing techniques (e.g. sound and image analysis) in such a way that we can interpret the signals in relation to the interesting variables on the animals. It is a main task to connect the meaningful variables from the different subsystems (e.g. skeletal system, nerve system, muscle system, metabolism, sensory perceptions and brain) in an animal to the dynamic signals that we collect from our sensors somewhere on the body (Figure 2).

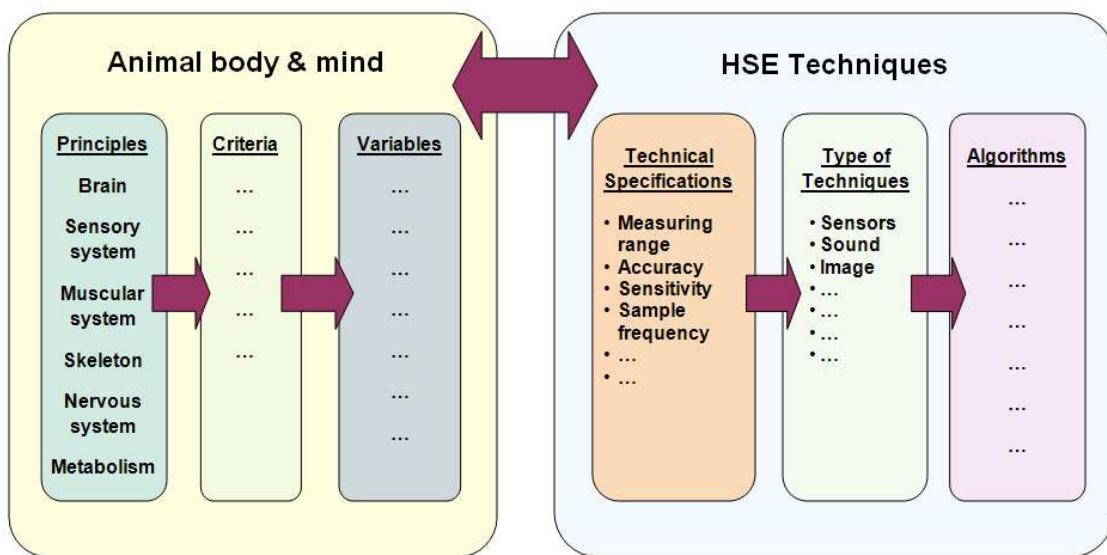


Figure 2. Linking animal variables to sensor variables.

Today, the availability of reliable, robust and accurate sensors still is the main bottleneck to apply PLF in practice. The price of this new technology is not a main problem since as shown by many examples (CD player, mobile phone, GPS) the number of produced units is the main factor influencing the price. The livestock market is only about huge numbers since at the end each individual animal should be monitored in one or another way.

Exemplar 1: Real time sound analysis to detect health status in pigs

A first example of PLF in monitoring animals is a system to detect infections in fattening pigs by on-line analysis of their produced sound. The basic idea is that the respiration system is producing a sound when coughing. When the animal is infected by a respiratory disease, the characteristics of the respiratory system, such as the cell of the air pipes, are changing. Consequently, the characteristics of the energy in the sound signal that is produced when air is pulsed through this system, when coughing, will be different as well. If this difference in sound signal can be detected fast enough after infection, on-line monitoring of pig's coughs and other animal sounds could be useful as a biomarker for infection and improve disease management (resulting in, among others, reduced antibiotics usage) (see also Figure 3).

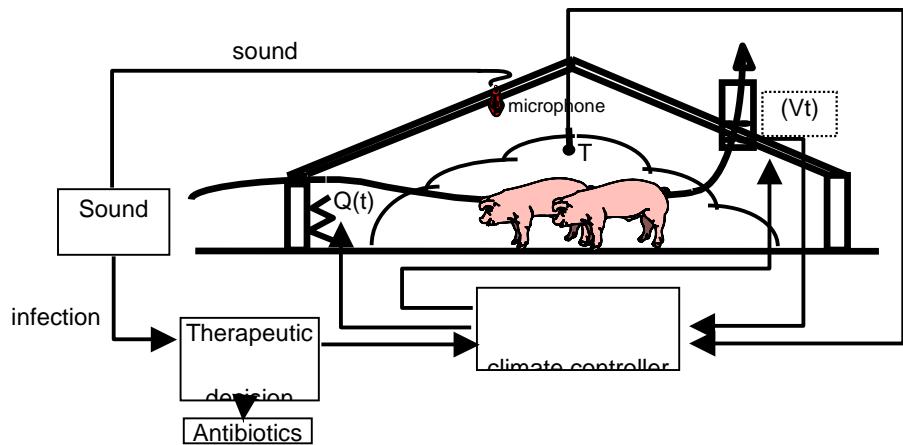


Figure 3. Use of on-line sound analysis as a basis for health monitoring in pigs.

Algorithms have been developed to detect coughs of pigs out of a raw sound signal (Van Hirtum et al., 1999; Chedad et al., 2001). In a first step, these algorithms make a distinction between a sound and no sound. Secondly, the sounds are classified in coughs and no coughs (other sounds) and finally also a distinction can be made from healthy and sick coughs (Van Hirtum and Berckmans, 2002) (cf. Figure 4).

Based on laboratory experiments, it could be demonstrated that pig's coughs could be classified correctly in 94% of the cases (Van Hirtum and Berckmans, 2003). Testing of the developed algorithms in practice, showed that in pig houses in the field the coughs could be correctly classified in 86% of the cases (Guarino et al., 2004, 2008).

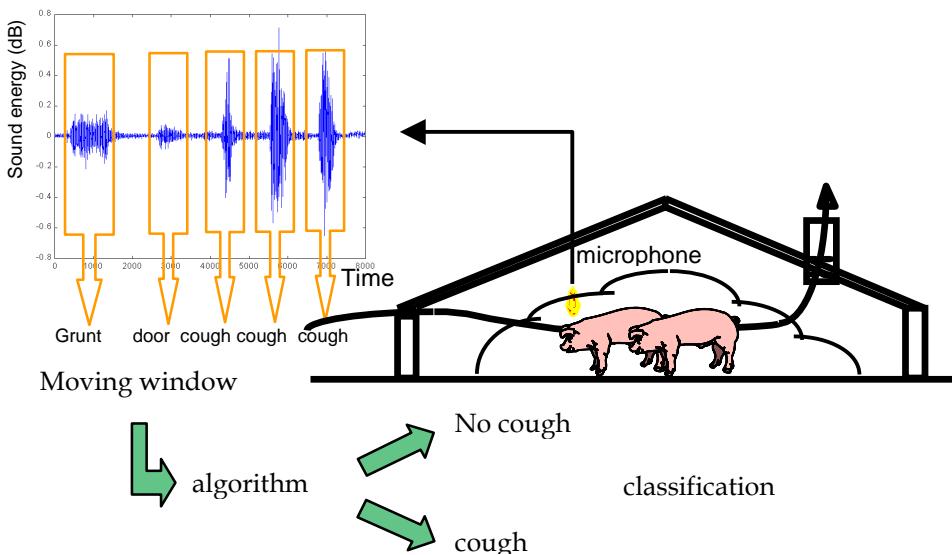


Figure 4. Classification of pig coughs.

Exemplar 2: Real time identification of the behaviour of laying hens to monitor animal welfare

A second example of PLF in monitoring animals is a system to monitor fully automatically the activities of laying hens to score their welfare and to use this information for better managing the production process environment (cf. Figure 5).

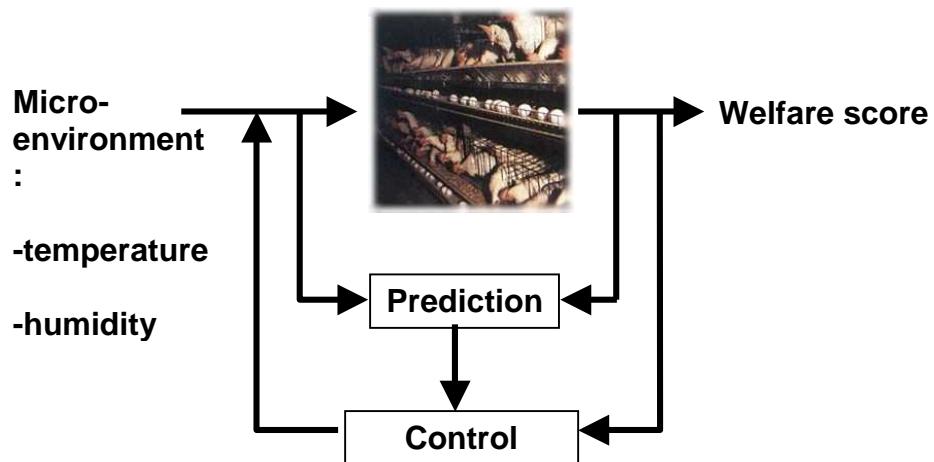


Figure 5. Integration of on-line monitored welfare score in the management of production processes for laying hens.

Behavioural characteristics are usually evaluated by audio-visual observation done by a human observer present on the scene. This method is time consuming, expensive and cannot be done continuously during the life time of the animal. Automated objective surveillance, by means of cheap cameras and image-processing techniques, has the ability to generate data providing a continuous measure of behaviour, without disturbing the animals. A fully automatic on-line image-processing technique was developed to quantify the behaviour of laying hens as opposed to the current human visual observation. The classification of the hen's behaviour was performed by dynamical analysis of a set of measurable parameters, calculated from the images using image processing techniques. A first implementation of the system allowed identifying three different types of behaviour (standing, walking and scratching) (Leroy et al., 2003). In Figure 6, an example is shown of automatic scratching detection based on the developed algorithm (see also <http://www.m3-biores.be>).

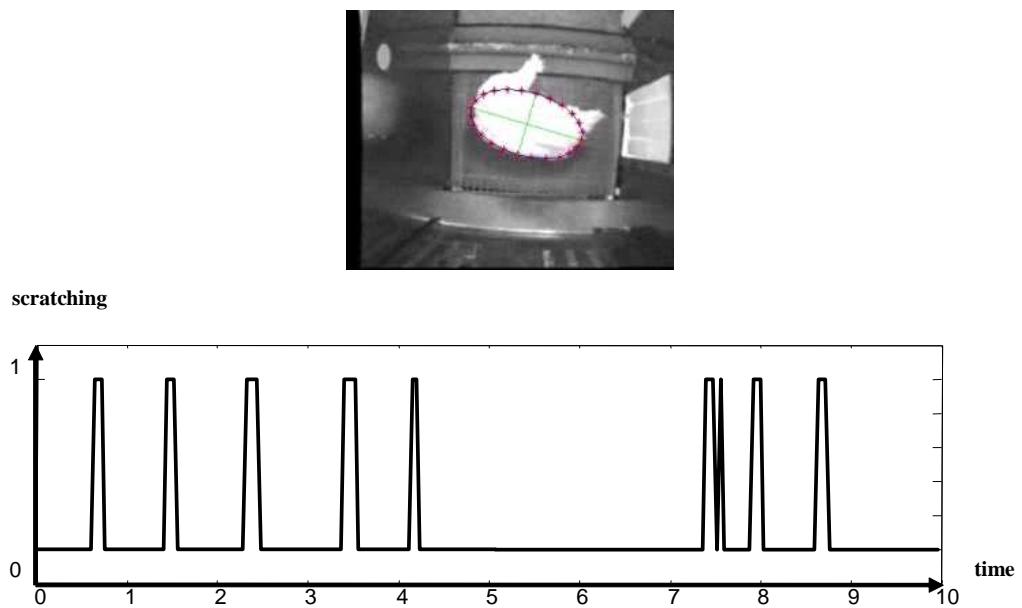


Figure 6. Automatic detection of scratching behaviour for laying hens.

Conclusion

Precision Livestock Farming involves the measurements, data-analyses and modelling of animal variables. PLF offers totally new possibilities to collect and analyse data from farm animals in a continuous and fully automatic way. It is shown that modern technology, sensors and sensing (image, sound) systems can replace the farmers "eyes and ears" to each individual animal as in the past. Even more several other variables (infections, physiological variables, stress, etc) will soon be measurable in practice. The bottleneck today to apply this technique is in the availability of reliable sensors and sensing systems, since it has been shown that the required mathematical algorithms can be developed.

The PLF techniques cannot and will never replace the farmer, it can offer a working tool to support and help the farmer to monitor and manage this animals.

The application of this technology offers new possibilities to realise food safety and quality, efficient and sustainable animal farming, healthy animals, guaranteed animal well being and acceptable environmental impact of livestock production.

Therefore, efforts should be increased for bringing this challenging approach of Precision Livestock Farming to practice. This is only possible when teams from different research disciplines, such as physiology, ethology, nutrition, hygiene, engineering, etc. join their research efforts.

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27 ■ Animal housing and welfare

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In the future, a specific attention should be paid to the welfare of animals (taken as a whole) when designing animal buildings, along with other major societal issues such as energy consumption and environmental footprint.

Agricultural activities shall not only feed people but also answer various societal issues in relation to the sustainability of production systems: Agriculture should ensure income to producers while maintaining resources for future generations, and be socially acceptable. Hence, the reduction of the consumption of energy, the preservation of the environment (landscape, reduction of pollution), and the protection of animal welfare are nowadays key objectives. The present paper focuses on animal welfare and more precisely on how it can be taken into account in housing.

The Farm Animal Welfare Council identified five freedoms to ensure animal welfare (Farm Animal Welfare Council, 1992):

1. Freedom from Hunger and Thirst - by ready access to fresh water and a diet to maintain full health and vigour.
2. Freedom from Discomfort - by providing an appropriate environment including shelter and a comfortable resting area.
3. Freedom from Pain, Injury or Disease - by prevention or rapid diagnosis and treatment.
4. Freedom to Express Normal Behaviour - by providing sufficient space, proper facilities and company of the animal's own kind.
5. Freedom from Fear and Distress - by ensuring conditions and treatment which avoid mental suffering.

Freedom 2 depends definitively on the quality of housing. The quality of housing can also have an impact on Freedom 3: inappropriate housing can lead to injuries (e.g. due to slippery floors, lack of bedding), poor ambiance in barns can increase respiratory diseases while a soiled bedding can increase the occurrence of mastitis. Freedom 4 also depends intimately on housing that offers more or less opportunity to animals for expressing their behaviour. For instance lack of space allowance and the resulting overcrowding can modify the expression of social behaviour, and tethering thwarted movements. Therefore housing plays a pivotal role in animal welfare.

In recent years, along the societal acknowledgement that animals are sentient beings (European Union, 1997), there has been growing scientific evidence that farm animals do not only react physically to their environment but also construct a perception to their environment and can feel mental states depending on this perception (Desire et al., 2002; Harding et al., 2004; Veissier and Boissy, 2007). The welfare of animals is not related directly to their needs but to how they feel about their environment (Duncan, 2002). Therefore the point of view of the animals themselves is essential to have an idea of their welfare.

Housing shall allow animals to perform correctly their basic activities. Principles of ergonomics have been successfully applied to design cubicles or troughs in accordance to animals' size and movements (CIGR, 1994). This helps to define (very) minimal requirements, e.g. in terms of space required for an animal to perform a given movement (such as for a cow to lie down).

Ergonomics nevertheless does not completely take into account the point of view of the animal. This can be studied in choice tests where the preference for one good over another one is assessed (Williams et al., 2008; Nicol et al., 2009). The strength of a preference can also be assessed by asking animals to perform a task and checking how much they are ready to work to obtain a reward or have access to some environmental feature (Cooper and Appleby, 2003). Enrichments of the environment of hens have been proposed based on such studies (perches, nests). The consequences of some aspects of the housing can also be measured (Friend et al., 1979; Hickey et al., 2000; Mirabito and Michel, 2003; Veissier et al., 2004; Princz et al., 2008). Impacts on the behaviour of animals (e.g. time budget, lying down movements, social behaviour), stress responses, immune responses, injuries (due to interactions between animals or directly to the environment), diseases (subclinical disorders such as udder health assessed through somatic cell counts, or clinical diseases), and general fitness (feed intake, growth, milk production) are assessed and these elements are used to judge whether a given situation is detrimental vs. favourable to animal welfare. The impact of the prevention of some behaviours due to environmental restrictions can also be measured by checking whether the expression of the behaviour is over-expressed when released from impediment (Mackintosh, 1974). For instance, once released in a vast enclosure tethered cows walk more than those that were in loose house barn (Veissier et al., 2008).

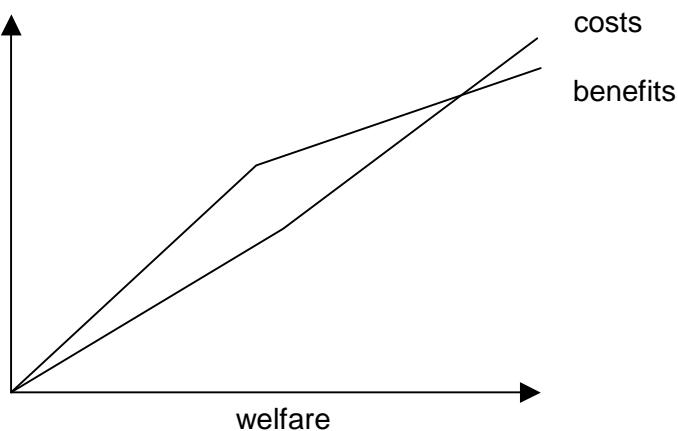
These elements help us to understand how animals feel about their environment and should be used in to create appropriate housing conditions. This has been applied for a long time in the design of e.g. cow cubicles, although not always applied appropriately (Veissier et al., 2004). Other good examples can be found in the design of platform for rabbits to release the pressure of a wired floor on their feet or an elevated platform for turkeys to access to more space and reduce attacks between animals (Mirabito, 2003; Mirabito and Michel, 2003). Various enrichment materials are also used in fattening pigs, leading to a reduction of aggression between animals and a better health (Bracke, 2008). A key element to ensure animal welfare is the freedom for them to predict and control their environment (Greiveldinger et al., 2007; Greiveldinger et al., 2009). Therefore, efforts should be made to ensure that animals understand their environment, by applying regular routine (for feeding, milking...) or signalling their occurrence e.g. by a noise, or to allow animals to act on their environment (choosing when to go for eating, or for milking...) (Wiepkema, 1987; Wiepkema and Van Adrichen, 1987; Langbein et al., 2009).

In general, an increase in animal welfare is accompanied by an increase in production: cows produce more milk when their cubicles are equipped with mattresses (Bony and Barbet, 2000) and growth rates of bulls are reduced on too small space allowances (Hickey et al., 2000). Veterinary costs can be reduced thanks to lower health problems (Madsen, 1987). The quality of products, essentially meat, can also be affected by stressful conditions on the farm and during transport to slaughter (Lensink et al., 2001). We believe that housing can affect human-animal relationships, by altering the frequency of contacts between them as well as by facilitating vs. rendering more difficult the handling of animals and this can ultimately affect the quality of products: e.g. lack of loading facilities can increase the stress of bulls transported to slaughter and reduce the decline of meat pH (Mounier et al., 2006). In general improvements of animal welfare are accompanied by improvements of performances. Such improvements can increase farmers' profits only when the benefits are higher than the costs. There are numerous examples where this is the case: mattresses for cows (Veissier et al., unpublished data), appropriate handling in calves (Lensink, 2000). Nevertheless, in case of the enlargement of space allowance, the benefits may not counterbalance the costs, at least when these are assessed only in terms of money. It is likely that when improvements are made from a very poor situation to an average one, then costs are largely paid by benefits whereas when improvements are made from average to excellent situations, the difference between benefits and costs may diminish (Figure 1). However this has to be substantiated by more empirical data. Last but not least benefits are not only a matter of economic return. There can be benefits for the farmers in the form of a higher self-esteem resulting from offering a good life to animals and/or being in line

with citizens concerns. This has been especially the case for veal producers that moved from individual crates to group housing (Bertin et al., 2006).

In conclusion, housing plays a major role in the welfare of farm animals. Future animal buildings need to be designed so as to cover animal welfare. Welfare friendly animal housing can be beneficial both to animals and farmers. Due to the many ways by which housing can affect animal welfare, we recommend to reason animal welfare as a whole, with a view to develop innovative buildings that can cover all aspects of welfare at the same time (comfortable lying area, appropriate climatic conditions, possibility to express behaviour). Cost/benefits analysis of such systems compared to more conventional ones should give us a clear view of their sustainability.

Figure 1: Hypothetical relation between welfare improvements and resulting benefits or costs.



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Within a context of major reorganisation and adaptation of livestock housing to meet tomorrow's issues, this forum provided an overview of recent and current research and extension initiatives, with the aim of creating together a coherent visualisation of what will be livestock housing of the future.

This forum was organised by "RMT Livestock housing of the future" which is co-presented by the Institut de l'Elevage (French Livestock Institute) and the Chamber of Agriculture of La Manche, in close collaboration with the Pig Breeding Technical Institute (IFIP) and Poultry Breeding Technical Institute (ITAVI), and also the French Chambers of Agriculture network. The ISA Lille (Life and Earth Engineering Institute) also supported this event.

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