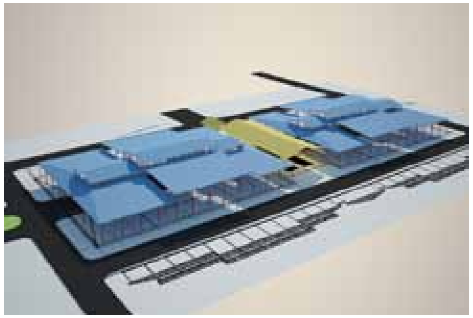
LIVESTOCK RESEARCH
WAGENINGEN UR

Prospects for bedded pack barns for dairy cattle

Contents



Paul Galama
Researcher for sustainable dairy farming systems.

Preface

Since late 2006, I have been working together with a group of dairy farmers, searching for alternatives to the free stall barn that can strongly improve animal welfare, reduce environmental impact, increase faeces quality and be cost-effective. This search was supported by the then Ministry of Agriculture, Nature and Food Quality through practical networks. Free stall barns have been widely used for more than 40 years. This system was developed in the 1960s, mainly to improve labour efficiency. Today the emphasis has shifted towards animal welfare, with the need for more space and less concrete and steelwork in livestock houses. The demands of the cow, the farmer and the environment have increased. For a sustainable housing system it is very important that the emission of ammonia and green house gasses are low. Question is, whether it is possible to develop a different housing system that meets the new demands.

Inspired by a congress in Minnesota (USA) in June 2007 on 'Compost Dairy Barns' and a study tour with dairy farmers to Israel in 2008, we have made a start with bedded pack barns. Together with colleagues of Wageningen UR Livestock Research and NIZO Food Research BV a tentative study was carried out on the feasibility of the system in the Netherlands, and experiments have been carried out on experimental farms. Since 2009 several dairy farmers have installed bedded pack barns or a barn with a synthetic floor. Some of them are experimenting on a small scale. Developments have been rapid. And now we can present results of the experimental farms and the first practical experiences. I want to express my thanks to all researchers and dairy farmers for their contributions. I also want to thank Mr. Yehuda Sprecher for his inspiration at the meetings with dairy farmers and for making a number of innovating realistic outlines.

Inspiration from Israel

This publication on the prospects of bedded pack barns responds to the wishes of the financiers, the Productschap Zuivel (PZ – Netherlands Dairy Produce Board), the Ministry of Economic Affairs, Agriculture and Innovation (EL&I) and TransForum, to implement sustainable dairy farming systems. This publication is primarily meant for dairy farmers who want to invest in bedded pack barns but aims also to inspire advisors, policy makers and researchers to develop the bedded pack barns to a sustainable livestock system. Results of recent research, new designs and aspects that need further development are included. Especially the development towards a low emission stable is important. I hope you will enjoy reading this publication and that it may be a source of inspiration.

Paul Galama
Bedded pack barns project manager
Wageningen UR Livestock Research

Introduction

What is a bedded pack barn?

A bedded pack barn does not have cubicles and the resting and exercise areas are largely combined. This combined resting and exercise area is spacious and provided with a soft, permeable and/ or moisture-absorbing bedded pack. In its design, there is a certain similarity between a free stall barn and a deep-litter house. But there are several differences. The bedded pack in a deep-litter house is generally dug out, whereas the resting and exercise area in a bedded pack barn can also be built up from ground level. The main difference with a deep-litter house, however, is the much larger resting and exercise space that is available to each animal, a larger variety of pack materials and for some bedded pack barns the active manipulation of processes in the pack to control the environmental effects. Another type of bedding is a synthetic floor.

Intended advantages

The bedded pack barn comes with opportunities to improve sustainability in dairy farming. The challenge is to combine more space for the animals with lower emissions and at the same time a reduced cost price (or at least a stabilised cost price). More space on a softer bedded pack can result in less claw problems and a more natural behaviour. We may think of various types of bedding material, such as sand, compost, wood chips, sawdust, dry manure or soil (clay or peat). The bedding material, when soiled with faeces from the cows, produces a fertiliser with much organic matter to improve soil fertility. Other countries have gained experiences with various types of organic bedded packs. It remains to be seen what can be achieved under Dutch conditions (climate!). In addition, the Netherlands are performing small-scale experiments with synthetic floors in bedded pack barns. Urine is drained through the bottom layer to reduce the emission of ammonia, whereas the solid fraction stays behind on the top layer. This creates two types of manure, a solid and a liquid fraction, which allows for a tailor-made application of manure.

Uncertainties

Environment is an important aspect of sustainability. Precisely about this aspect there are uncertainties. This book describes the emission measurements of ammonia, methane and carbon dioxide on three experimental farms. The emission of nitrous oxide is not measured. Research about emission of ammonia and green house gasses is still going on practical farms. Also odour and particulates in the air are measured on these farms. Another important issue of uncertainty is the type of bedding material which is allowed from a point of view of food safety and risks to animal diseases.

Towards integral sustainable livestock farming systems

In May 2009 several stakeholders agreed upon a mutual strategy towards sustainable livestock farming in The Netherlands. Among the stakeholders were the ministry of Economic affairs, Agriculture and Innovation (EL&I), the Dutch Federation of Agriculture and Horticulture (LTO) and representatives of the dairy industry, feed industry, financial sector and environment and animal protection organisations. It is stated in this strategy that livestock farming in the Netherlands should develop over a period of 15 year to a sector that is sustainable in all human, animal and environmental aspects and that has a broad public support.

1. Needs of the cow, the farmer and the environment

1.1 What does the cow want?

Within the Cowfortable project (part of the Dairy adventure programme) three sub-reports have been published. The latest report 'Grensverleggend huisvesten van melkvee' (New horizons for dairy cattle housing) describes new housing systems on the basis of a bedded pack barn (Galama et al., 2009). Major demands of cows have been elaborated in a joint effort with Courage, dairy farmers, researchers of Wageningen UR and animal welfare experts (see also Bos et al., 2009).

The bedded pack barn caters for these demands of the animals, which are:

1. Space (physically, socially and logistically)
   The bedded pack barn offers much space for adequate exercise and natural behaviour as well as for eating, drinking, defecating and urinating. Animals can easily avoid each other or rather seek each other's company.
2. Exercise
   The bedding material of the bedded pack barn is soft and provides a good grip. This allows the animals to move easily with less chance of lesions or ailments (claws).
3. Resting and lying down
   The bedded pack barn provides much physical space for lying down and getting up. The result is that the animals can experience much rest, which reduces the burden on joints and claws.
4. Social interaction within the herd
   Limiting the herd size to approximately 60 animals and leaving the cows that need extra attention within the herd, allows for a good social contact within the herd. In bedded pack barns, herds of some 150 cows also seem to be possible, as practical experience has shown that cows tend to lie down close to each other, creating many open spaces that can serve as refuge areas.
5. Thermoregulation and air quality
   A very open, well-ventilated and large-volume bedded pack barn is a guarantee for adequate air quality. The in-house temperature will be about the same as the outside temperature (which is not only typical for the bedded pack barn).

1.2 What does the farmer want?

The dairy farmer is an animal caretaker, manager and entrepreneur. As an entrepreneur he aims at continuity of the farm. As a manager he prefers a livestock house with low investment costs and low annual costs. He also benefits from a long life with low health costs. To him as an animal caretaker a healthy herd and a labour-extensive livestock house design are important. One of the advantages of the bedded pack barn is the reduction of the costs of manure storage, as the exercise and resting area also serves as manure storage. The additional space needed per cow requires a cheaper superstructure. Apart from the costs of the house, the efficiency of the bedded pack barn will largely depend on cost savings due to better animal welfare and improved animal health on the one hand and a better manure on the other hand.

1.3 What does the environment want?

The mutual strategy towards sustainable livestock farming it is stated that progress has to be made on the issues of animal welfare (increasing possibilities for natural behaviour), animal health (reducing the use of antibiotics), environment (minimizing nitrogen, phosphorus and carbon losses), energy use (direct and indirect) and landscape planning (fitting large scale facilities into the landscape). Progress on single issues must not hamper the progress on the combined issues.

The demands of the environment are that the buildings fit into the landscape and the environmental impact is minimised.

- Emission of ammonia
- The challenge is to reduce the emission at a level of maximum 9,5 kg ammonia per cow per year despite the larger soiled area per cow as compared with a free stall barn.
- Emission of greenhouse gases
- It is the ambition that the bedded pack barn will strongly reduce these emissions.
- Odour emission
- It is the ambition that this is much lower in a bedded pack barn than a freestall.
- Fine dust emission
- It is the ambition that no more fine dust is emitted from the bedded pack barn than from a free stall barn.
- Energy consumption
- The direct energy consumption against that in a free stall barn can increase in a bedded pack barn due to the working of the top layer and additional mechanical ventilation, if necessary. But the indirect energy consumption will be lower due to a simpler layout of the livestock house.
- Noise
- The noise produced shall not increase.
- Light radiation
- The radiation of light shall not increase
- Food safety
- Risks to food safety shall be limited, e.g. as can be caused by spore-forming bacteria in the bedding material. At this moment results from research show no risk. More research has te be done.

The pack in bedded pack barns in Minnesota consists of wood chips and sawdust. The pack material is built up from the ground, consequently not from a recess in the surface. The top layer is aerated or worked once or twice daily. The resting area (which does not include the feeding passage) provides 7 to 8 m^2 per cow.

2. Experiences from abroad

2.1 USA

As from 2001 experience has been gained with compost barns (Compost Dairy Barns), mainly in the state of Minnesota. The bedding material in these bedded pack barn mostly consists of a combination of wood chips and sawdust that is composting together with the faeces. In 2001, Portner Brothers, dairy farmers in Sleepy Eye, started a compost barn. Their main reason was to improve cow comfort. After a couple of years' experience they observe less claw problems, less stress and higher yields per cow. Meanwhile more than 70 dairy farmers in Minnesota have gained experience with compost barns. The University of Minnesota has collected intensive practical experiences from 12 farms. These were presented at a congress in June 2007. There was much interest from several states and other countries. The very interested 150-strong audience consisted of researchers, extension workers, advisors and dairy farmers.

Positive effects of the compost barns were reported, such as:

- An average of only 8% leg and claw problems, varying between 0% and 21% (against an average in free stall barns between 25% to 28% according to US research).
- The percentage of cattle replacements reduced from 35% to 27%.
- The milk yield per cow increased.
- Cell count remained nearly unchanged

Remark: Here the compost barn was compared against the previous situation on the farm involved (often a tie-up cow house or an obsolete free stall barn).

2.2. Israel

The first dairy farmers who emigrated from Eastern Europe to Israel kept their cows in tie-up houses. This type of housing became much too tight for the ever increasing size of cows. To prevent heat stress cows were kept more in open air, allowing them to get rid of their heat.

The tie-up house was followed by a development of some type of deep-litter houses with straw, providing approx. 5 to 8 m^2 per cow. The price of straw was still low, then. However, the changing height difference with the feeding area was felt a disadvantage. Therefore, in the 1970s the 'corral system' was 'imported' from California, where only the resting area was roofed, so that cows could also move outside.

Canada

Hungary (sand)

But since the year 2000, when the environmental regulations were tightened, cows were no longer allowed to stay outside. Then, a house was developed with a gradually sloping roof and a central feeding passage where the cows were given much space. The farmer could save on bedding material, as the cows were kept on dried manure. Parallel to this development free stall barns were also introduced in the period from 1970 to 1980. The past few years, however, the bedded pack barn ('loose housing') has by far been the most common type of livestock house. The cows have a space of 15 to 20 m^2 on a resting bed of dried manure. In comparative research between the free stall barn and the bedded pack barn, the bedded pack barn was preferred, provided it is well situated and well ventilated. The yield per cow was higher, fertility was better and there were less claw and leg problems than in a free stall barn.

2.3 Europe and South Korea

In France, Great Britain and Ireland experience has been acquired with 'outdoor winter pads', a drained and roofless bedded pack. In Germany and Austria experience is being gained on a small scale with bedded pack barns after the example of compost barns in Minnesota and the Netherlands. In Denmark there is also strong interest in this development of bedded pack barns. In South Korea bedded pack barns have existed for some time now.

Austria

South Korea

3. Prospects for the bedded pack barn in the Netherlands

In 2008, the Productschap Zuivel (PZ – Dairy Produce Board) financed a pilot study on the prospects of bedded pack barns in the Netherlands. There were many questions from the farming practice whether the bedded pack barn, as developed in the USA (Minnesota) and Israel, is feasible for Dutch conditions, as moisture evaporation is crucial. Every day a dairy cow produces some 65 l of moisture as urine and faeces. How much of this will evaporate in the Dutch climate? To find an answer to this question a moisture balance was calculated for the climate in these three countries. In addition, the bedding materials used in these three countries are quite different. This also has consequences for the environmental effects of these packs. In Israel and the USA the environmental impact has remained underexposed so far. For that reason, a start has been made by setting up laboratory experiments to make a tentative estimate.
In the Netherlands there is a growing interest in using materials that are cheaper than sawdust. To clarify the financial impact, a free stall barn (with cubicles) was compared with two types of bedding material in a bedded pack barn, one with compost material from the compost plant and the other with wood chips that are composted by forced aeration.

3.1 Moisture balance
The results given here have been amply described in Wageningen UR Livestock Research report 230 (Smits & Aarnink, 2009).

Researh farms
Compost- en composting bedding
Synthetic floor

1. Wiersma: composting
2. Noord: synthetic floor
3. Groenewegen: compost
4. Waiboerhoeve: composting
5. Aver Heino: sand
6. Zegveld: clay soil with reed
7. Pape: synthetic floor, cow garden
8. Havermans: compost
9. Peeters: compost
10. Hartman: composting

Climate differences

The outside temperatures in the Netherlands (location De Bilt) are 5.2 to 6.4 °C lower than in Israel (Jerusalem). The temperatures in Minnesota (continental climate) are higher in summer but lower in winter compared to those in the Netherlands (maritime climate). The relative humidity in the Netherlands is structurally higher than in Minnesota where, in turn, it is higher than in Israel (Jerusalem). see figure 1.

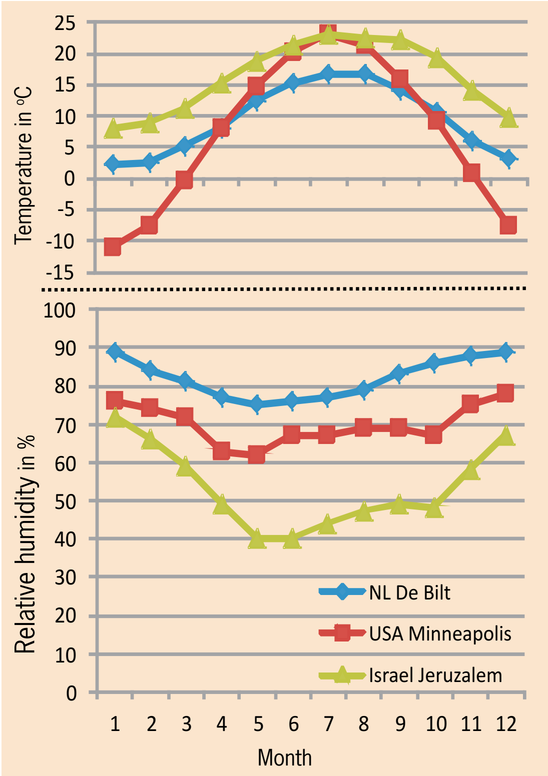


Figure 1. Monthly averages of temperature and relative humidity in the Netherlands, Israel and Minnesota

These diagrams indicate that the weather conditions for evaporation are more difficult in the Netherlands than they are in Israel and that the weather conditions for evaporation in Minnesota are easier in summer, but might be more difficult in winter than those in the Netherlands.

Model calculations

To get insight into the feasibility of bedded pack barns under Dutch climate conditions it must be estimated whether the packs remain sufficiently dry. For this, a combination was made of two existing models for composting and drying. In the model approach, the moisture input by urine and faeces was integrated. Then, calculations were made to estimate the evaporation from resting areas of bedded pack barns under Dutch, Israeli and US (Minnesota) climate conditions and for an available space of 9 versus 18 m^2 per cow. For a pack that totally depends on evaporation, a sand bedded pack or a bedded pack of another (inorganic) material can be considered, whereas a pack in which composting also plays a role, will probably consist of organic, degradable materials.

Netherlands versus Israel versus Minnesota

For the Netherlands the calculations without composting reveal that all the moisture input with urine and faeces can be evaporated only by applying very high air velocities through the house (in the order of 5 m/s). Such high air speeds can only be achieved by very powerful fans, also causing draught problems.

The calculation results for composting under Dutch climate conditions show that the daily moisture input can be fully evaporated for part of the year (at summer temperatures). A forced increase of air speed in winter may cause problems, as heat losses may increase to such an extent that the composting process is impeded.

In Israel composting results in sufficient evaporation, and also without composting more moisture evaporates than in the Netherlands. In Israel the model calculations indicate that evaporation at low air speeds may still be insufficient.

As to Minnesota the model calculations for the hot summer months indicate that composting produces sufficient evaporation, whereas this effect is only limited in the cold winter months. In the very cold winter months, composting would seem to be difficult. In Minnesota in the summer months without composting, the calculated evaporation appears to be slightly higher than in the Netherlands and in winter it is on a comparable level.

9 versus 18 m² per koe

Figures 2 and 3 apply to the Dutch climate, for spaces of 9 and 18 m² per cow, and present the evaporation at different air speeds with and without composting.

Evaporation is related to the excretion of urine that is released into the pack. If more space is made available per animal, the average amount of urine and faeces water per m² on the total area available is smaller and, consequently, the average amount of moisture to be evaporated per m² is less. It is also important, however, that evaporation will occur sufficiently fast on locations where the animals leave their urine (where a spot of 0.7 m² will be 'wetted' each time, irrespective of the total area available), to ensure that the animals are not soiled and milk hygiene remains good. Only to a very limited extent do cows avoid wet spots in the resting area when lying down. This means that adequate evaporation or absorption remains crucial, even if the space per animal is larger.

Evaporation strongly depends on heat production due to the conversion of organic matter (composting) and heat removal. Heat removal strongly depends on the speed of air over the surface of the pack. At (too) high air velocity too much heat will be removed, slowing down evaporation and possibly even the composting process. At a space of 18 m² per cow, however, the degree of evaporation is less susceptible to excessive air speed, and Figure 3 shows that the evaporation does not decrease at a higher air speed of 0.32 m/s, whereas this does happen for an area of 9 m² per cow.

Figure 2. Water excretion (moisture input as urine and faeces) and evaporation for a space of 9 m² per cow

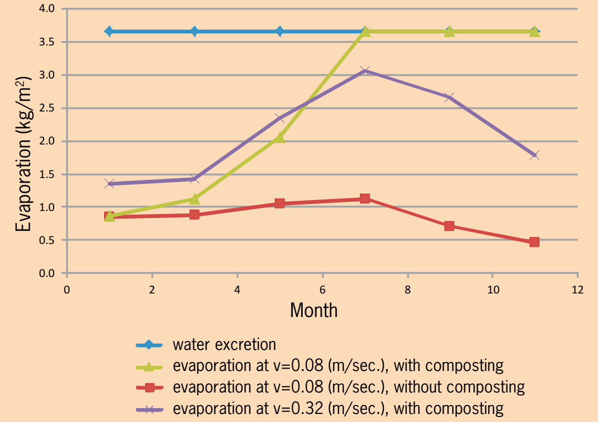
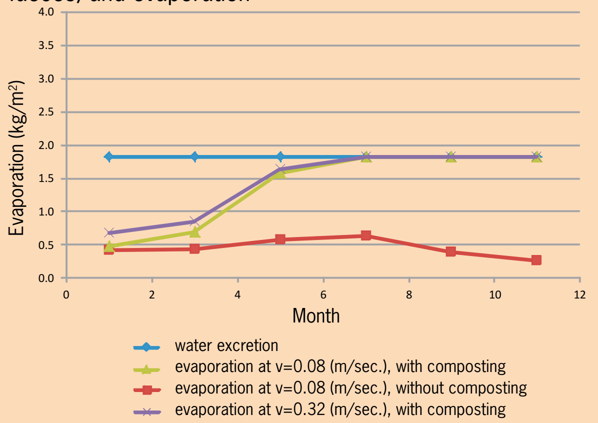


Figure 3. Water excretion (moisture input as urine and faeces) and evaporation



A dry top layer
Day after day the bedded pack receives a certain amount of water (approx. 65 l per cow per day) with the urine and faeces that the cow leaves in the exercise area. When the model calculations indicate that only a fraction of the daily water input into the bedded pack can evaporate from the top layer, the remainder of that water input will either have to disappear through the top layer (drain) and through the lower part, or an amount of dry bedding material must be added to achieve a sufficiently dry top layer. This dry material can be purchased (sawdust, straw, dry compost, dried manure), but it is also possible to store a buffer of previously dried material (from the summer months). Another option is to dry bedding material outside the house under controlled conditions, for instance in a tunnel greenhouse with forced air movement and washing of exhaust air.

Apart from adding dry material it is possible to apply a well-draining sand bedded pack, so that the moisture is removed through the bottom layer.

3.2 Environment
The chances for the bedded pack barns in The Netherlands are mainly determined by the emission of ammonia, greenhouse gasses like carbon dioxide, methane and nitrous oxide, odour and dust. The emission of ammonia and dust are also relevant getting the required permits. Maximum ammonia emission from dairy facilities is set by law at 9.5 kg NH_3 per cow place per year. Livestock housing systems with an official emission factor for ammonia are listed in the annex of the Regulation on ammonia en livestock farming (Rav: Regeling ammoniak en veehouderij). Zero grazing systems always have a higher emission factor than the similar housing system with grazing. The zero grazing emission factor of the standard housing system (slatted concrete floor with deep pits) is 11.0 kg NH_3 per cow place per year. Farmers close to a so called Natura 2000 areas have to meet probably other requirements concerning ammonia emissions.

Emission measurements with a dynamic box

Ammonia emissions have been measured on a laboratory scale, on the three bedding materials on experimental farms. On the experimental farms also tentative measurements have been carried out as regards greenhouse gas emissions: carbon dioxide and methane. No data are available of nitrous oxide yet. Research on odour and fine dust emissions is still being performed on a practical farm. These are all tentative measurements.

Ammonia emission on a laboratory scale
The ammonia emission has been measured on a laboratory scale for several bedding materials (Smits et al., 2009).
The conclusions from this experiment are:

- The ammonia emission from the sand bedded pack is the highest, that from clay material the lowest and that from the solid fraction of separated excrements is in between.
- The looser the bedded pack, the lower the ammonia emission. This is explained by the good penetration of the urine.

Ammonia and greenhouse gas emissions from experimental farms
On the Aver Heino, Waiboerhoeve and Zegveld experimental farms three bedded pack floors have been prepared with sand, compost and dried clay or peat with reed, respectively. For five measuring days divided over about eight months the emissions of ammonia and greenhouse gases (methane and carbon dioxide) from these three packs were measured. All measurements were performed on four spots using a ‘dynamic box’ (see figure). This chapter describes the results of the ammonia measurements. More information is available in Van Dooren et al., 2011, report 411.

Ammonia measurement slatted floor as reference

Emission measurements with a dynamic box
The dynamic box was used to measure the emission from a certain area of bedded pack, and the results were compared with the results for a slatted floor in a free stall barn. As regards the area soiled with faeces there appeared to be substantial differences between a free stall barn and a bedded pack barn. This is shown in Figure 4.

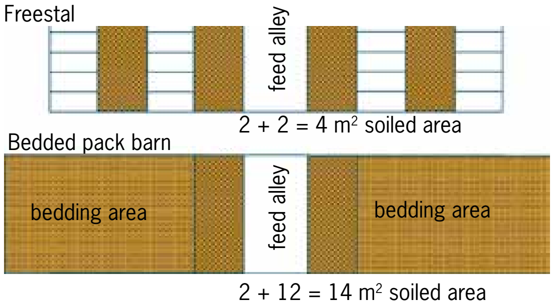


Figure 4. Soiled area in a free stall barn against that in a bedded pack barn

The soiled area on the passages between the cubicles and along the feeding rack is approx. 4 m^2 per cow. In a bedded pack barn with a passage behind the feeding rack the soiled area totals 14 m^2 per cow at a resting area of 12 m^2 per cow.

Figure 5 compares the ammonia emission per m^2 against that in a free stall barn and Figure 6 does so per cow. Figure 6 for the bedded pack barn distinguishes between the emission from the slatted floor behind the feeding rack and the resting area.

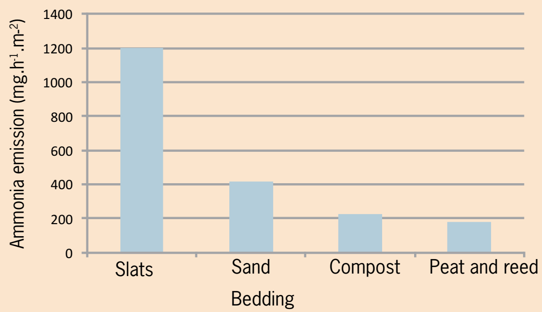


Figure 5. Ammonia emission per m^2 of area in the bedded pack barn against that from the free stall barn.

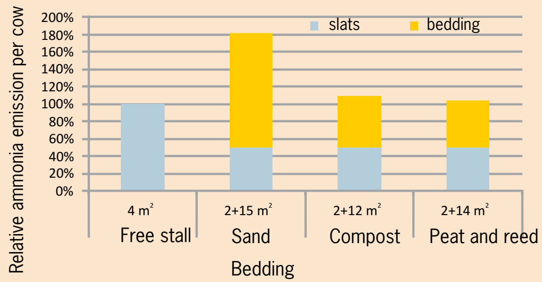


Figure 6. Ammonia emission per cow of area in the bedded pack barn against the free stall barn.

Conclusions of tentative measurements

- The ammonia emission per m^2 in a bedded pack barn is only 15 to 35% against that from a slatted floor in a free stall barn.
- The ammonia emission per cow from a sand bedded pack is much higher than in a free stall barn. The ammonia emissions per cow from the composting bedded pack and the bedded pack of dried clay or peat with reed are of a level comparable to those from a free stall barn (higher by 5% and 10%, respectively).

As stated before the emissions per cow are calculated from the measured emissions per square meter. For the slatted floor these measurements were done in the past on other farm. Another approach to compare the ammonia emission per square meter of different beddings with the slatted floor is to calculate the emission per square meter from the official emission factor per cow. Taking that factor of 11.0 kg NH_3 per cow place per year as a starting point the emission per square meter is much lower than measured: 314 mg NH_3 per m^2 instead of the measured 1200 mg NH_3 per m^2. As a result relative emission per cow of the bedded pack barns compared to the slatted floor system are than 5.5, 2.75 and 2.55 times higher for sand, compost and 'toemaak' respectively. Therefore, calculated emission per cow from bedded pack barns must been as indicative. There also seem to be good opportunities to improve the environmental performances. Preliminary conclusion at this moment is that the chances to meet the emission limits in the nearby future are highest for the compost and 'toemaak' bedding. Further measurement at farm scale should prove these expectations.

Methane and carbon dioxyde

From the sand bedded pack hardly any methane emission was measured. Methane emission from the compost bedded pack varies strongly between 0.4 and 3.7 g methane per m^2 per hour. For the bedded pack of dried clay or peat with reed this value varies between 0.7 and 0.8 g per m^2 per hour. Carbon dioxide emission from the compost bedded pack varies between 54 and 181 g per m^2 per hour and from the bedded pack of dried clay or peat with reed between 14 and 23 g per m^2 per hour.

Laughing gas

The emission of laughing gas (nitrous oxide) is not measured at the bedded pack barns. It is expected that emission will be low at the sand and bedding of dried clay or peat with reed ('toemaak' bedding) In the compost bedding the changes of production and emissions during the composting process are high. Management of the process and the bedding are therefor supposed to be crucial. In a worst case scenario the great part of the available nitrogen is converted to nitrous oxide and emitted. Again, farm scale measurements should give more insight.

With a compost bedded pack the objective is not composting. Here compost is brought in from elsewhere and used as a bedding material in the house. The compost acts as a buffer to collect the urine. Some conversion (composting) in the house is possible, but this is not stimulated. The compost can be of various origins, such as pruning or garden waste.

3.3. Economie

As regards organic bedding material the farming practice seems to be very interested in composting bedded packs or compost bedded packs. The difference between these two types is that a composting bedded pack contains various degradable organic materials (e.g. wood chips) that will compost inside the house, together with the manure. The aim is to initiate and maintain a composting process, for instance by cultivating and aerating the pack. In this way a compost-like material is produced, however without the status of compost, but remaining just the status of (animal) manure.

The heat created in the composting bedded pack will step up evaporation so that a dry top layer can be obtained as compared with a compost bedded pack at a smaller space per cow. Additional air movement due to fans, cultivation, sunlight or adding more compost must keep the top layer of a compost bedded pack dry.

Furthermore, synthetic floor developments are continuing. The top layer separates the solid fraction from the liquid fraction and the urine is drained through the bottom layer.

The investment costs and the annual costs of a free stall barn are compared with those of a composting bedded pack and a compost bedded pack.

As the calculation results strongly depend on the starting points, a sensitivity calculation has also been made.

Slatted floor as reference

Calculations for organic bedded packs

Table 1 Comparison of two types of bedded pack barns with a 150-cow free stall barn

	Free stall barn	Compost	Composting
Number of dairy cows	150	150	150
Resting area per cow (m²)	3	15	8
Bedding material		Compost	Wood chips
Bedding material per year (m)		0.5	1
Price of bedding material per €/m³		€ 10	€ 5
Length of house (m)	48	49	49
Width of house (m)	29	59	37.5
Available area per cow	7.7	17.6	10.6
Area of house/cow (m²)	9.3	19.3	12.2
Price of superstructure (Pos) (€/m²)	80	80	80
(Pos) with slurry pit €/m²)	180		
(Pos) of bedded area (€/m²)		24	49
(Pos) of feeding and exercise areas (€/m²)		49	49
Required labour time/cow/year (h)	1.2	1.8	1.2

Investments in the housing systems differ very much. The bedded pack barn with a compost or composting bedded pack requires a lower investment in substructure than a free stall barn. This is caused by the lower costs of the slurry pit. But on the other hand an external facility for manure storage is needed. The superstructure, however, is more expensive due to the larger area of the bedded pack barn. A standard free stall barn is designed for 9.3 m² per cow, the house with compost bedded pack for 19.1 m² and the house with composting bedded pack for 12.1 m² per dairy cow (inclusive of feeding passage). Consequently, the differences in space per cow are large.

The calculations are for a 150-cow farm. Table 1 makes a comparison between a free stall barn, a bedded pack barn with a compost bedded pack (pruning waste compost from a composting plant) and a bedded pack barn with a composting bedded pack (wood chips and aeration).

The length of the house is the same for all concepts, so that the feeding space at the feeding rack is the same. The differences in house area depend on the width of the house. The 'compost barn' is than very wide: nearly 60 m.

The calculations for the free stall barn are based on ample cubicles (1.20 m wide and an average length of 2.5 m), wide passages (3 m between cubicles and 4 m behind the feeding fence) and a feeding area of 5 m. For the bedded pack of compost an area of 15 m² per cow is assumed, with 0.5-¬m thick bedding material. For a bedded pack of wood chips the calculations are based on 8 m² per cow, though with more and cheaper material. This means that a bedded pack of 1 m thick is needed, as composting will reduce the volume by half. Consequently, in one year an average bedding thickness of 0.5 m will remain of a 1 m thick bedded pack. The price of wood chips is € 5.00 per m³ and of compost € 10,- per m³. These prices will differ strongly between regions, depending on availability.

The costs of layouts do not vary much. A free stall barn requires higher investments for cubicles, but has lower lighting costs, whereas the two other systems need ventilation and possibly also aeration. The 'composting barn' is € 430 cheaper per cow place than a free stall barn, and the 'compost barn' is € 128 per cow more expensive, especially because of the additional m² per cow (see Table 2).

Table 2 Investments for house systems (€)

	Free stall barn	Compost	Composting
Carcass			
Preparatory work	10,850	9,378	7,002
Substructure	250,387 *)	83,859	88,659
Superstructure	111,283	228,750	144,750
Total construction	372,521	321,988	240,412
Layout			
Manure removal equipment	7,500	5,000	5,000
Feeding rack	10,819	10,920	10,920
Cubicles, coverings, water troughs	43,800	15,000	15,000
Lighting	6,955	14,297	9,047
Water and electricity	10,000	10,000	10,000
Fans		24,000	12,000
Aeration			18,000
Total layout	79,074	79,221	79,969
Manure storage			
Slurry silo (for 6 months)		63,360	63,360
Solid manure plate (for 6 months)		6,188	3,300
Total manure storage	0	69,548	66,660
Total	451,595	470,756	387,041
Total per cow	3,011	3,138	2,580
Difference with free stall barn		+128	-430

*) Inclusive of manure storage

The total annual costs for the composting barn are € 14 per cow per year lower and for the compost barn € 91 higher than those of the free stall barn (Table 3).

Table 3 Jaarkosten stalsystemen (€/koeplaats/jaar)			
	Free stall barn	Compost	Composting
Carcass	236	204	152
Fittings	48	49	50
Manure storage	0	44	42
Energy	57	68	63
Bedding material	20	75	40
Labour	24	37	24
Total	385	477	371
Difference with free stall barn		+91	-14

Table 4 Sensitivity analysis (euro/cow place/year)			
	Free stall barn	Compost	Composting
Price of investments (+10%)			
- investments	301	314	258
- annual costs	28	30	24
(Resting) area for cows (+1 m²/cow bedded pack barn)			
- investments	n.a.	110	160
- annual costs	n.a.	16	20
Amount of bedding material used (+10%)	n.a.	7.50	4.00
Price of bedding material (€ 1/ton)	n.a.	7.50	8.00

The building costs of the compost barn and the free stall barn are the most sensitive to price level fluctuations. This is in line with the higher investments in these houses. The effect on the annual costs per cow for the various house systems is limited.

The low investments and resulting low annual costs are the main causes of the low costs for the composting barn. The compost barn requires both high investments and more expensive bedding material.

The advantages and disadvantages of the above systems strongly depend on price levels and materials needed. This can be demonstrated by means of a sensitivity analysis (Table 4).

Composting stable

Extending the resting area by 1 m^2 per cow has the largest effect on the costs of the composting barn. A composting barn as presented here, requires another, more expensive bedding material for the resting area than a compost barn, which is caused by the more intensive aeration. Though the additional investment of 1 m^2 additional area of a free stall barn has not been included, it should be noted that the extra costs of a free stall barn will be much higher here.

Because of the large area in m^2, the compost barn is the most sensitive as regards the amount of compost required. As in the case of composting, material has to be added all the time to maintain a sufficiently thick layer, much material is needed, despite the smaller area. At a price of wood chips of € 7.00 per m^3 there is no difference in cost price between a free stall barn and a composting barn, whereas the operation of a compost barn is more expensive than that of a free stall barn, even if the compost is acquired for free.

Synthetic floors

A synthetic floor with a bottom layer to drain the urine has the advantage that no bedding material has to be supplied and removed. On the other hand there are the costs of top and bottom layers as well as the costs of removing the cow pats from the top layer. The third Cowfortable report (Galama et al., 2008) 'Grensverleggend huisvesten van melkvee' (New horizons for dairy cattle housing) compares a synthetic floor with a free stall barn and a composting bedding in a bedded pack barn. An indication: the investment costs of the synthetic floor (inclusive of robots to clean the floor) are approx. € 1000 higher per cow than those of a free stall barn and a composting barn. This report estimates the annual costs of both a composting barn (without aeration) and the synthetic floor, both with a resting area of 15 m^2 per cow, to be higher than those of a free stall barn, being € 65 and € 50 higher per cow, respectively.

Final returns

The final returns from a bedded pack barn also strongly depend on the effects on animal welfare, life expectancy of cattle, yield per cow and manure quality in relation to fertilisation and soil fertility. The third Cowfortable report (Galama et al., 2008) gives a few examples. If the yield per cow can increase by 250 kg per year at the same feed intake (due to healthier animals), and the annual stock replacements decrease by 10%, the benefits for an extensive farm amount to € 135 per cow (without sale of manure) and for an intensive farm to € 188 per cow (with sale of manure). These calculation results are for the situation without milk quotas.

4. Experiences acquired from experimental farms

4.1 Principles underlying bedded packs

Three experimental farms of Wageningen UR Livestock Research have tested three different bedding materials. The pilot study demonstrated that it is very important to keep the top layer dry by means of heat development in the pack and/or moisture-absorbing and/or draining material. In addition the emission of ammonia shall be reduced. Table 5 shows the principles which are illustrated with drawings in figures 4 to 6.

Table 5 List of type pack materials for bedded pack barns and underlying principles

Designation	Starting material	Moisture	Nitrogen
'Sand bedded pack'	Sand with lavelith	Drainage	Separation of faeces and urine
'Composting bedded pack'	Wood chips and sawdust	Evaporation	Conversion and fixation
'Toemaakbodem' *)	Clay dredgings with reed	Absorption	Fixation

*) 'Bedded pack of dried clay or peat with reed'

Experiments are not only carried out on these three experimental farms, bedding materials for bedded pack barns are also applied or developed on other locations (see Chapter 5).

One of the solutions that are tested in two initiatives is the synthetic floor. The underlying principle of the synthetic floor, like that of the sand bedded pack, is based on the separation of faeces and urine and on removal of the liquid fraction.

In farming practice both the composting bedded pack and the compost bedded pack are applied in several variations. One example is provided with underfloor aeration to stimulate the composting process.

In another example the compost bedded pack is kept dry by providing additional compost and floor heating. Internal heating by the composting process may occur but is not the main objective.

Zwier van der Vegte
Challenge: Automation of faeces removal from top layer

4.2 Explanation to three bedding materials

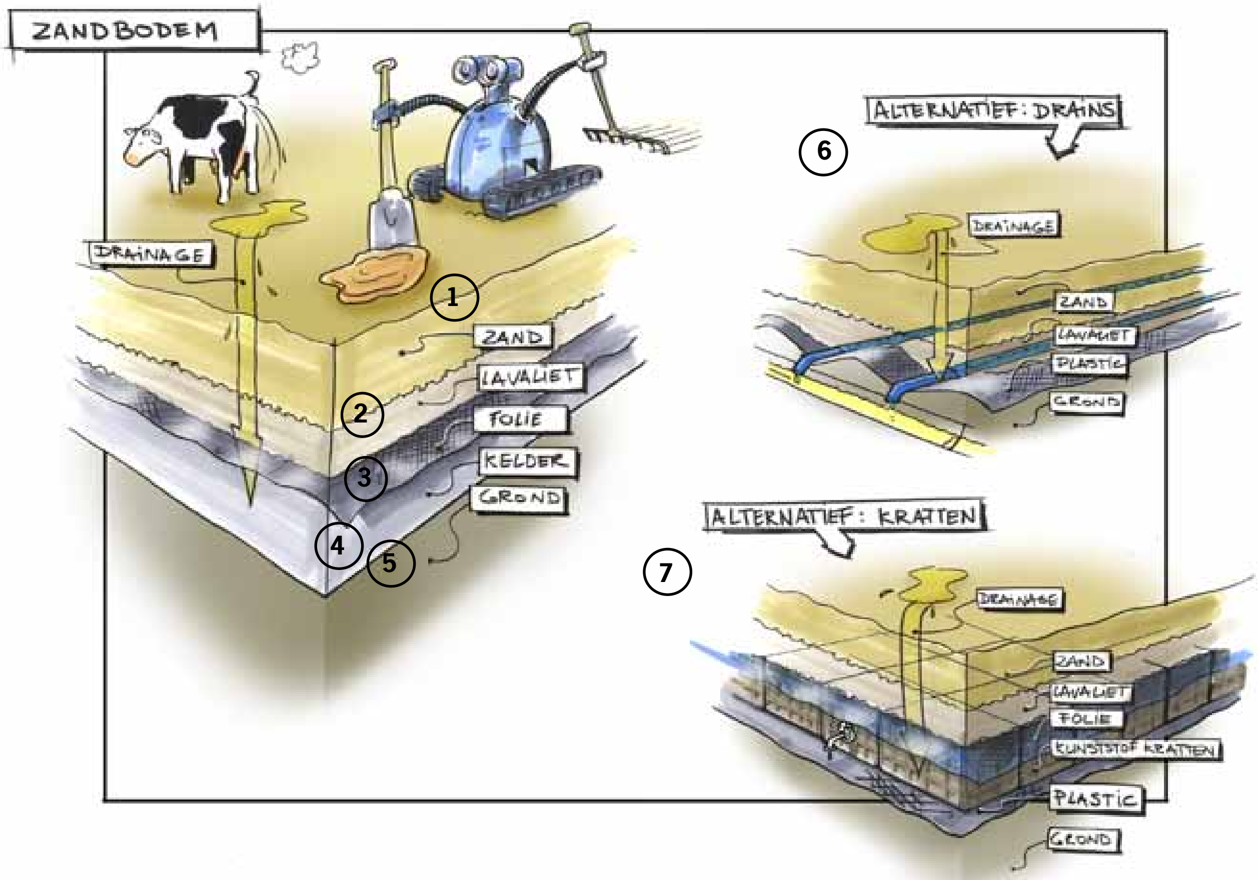


Figure 7. Sand bedded pack on Aver Heino experimental farm: The manege-like exercise area for cows

1) The removal of cow pats prolongs the life of a sand bedded pack
2) Drainage sand provides a permeable top layer and resting comfort
3) Lavalith provides stability, filters and passes urine to the slurry pit below
4) Ground cloth keeps sand out of the slurry pit
5) Slurry pit
6) Alternative with drain pipes that carry off urine to the central storage
7) Alternative with synthetic box units to be used as a slurry pit

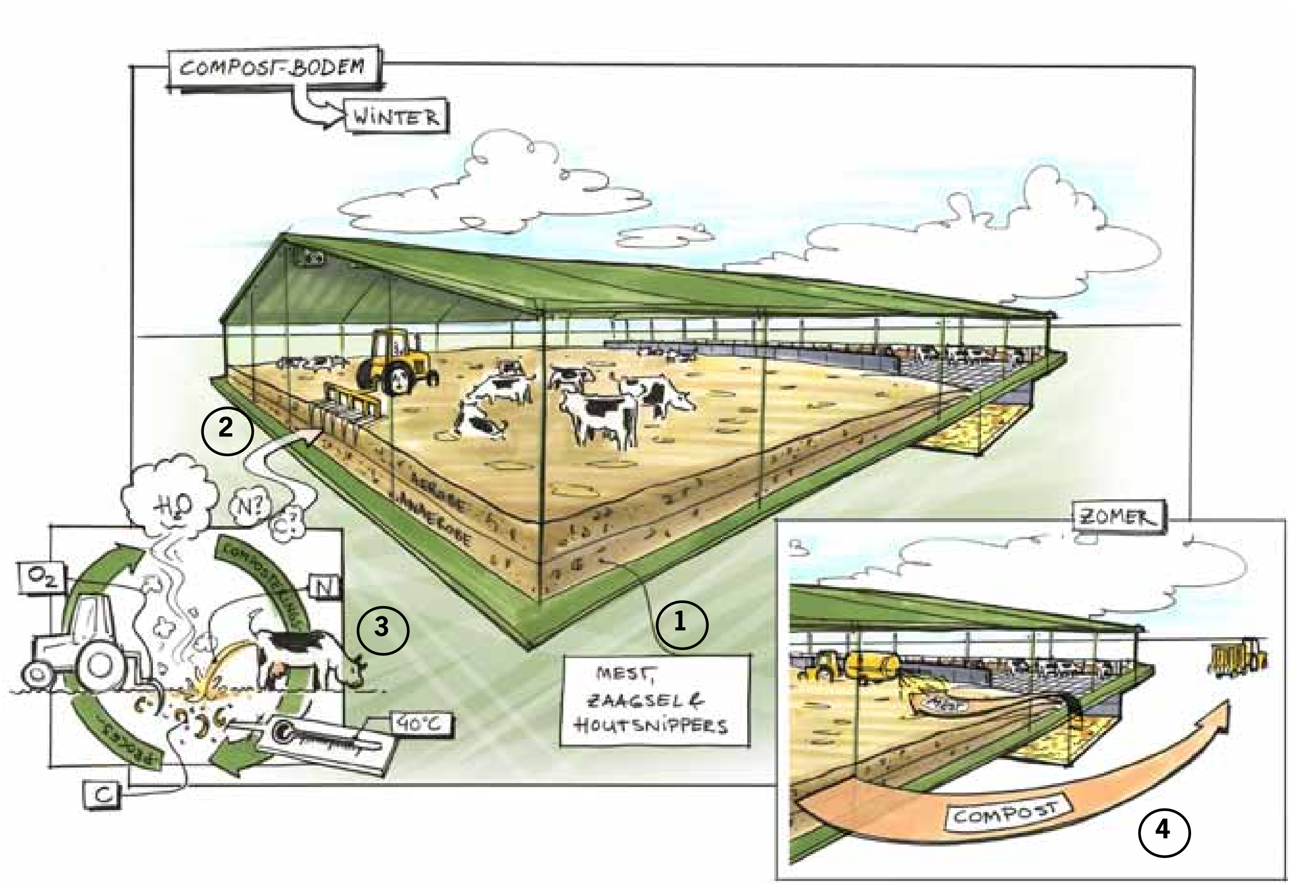


Figure 8. Composting bedded pack on De Waiboerhoeve experimental farm: Composting cattle manure

1) Wood chips provide firmness and airiness, sawdust absorbs moisture.
2) Twice daily working the pack will mix the top layer and brings oxygen in, causing it to compost together.
3) Moisture, oxygen, carbon and nitrogen are the ingredients needed for a proper composting process, causing the temperature to run up to 40 – 50 °C.
4) Composting in summer without cows by applying manure to the resting area.

Jan Bloemert
Challenge: Heat development in bedded pack, no mastitis

Frank Lenssinck
Challenge: Cheap and solid packs with excellent fertiliser quality and clean cows

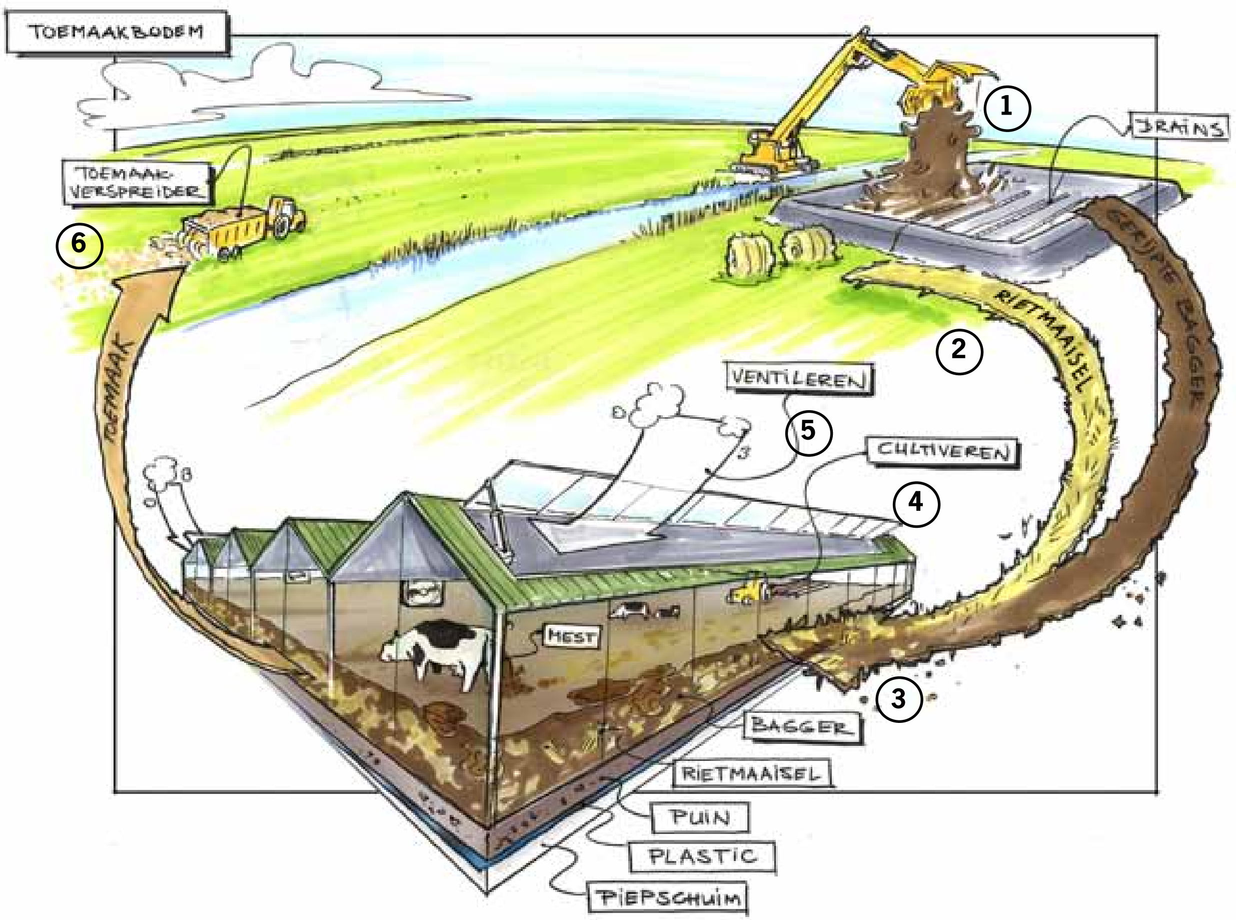


Figure 9. Bedded pack of dried clay or peat with reed on Zegveld experimental farm: renewed practice of ancient method of manure application

Bedded pack of dried clay or peat with reed: A facelift for an ancient manure application method

1) Dredgings from ditches and waterways mature in store.
2) Mown reed from nature areas is harvested.
3) A mixture of matured dredgings and mown reed produces the bedded pack in the house, cows will enrich the mixture with manure.
4) Daily working provides a homogeneous mixture.
5) Maximum ventilation through side walls and roof keeps top layer dry.
6) Spreading of dried clay or peat with reed mixture, to improve soil fertility.

4.3 Experiences with three types of bedding materials

The experiences have been described in great detail in report 411 of Wageningen UR Livestock Research (Van Dooren et al., 2011). Attention was paid to:

- Drying of the top layer
- Hygiene of the animals, animal behaviour and animal health (claw health and cell count)
- Food safety and the risk of mastitis by microbial contaminants
- Ammonia emission
- Emission of greenhouse gases
- Composition of bedding material

The results of the first three items were described in general and of each bedding type. The experiences are based on small numbers of animals (12 to 19 animals per house) and a relatively short period (approx. 37 weeks). Consequently, the experiences are indicative, especially of claw problems or cell count.

General - bedded pack barns

- In general there were no strong deviations from the free stall barn as regards claw and udder health.
- Hardly any skin lesions were found for any of the bedded pack barns.
- In a bedded pack barn cows are resting about 45 to 50% of the time, which is comparable with that in a free stall barn.
- In a bedded pack barn animals tend to lie down and get up easier (faster).
- Especially stiff animals seem to benefit from a bedded pack barn.

Sand bedded pack on Aver Heino experimental farm

Drying of top layer
- The draining performance of sand was less than expected.
- The moisture increase in the pack was about 5 l per cow per day.
- Approx. 15 m2 per cow was needed to prevent a rapid saturation with moisture.
- Provided the cow pats were removed from the surface by hand, the top layer of 5 cm had to be replaced after 75 to 100 days.
- For a sand bedded pack to be successful, the faeces must be removed frequently.

Animals
- Initially cows are clean, but they become slightly soiled in the course of time.

Microbial contaminants
- The microbiological contamination on the sand bedded pack was the lowest. In this pack the concentrations of spore populations and of streptococci, Kelbsiella and E.Coli were lower than in the composting bedded pack and the bedded pack of dried clay or peat with reed.

Composting bedded pack on Waiboerhoeve experimental farm

Drying of top layer

- The temperature of the bedded pack remained relatively low (approx. 25 to 30 °C) thanks to large heat losses and moderate composting process.
- Heat losses occurred as a result of too thin a bedded pack (approx. 30 cm), repeated working and a large exchange area. A thickness of at least 50 cm is needed to keep the heat in the bedded pack when it is worked.
- A moderate composting performance does not seem very likely to be caused by a lack of oxygen. Possibly insufficient availability of carbon plays a role here. The composting process can be stimulated by adding feed rests.
- The dry matter content of the bedded pack fell from 40% initially to 30% by the end of the experimental period.
- Dry material (sawdust) has to be added at regular intervals.
- An area of 12.5 m2 per cow is necessary.

Animals

- Cows remain clean.

Microbial contaminants

- Little difference in microbiological composition as compared with free stall barn (with sawdust).

Bedded pack of dried clay or peat with reed on Zegveld experimental farm

Drying of top layer

- Dried clay dredgings can be a good moisture absorbent, but also increases the risk of puddling, as a result of which the resting area becomes impermeable and the discharge of moisture (urine) stops.
- Reed has the disadvantage that it can absorb little moisture if compared with straw.
- It is better not to work the pack by cultivating or digging.

Animals

- Reed gives firmness to the pack, improving the bearing power. It makes sense, not to chop the reed but to integrate it into the bedded pack entirely.
- Especially the claws and hind legs become soiled.
- Placing the dried clay dredgings and reed in layers increases the bearing power of the bedded pack.
- In several cows high cell count values were observed.

Microbial contaminants

- The bedded pack of dried clay or peat with reed appeared to contain the highest concentrations of all spore populations against the sand bedded pack and the composting bedded pack.

5. Experiences acquired from practical farms

The experiences and opinions of six dairy farmers are described.

5.1 Peeters

"We were planning to build a new livestock house and for that reason I participated in a practice network of Wageningen UR Livestock Research that deals with the subject. Here we got the idea of a bedded pack barn. In 2008 my father went to Israel, with Paul Galama and Zwier van der Vegte of Wageningen UR Livestock Research as guides and several other participating farmers, to see bedded pack barns with compost bedding in practice. He became very enthusiastic and we have picked up the idea ourselves. We were the first in the Netherlands to build a bedded pack barn. Israel, it is true, was a fine source of inspiration, but is a very different country with a different climate. In the Netherlands, a bedded pack with dried manure will not be a success. Therefore we investigated the option of using compost from a nearby composting plant. Half a meter of compost can absorb much faeces and urine. To design our livestock house with one half of it dedicated to compost bedded pack and the other half equipped with cubicles, we called in a Dutch architect. In April 2009 we had our building permit and in July 2009 the house was ready for the cows.

Initially we had sixty dairy cows in the bedded pack barn, but we did not continue that. The problem was that there was no milking system in this half of the house, and installing a milking system requires many adaptations. Currently we keep young stock and dry cows on the compost bedded pack. All the dairy cattle are kept on the other side of the feeding area and are milked by milking robots.

The cattle on the compost bedded pack feeds at the feeding fence from their compost bedded pack. There is no passage along the feeding fence. This means all excrements get into the compost bedded pack. That is no problem with dry cows and young stock. In a time span of 18 months it has not yet been necessary to add new dry compost. However, we replace wet compost along the feeding fence area at certain intervals (every six months) by dry compost from the outside edges.

All in all we are satisfied, but being forerunners we don't know how much nitrogen will be lost and in what type of nitrogen (N_2 or NH_3 or N_2O).

Firtst bedded pack barn with compost in The Netherlands.

Aerating systems with pipes.

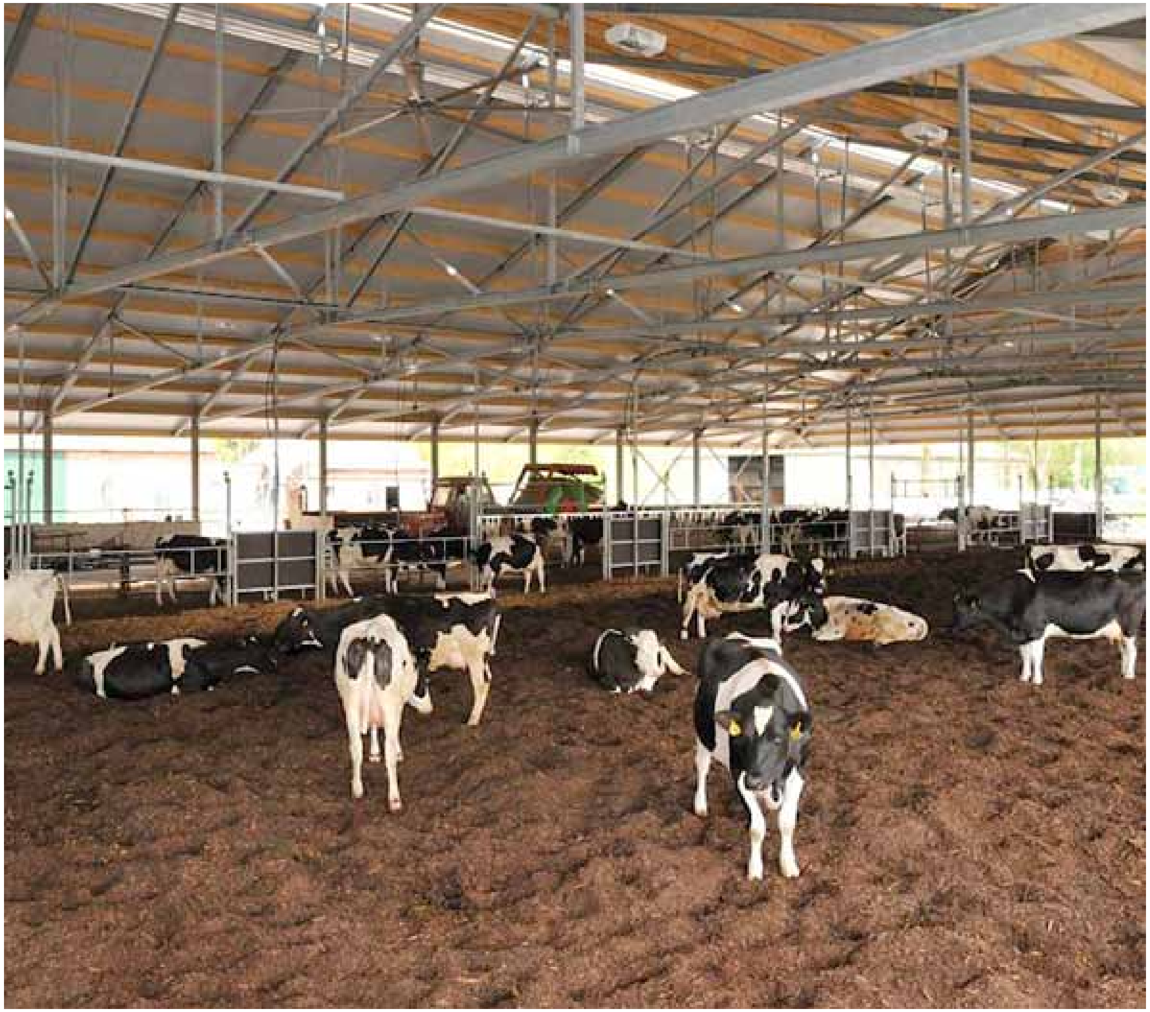
5.2 Wiersma

"In our livestock house with sixty cows we actively run a composting process and do not apply – like in Israel – manure drying. In our opinion that would increase the emission of ammonia, and then we would be on the wrong track.

We got the idea to make this livestock house because the farmers' trade journal De Boerderij published an article on cattle houses in the USA where composting was done inside. We wanted to concretise that idea. As we did not want any cubicles anymore, we arrived at a bedded pack barn with a composting bedded pack. The system has been operative since December 2009. It is simpler, both to the cows and to us. The cow has all space she needs, is walking around at will and has less claw problems. All work can be done by machines, physical efforts are no longer necessary, or only occasionally, and we are happy with that! The system is both cow-friendly and farmer-friendly and it does work. It could not be better!

We have deliberately decided for a composting bedded pack and not for a bedded pack of compost. The heat that is released in the composting process is essential to keep the top layer sufficiently dry. We use fresh wood chips as a bedding material. This keeps the pack airy and firm. The wood chips contain sufficient carbon. Every day the cows add nitrogen to the process. We try to bind this nitrogen to the carbon in an adequate composting process. Therefore we have installed an aeration system underneath the wood chips. At 2-m spans there are tubes between the concrete slabs. Air is forced through these tubes for 1 h per day to bring additional oxygen into the pack to enrich this layer with oxygen. In this way we can achieve a higher temperature of 55 °C in the pack, and that is ideal for the composting process. To me it is an improved version of the American composting barns, where at most a temperature of 40 °C is reached. In something more than half a year you can see that the coarse bedding material of wood chips has changed into a pack that is more or less like potting compost.

The volume will decrease in the composting process. Having supplied a total thickness of 1 m of wood chips, only 50 cm of pack material remains. As the pack is becoming more and more compact, it becomes more difficult to force air through it. To me the best solution seems to be that, from now on, we should start a new pack of fresh coarse wood in autumn, so that it can be kept dry in the wet autumn and winter seasons. But then the old pack must be stored outside the house, so that the old material (composted manure-enriched wood chips) can be applied to the farm-own fields in spring."



5.3 Havermans

“Five years ago I saw bedded pack barns with dried manure packs in Israel. I have been wondering how we could achieve this in the Netherlands too. Starting point was that the system had to be inexpensive and moisture-absorbing. We have chosen compost as a bedding material, so without active composting in the pack. The heat development that occurs a little bit then will stimulate the evaporation of moisture, but using compost as a bedding material is easier than the composting process as such. The past few years we have visited several houses with compost bedded packs and collected information from all parts of the world. Since the summer of 2010 we ourselves have been operating a bedded pack barn with compost bedded pack for 180 cows – the “Integraal Duurzame Vrijloopstal” (integral sustainable bedded pack barn - IDV) – which we are very proud of. Our IDV house has even won the ZLTO Initiative Award 2010. The house measures 50 x 100 m, so we have thought big from the start. Prior to this we made an 18-month experiment with dried compost in part of the old livestock house. Nowadays only the milking robots are located on the slatted floor, the rest all happens on compost, also feeding with special, mobile mangers.

So far I am very positive: animal welfare, yield and health all have improved, in fact the cows are no trouble at all. There are hardly any leg problems, and so there is no reason to trim their claws. Visitors often remark that it is so quiet in the house. And the animals have increased their visits to the milking robot. They are comfortable here! On top of that the building costs are considerably lower than those of a traditional house, which is due to the greenhouse construction and the lower costs for manure storage.

The biggest concern is that the bedded pack remains wet in winter. It has to dry off by outside air and partly by floor heating in combination with the special superstructure with its greenhouse roof. The latter is crucial for the manure to dry, because the sunlight shines through the roof and dries the top layer. In summer this is easy, but in winter more dry compost has to be added. In spring a spreader applies the manure-enriched compost to the fields and maybe part of the material will be sold to a tree nursery, but we have no experiences with that, so far.”

For more information: www.id stal.nl

5.4. Groenewegen

"In total we milk ninety dairy cows. On our Blokzijl farm we first had a free stall barn and, later, here in Kraggenburg we had a deep-litter house with straw. We were not very satisfied with straw, as we had to replace it every 2 or 3 months. A milking machine supplier put forward the suggestion of a compost bedded pack in a bedded pack barn with milking robots. On the internet I searched for more information and found out that they are very active with compost bedded packs in Israel. It was a challenge to us to try that here also. In September 2008 we made a start with the design and drawings. In January 2010 we could start building and by the end of August 2010 our bedded pack barn was ready for use.

For the compost bedded pack we called in a trading company in compost materials. That company wants experiment with their materials in various livestock houses and pays us. The initial three months we had a bedded pack barn on kitchen waste compost. Since mid-November 2010 we have had a bedded pack of green compost. Our first experiences are that green compost is firmer than kitchen waste compost. The cows tend to sink more into a bedded pack of kitchen waste compost when it is getting saturated, for kitchen waste compost is a very fine, low-structure material that can easily become mushy. Green compost contains much woody material and has a coarser structure.

We notice that cows are moving more freely. No longer do they have lumps, thick heels and bold spots. No longer do we need to use foot baths, what we used to do as a prevention once every three weeks. In the old unit 50% of the cows suffered from Mortellaro's disease. In October 2010, two months after we had started our bedded pack barn, we once more trimmed claws, but only some 20% of the animals showed signs of Mortellaro's disease. That indicates that we are on the right track. Furthermore, the new bedded pack barn with compost bedded pack is less expensive and also seems to be a more environmentally friendly husbandry system. It smells less, ammonia emission seems to be less, though that has not been measured officially yet."

5.5 Hartman

"I have a test setup with two cows on a pack of biological material. Consequently, I can only give observations, not concrete conclusions. A few years ago I had the plan to build a new cattle house and became enthusiastic about Pascal Peeters' bedded pack barn with a compost bedded pack; I also wanted this to be a low-emission house. Precondition was that I could keep the process completely under control. With that in mind I visited compost plants, mushroom growing room builders (who use much manure, as mushrooms grow on it, in a controlled process). I have contacted a consultancy on composting, a mushroom growing room builder and a greenhouse-type barn builder.

My experiment consists of a greenhouse-type barn of 9 x 4 m, a manure container and a synthetic collapsible roof. The bedded pack is made up of wood chips with a top layer of green compost. The wood chips and the green compost become softer in the process. That makes it even more comfortable to the cows.

It is not advisable to have a high temperature in the top layer as a result of the composting process. Therefore, we have searched for a composting method by which the top layer remains 'cool' and the composting activity remains limited. To achieve this we have opted for exhaust aeration to remove moisture and gases. It seems to be effective, though this is a very small-scale experiment. But what you smell is wood, not ammonia. The advantage is that the manure is better than slurry and that the cows show natural behaviour. Behind the feeding fence it is still difficult to keep the bedded pack loose and dry as the cows tend to stand there for a long time and tread down the pack. It does not seem cheaper than a conventional setup either, but there are several advantages, such as improved animal welfare, a longer animal life and a better soil fertility, that do not show in the economic picture. In the end what counts are the annual costs."

5.6 Noord

"We have chosen a bedded pack barn with a synthetic floor, which means it is all in synthetic material. We are still experimenting with a few cows, but in 2011 we want to operate the system on a full-scale basis. The objective is to come as close as possible to the pasture – which is the natural environment. The floor is placed directly on a flat (flattened) sand pack and consists of four layers.

The first, bottom layer is the basic floor. It consists of 13 cm thick, groove-jointed synthetic panels of 122 x 240 cm. They contain urine gutters to discharge the urine to a central point in the house where it is collected in a sink. From there it is pumped to the slurry storage.

The second layer consists of glass fibre grates of the same dimensions with a mesh size of 3 x 3 cm.

The third layer, the comfort layer, has been placed for the first time now. It is a soft, highly permeable mat that provides cow comfort. The comfort mat shall ensure that the floor feels like that of a comfortable cubicle, with this difference that the cows rest and walk on the same floor. So far, the comfort layer used to pose a problem as far as the passage of urine was concerned, but now we have found suitable prototypes. Currently we are performing experiments with two types of comfort layers, one of 2 cm thick and the other of 4 cm thick. For this we have arranged an experimental setup with 10 to 15 cows and monitor whether the cows show any preference. Will they rest anywhere in the house or just on the 4 cm-thick layer? On the basis of the result we can decide on the subsequent livestock house.

The top layer, the fourth layer, is the layer on which the cows walk directly. Adequate filtering is the most important property. Urine must be removed quickly to prevent any contact with faeces, for that would cause very high ammonia emissions. The synthetic mat is responsible for the quick filtering to achieve a rapid passage of urine and the retention of faeces (that shall remain on top). We are now performing an experiment with a new, thinner top layer that might have a better permeability.

The top layer is cleaned by a robot cleaner that sucks up the faeces. After about 15 min the robot has to dock at a charging station where at the same time it drops the faeces which are then sent to a storage depot.

The advantage of this floor is that the excrements are separated into a solid and a liquid fraction which can be utilised better. The liquid fraction contains much nitrogen that can be concentrated and used to replace artificial fertiliser in spring. In this way the cycle on one's own farm is closed! The solid fraction contains much phosphate which is good for arable crops, and is supplied to arable farmers. We hope that we can cut down the manure surplus in this way.

All in all we are very satisfied with the synthetic floor. The investment is somewhat higher, but one can save on bedding material, and it is less labour-intensive. Durability and flexibility are also major advantages of the floor; in case of any relocation the panels can easily be picked up and taken to another place. Also the cow has more space, and claw health seems to be better.

This seems to be an interesting system for all cattle farmers because urine is separated from the faeces. We now fully engage in the further development of this synthetic floor and try to place it also in existing cattle houses, including in free stall barns. The only concern is that the regulations shall allow this, if we want to realise this in a larger practical livestock house for all cows. Then it is our ambition to obtain an official ammonia label for the floor."

For more information: www.highwelfarefloor.nl

5.7 Pape

Cow Garden with a synthetic floor

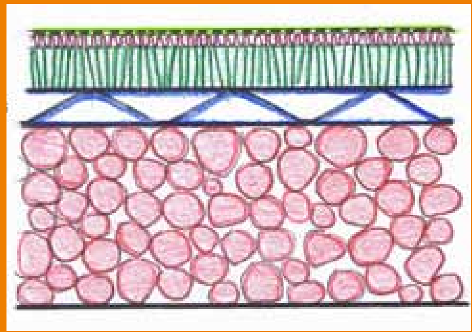
"The Cow Garden idea was developed in cooperation with the Courage Foundation. The Cow Garden is a bedded pack greenhouse-type barn with trees below and through the roof (with a fleece between the trees) and green strips serving as partitions. The floor is a synthetic one, though we prefer to speak of a pasture floor, as it is based on the natural situation, the pasture, and has been developed starting from the cow, like the house as a whole.

In recent decades, innovations always were farmer-oriented. Present-day cattle houses do not have much attention for the cow. In many cases these are production halls with much concrete and iron. With the Cow Garden project we try and return to the origin in an efficient way, with the focus on the cow. In fact we have taken the 'outdoors' indoors by creating a controllable, green environment. An agreeable environment for cows, farmers and citizens.

A cow tends to forage on the plain where she can find the best grass, but that is not her favourite place to be. It is difficult for her to stand heat and therefore she prefers the morning and the evening. She also has developed a gastric system that enables here to store the feed quickly after which she retires below trees or shrubs (cool and protected environment) to ruminate. Chewing the cud takes a substantial part of her day.

The Cow Garden has resting areas below trees, surrounded by green hedges and a feeding passage with plenty of daylight (the plain, foraging area). The entire house has a pasture floor. This is a synthetic floor of a resilient structure that gives the cows adequate grip and a soft bed. It consists of a top layer (cloth) that quickly passes the urine and retains faeces. Below that is a permeable flexible layer, with a stabile draining layer with drainpipes underneath. The bottom layer is impermeable and ensures that the urine does not get into the subsoil. The top layer is cleaned by a robot: it collects the faeces, cleans the cloth to keep it permeable and brings the faeces to a central location in the house from where it is removed to a storage facility. We have tested the floor by presenting the cows the choice between cubicles with bedding material and the pasture floor. After one night the cows showed their preference for resting on the pasture floor. They can walk there with more ease and can get up easier. Calving on the floor is also experienced as positive, both by the cow and the farmer. This synthetic floor was made specifically for cattle. In my opinion it cannot be used right away for other sectors (pigs, poultry). This requires research first."

For more information: www.koeientuin.nl



Cross section floor

6. Livestock house designs

The first bedded pack barns in use already show a great variety of bedding materials and house designs. More options are conceivable. To demonstrate a number of these options and to gain inspiration, various layouts have been made for a bedded pack barn for 120 or 240 cows with a resting area of approx. 15 m^2 per cow. The milking system in these layouts consists of milking robots. From the resting area the cows arrive in a small collecting yard before the milking robot. Next to the milking parlour there is a separation area. The feeding system in these layouts varies. Another concept presented consists of a rotary milking parlour with an animal-friendly collecting yard: the 'landscape farm'. Drawings have also been made for a circular cattle house. Finally an idea was supplied to make a foil livestock house shaped as a greenhouse to make an attractive element in the landscape, and layouts and 3D drawings have been made of a pagoda livestock house with a gradually sloping roof.

6.1 Bedded pack barn with a conventional feeding area

Figure 10. 2 x 60 cows with a conventional feeding area and walk-through concentrate feeders

6.2 Bedded pack barn with an automatic feeding system

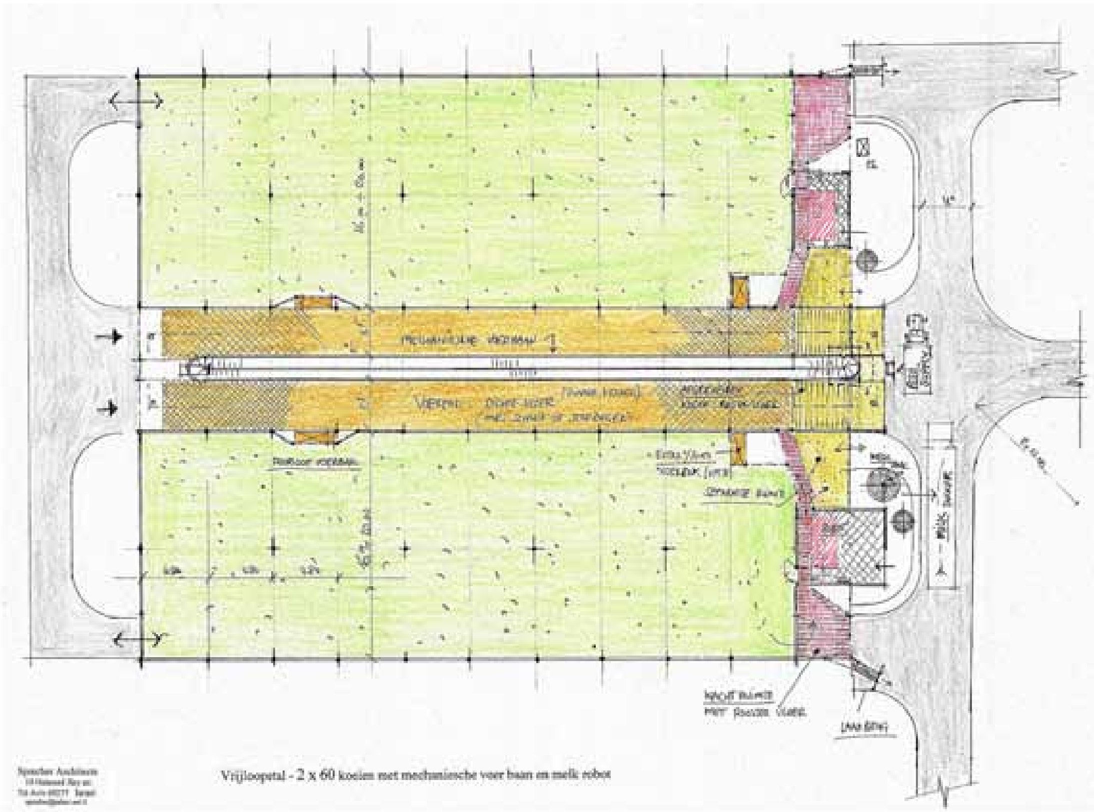
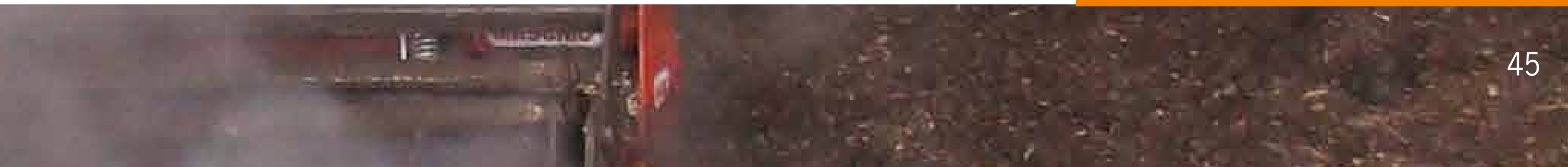


Figure 11. 2 x 60 cows with automatic feeding system (feeding trough with chain)

Maps designed by:
Yehuda Sprecher, Architect Israël



Cows have sufficient feeding space around an automatically filled feeding trough. The plants in and around the greenhouse ensure that the house fits in well into the landscape and on hot days also provides some coolness. The synthetic floor is swept clean by robot cleaners.

6.2a Bedded pack barn with an automatic feeding system

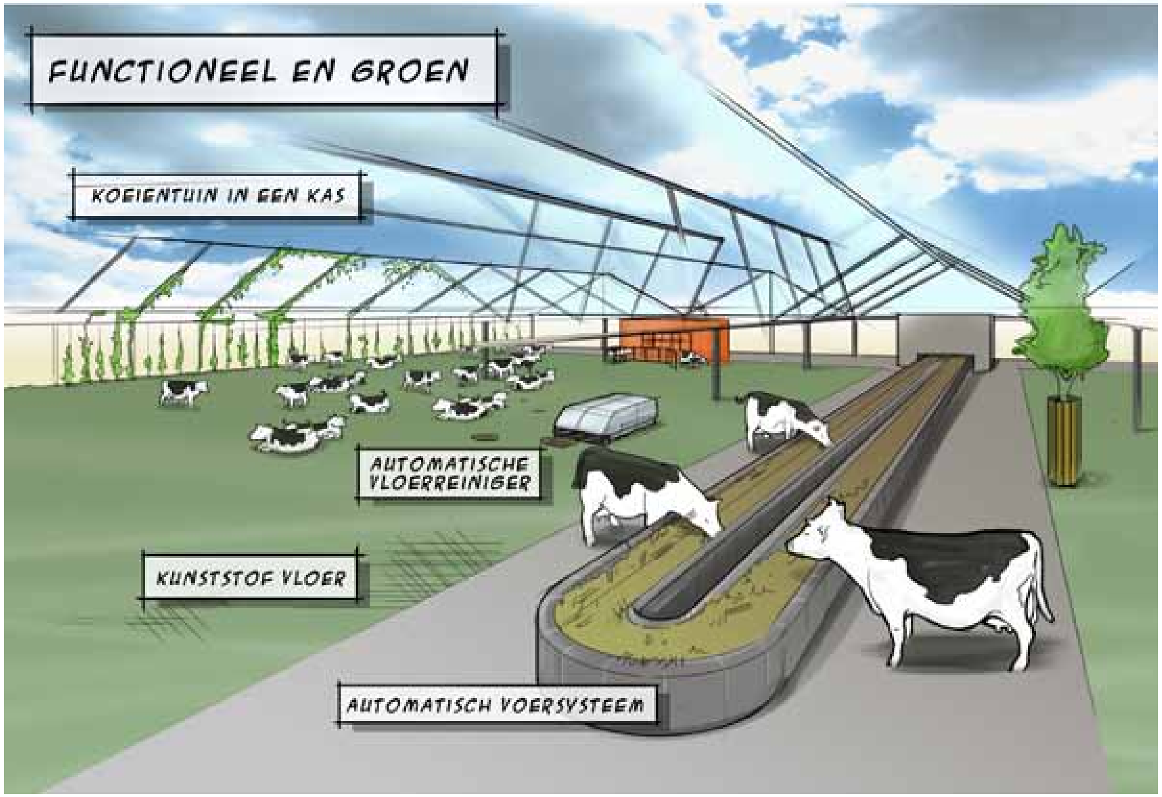


Figure 12. Cow Garden with an automatic feeding system

6.3 Bedded pack barn with a high degree of automation

Figure 13. 2 x 60 cows with an automatic individual feed station (rotary feeding parlour)

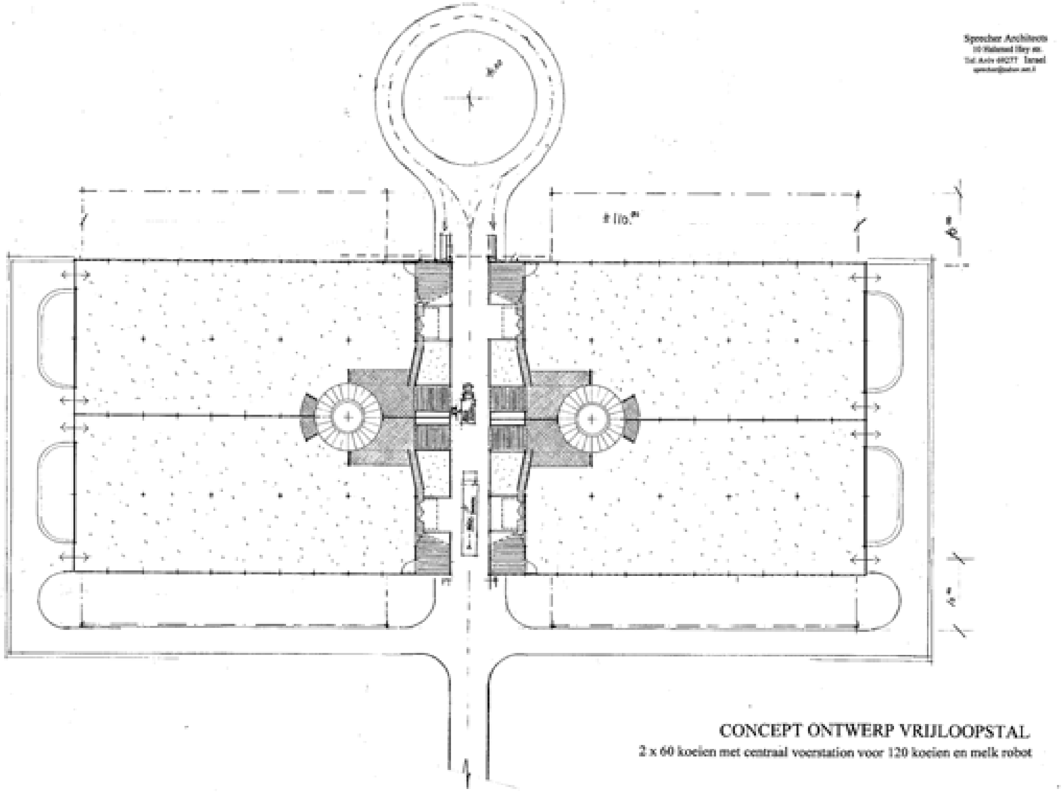


Figure 14. 4 x 60 with rotary feeding parlour

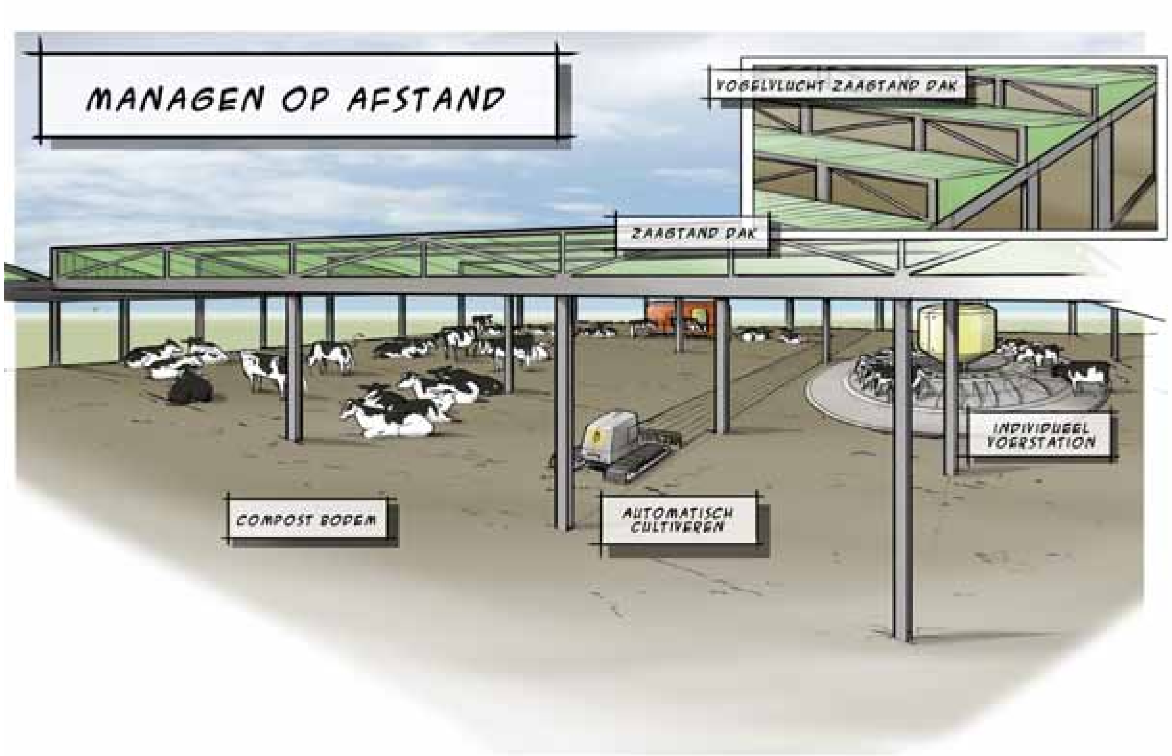
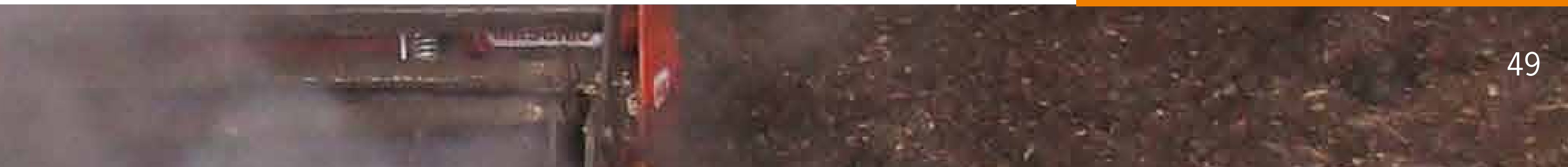


Figure 15. Bedded pack barn with a high degree of automation

The cows are housed under a saddle roof on a compost bedded pack that is cultivated with a self-propelled caterpillar vehicle. They are fed individually in a rotary feeding parlour. This may be rotating for maximum cow comfort, but that is not required. A rotary feeding parlour may be designed with the cows' heads directed either inside or out (see drawing). Cows are milked by milking robots.



6.4 Bedded pack barn with mobile components

Figure 16. 2 x 60 cows with movable mangers

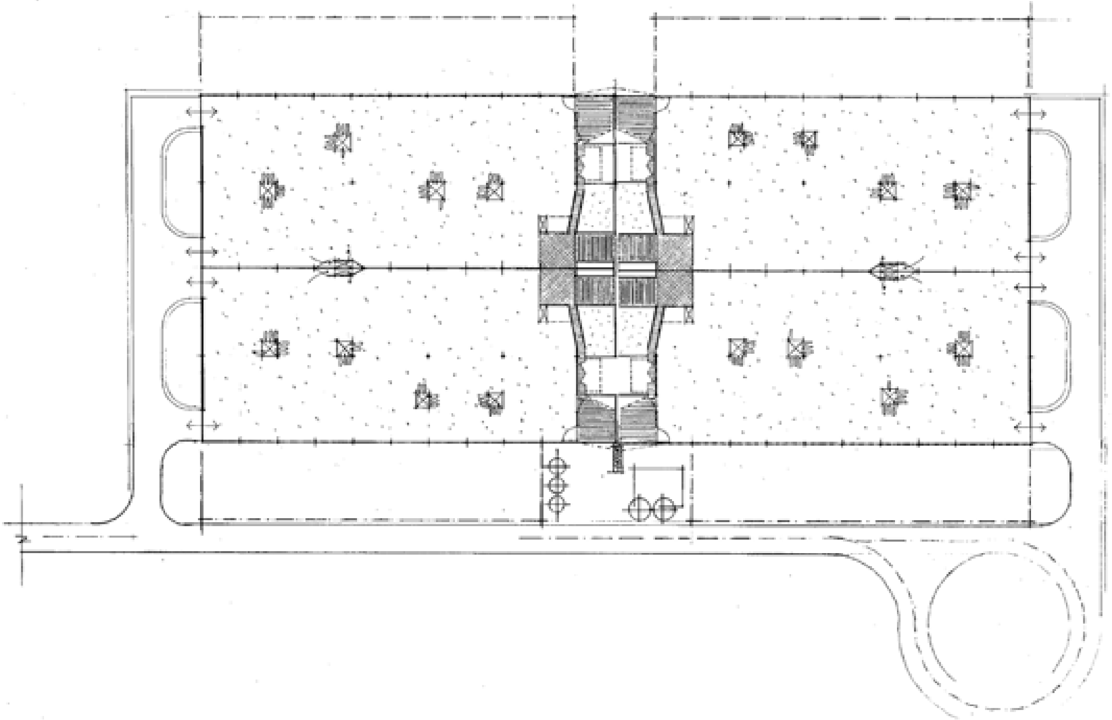


Figure 17. 4 x 60 cows with movable mangers

An example with mobile components. There is no feeding area. The cows can take forage from mobile mangers and concentrate feed from walk-through feeding parlours. The milking parlour is mobile. The cattle house serves as a collecting yard. A tractor with cultivator works the top layer on a daily basis. The spacious house has a gradually sloping saddle roof. The roof can be opened and closed.

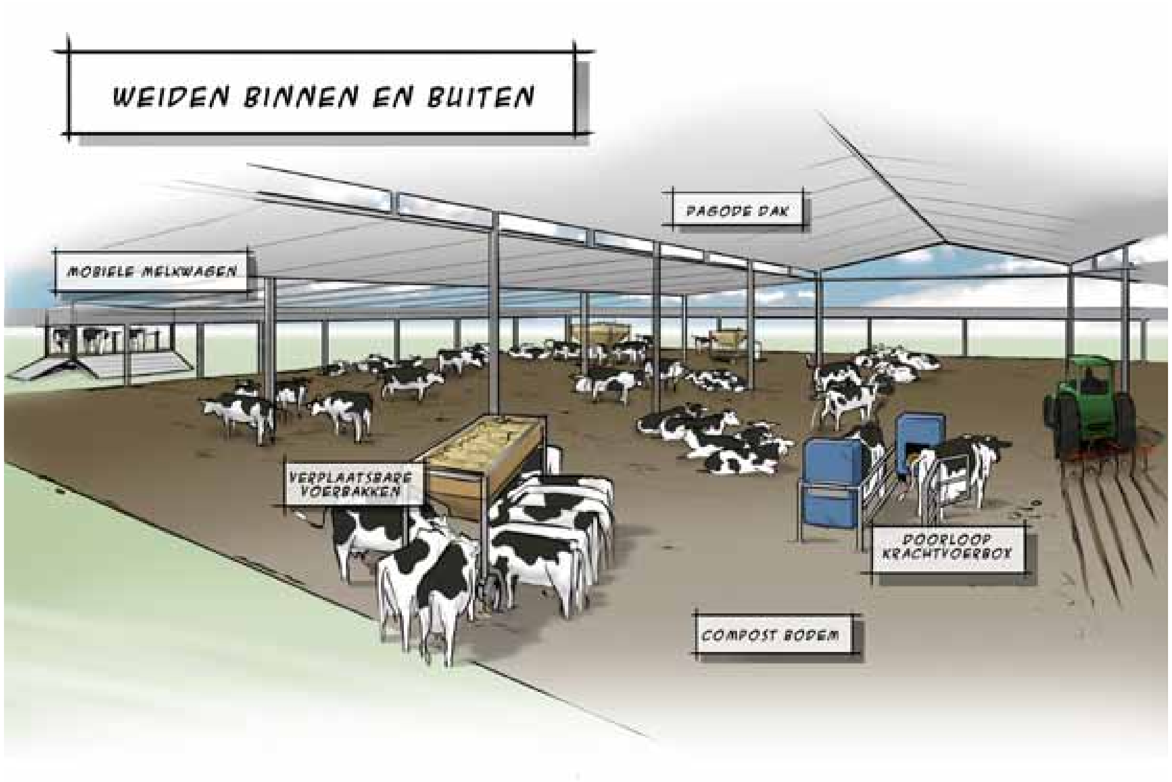


Figure 18. Cattle house with mobile components

6.5 Landscape farm

The landscape farm creates an agreeable environment for the cow, the farmer and the general public. The central position is occupied by a rotary milking parlour with an animal-friendly collecting yard around the central milking plant. Eight houses with 100 to 120 cows each are positioned in a circle around it. Feeding is automatic here. Through an outer circle the cows can be moved from one house to another. An inner circle is available for lorry traffic. The forage box supplies the containers for the automatic feeding system and the milk lorry collects the milk.

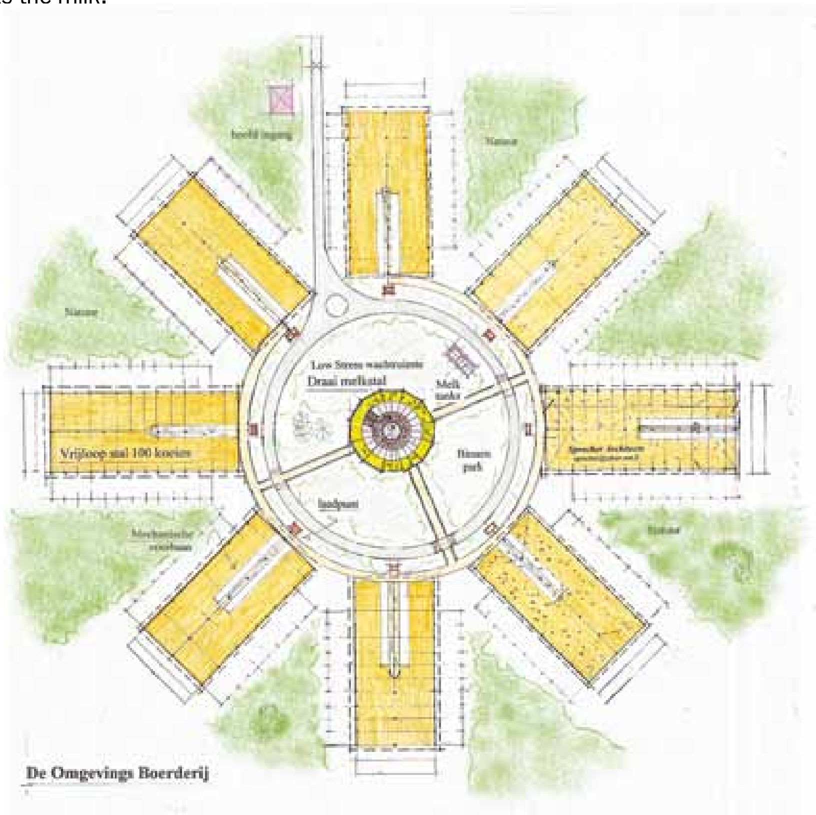
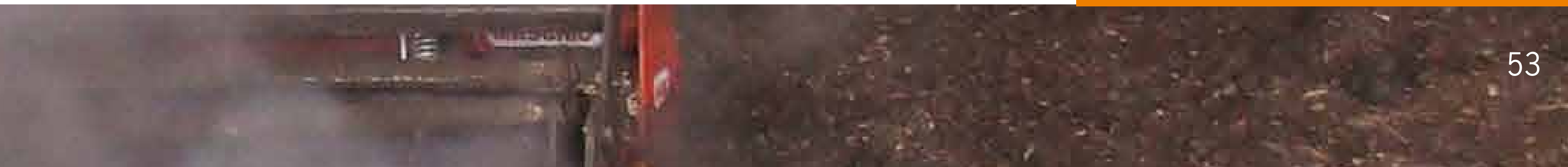


Figure 19.

The entire unit has a diameter of approx. 260 m. That brings the total area to approx. 5.5 ha, not including young stock, manure storage, feed storage and transition cows. Several spots have been planted. There is an inner garden in the double deck rotary milking parlour that is located on a hill. The area between rotary milking parlour and circular road can be decorated as a park. The spaces between the houses are also available for landscaping. A vista to this farm from the road will be something very special. The circular arrangements of the houses and the many open spaces will create several vistas.



6.6 Round cluster barn

The round cluster barn consists of several circular houses for dairy cattle and young stock with dry cows. The calves are housed in a calf rearing unit in a mobile house, which facilitates cleaning.

The total area of the circular house consists of a composting bedded pack with aeration which receives all excrements. The advantage of a circular shape is that there is much feeding area on the outside. A 15 m radius (30 m diameter) with 50 cows offers a resting area of 14 m^2 per cow and a feeding width of 190 cm per cow. Cow traffic towards the milking robots and the tractor for daily working the pack need an opening of approx. 10 m of the outer circle. This reduces the feeding width to approx. 170 cm per cow. The feeding spot changes every day, preventing the pack from becoming too wet on these spots (and consequently, the feeding space is not 170 cm wide every day, though a width of approx. 70 cm per cow is available every day).

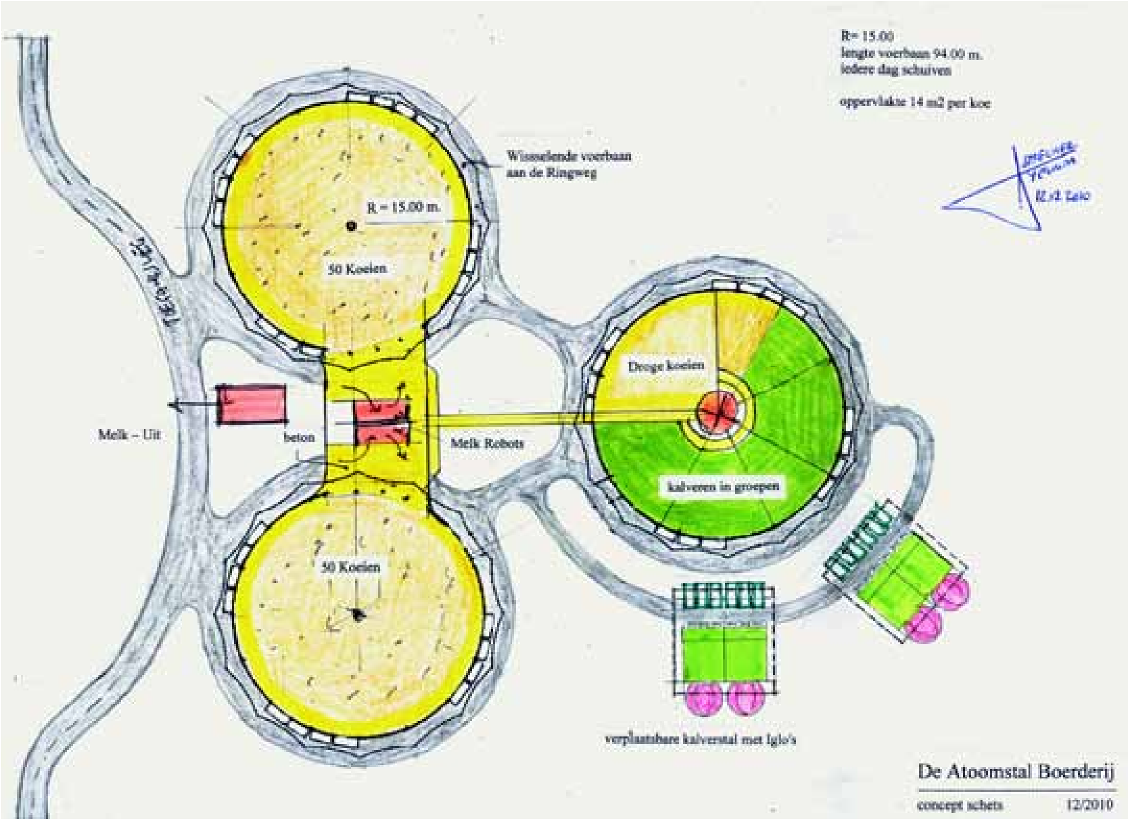
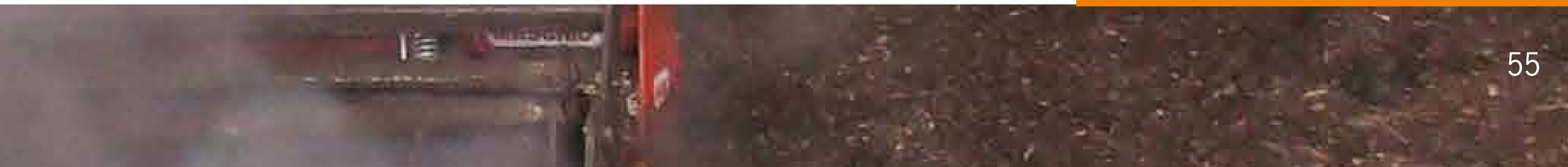


Figure 20. The round cluster barn consists of several circular houses

Feeding with mobile manger



‘Serrestal’ (stable)

6.7 Cattle in a greenhouse

The advantage of a greenhouse construction is that ventilation can be arranged through the roof and that the ridge height is limited. Furthermore, the construction offers the option of easy extension in length and in width. The challenge is to provide the greenhouse with an attractive appearance in the landscape.

Temporary foil greenhouse for 15 cows on Zegveld experimental farm

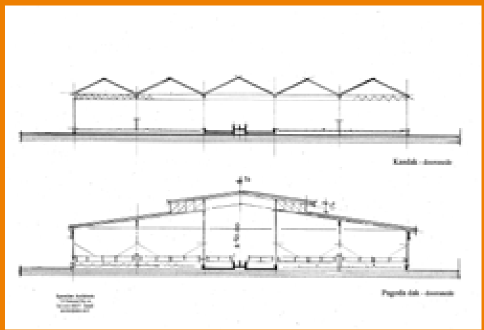


Figure 21. Cross-section of greenhouse

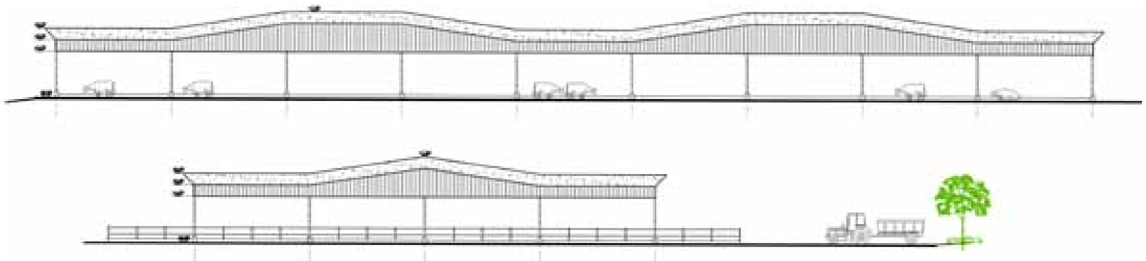


Figure 22. An undulating edge along the greenhouse at the front and side walls will provide a greenhouse with attractive appearance in the landscape

Figure 23 images:

Figure 23. Edge along the greenhouse to make attractive in the landscape (source Libau and DLV).

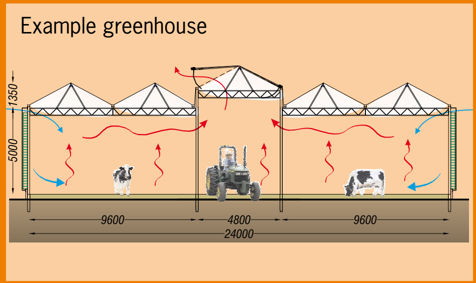


Figure 24. source Heuvel-Folie-serres

The pagoda livestock house is a unit for four groups of 60 cows each. At the centre there are four milking robots under a separate shelter. The milk tank is also placed at the centre in a special building. The house is 42 m wide. The total roof has a 15% slope, which is 20% at the centre, which keeps the ridge height as low as 11 m. Several openings in the building provide adequate ventilation and a nice appearance in the landscape.

The cows are kept in a bedded pack barn with a free range outside. The free range area is drained. Experience with this system has been gained in Ireland and France. The cows can be put out to pasture in summer.

6.8 Pagoda livestock house with free range

Drawings of pagoda livestock house (Sprecher)

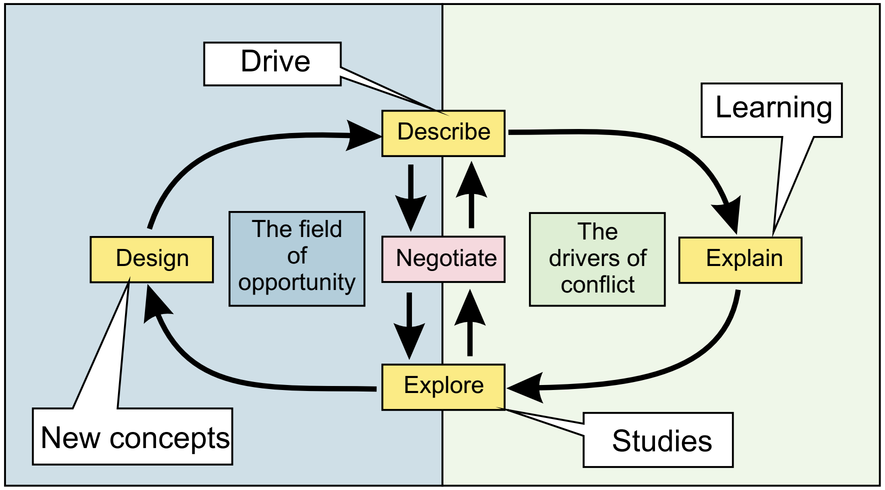
7. Reflection on the innovation process

Much has been learned from international contacts, experiences on experimental and practical farms and talks with suppliers of housing layout, buildings aesthetics committees, architects, composting experts and policymakers. However, we are only on the threshold of the development and implementation of bedded pack barns, which are surrounded by many uncertainties. The experiences bring answers, but at the same time raise new questions.

It is an ongoing learning cycle that in the end shall result in a widely applied alternative concept of dairy cattle housing that complies with preset requirements. This paragraph more closely looks at that innovation process. For this the DEED model is used. DEED stands for 'describe', 'explain', 'explore' and 'design' and describes the learning cycle and the factors involved.

What have we learned?

Figure 25 is a diagram that shows the aspects involved in the innovation in practice.



DEED approach for farm components or farming systems

Figure 25. Iterative cycle of learning process with farming participants (DEED method, applied by Giller et al., 2008)

Drive (motivation)

The drive for bedded pack barns is attuned to the needs of the cow, the farmer and the environment. At meetings with dairy farmers who consider acquiring a bedded pack barn, their main motives for alternative dairy cattle housing include:

- Better animal welfare
- Healthier cattle with a longer life expectancy
- Better manure with little odour emission
- Smaller manure volume

Describe

A crucial component of the bedded pack barn is the pack material. The principles of the packs are different, all having the objective of keeping the top layer dry and reducing the emission of ammonia:

- Sand pack and synthetic floors; drainage of moisture and separation of faeces and urine.
- Composting bedded pack; evaporation of moisture by heat development in the pack and conversion and fixation of nitrogen.
- Compost bedded pack and bedded pack of dried clay or peat with reed: absorption of moisture by large amounts of dry material and fixation of nitrogen.
- Synthetic floors: separation of faeces and urine.

Important aspects in addition to the type of pack material are the management of the bedded pack and the ventilation method (forced and natural). Also several choices are made as regards house layout, feeding system, milking system and superstructure. In this phase differences are described and questions formulated.

Learning and explain

The evaporation study has demonstrated that the moist Dutch climate requires additional measures to keep the top layer of organic bedded packs dry. The economic study has revealed that not only the costs of the house are decisive, but also the manure quality and the benefits of improved animal welfare. Much has been learned from the experiments on experimental and practical farms.

Figure 26 (page 62) shows the factors on which a good composting process relies.

Several experiences are still in development, as follows:

- *Sand bedded pack*
  The draining action of the sand bedded pack on Aver Heino experimental farm was less than expected. In combination with the soiling of the sand bed this resulted in too high an ammonia emission.

- *Synthetic floor*
  Rapid separation of faeces and urine is possible, as a result of which little ammonia is produced, theoretically. Measurements shall reveal whether this will result in a low ammonia emission.

- *Composting bedded packs*
  The Waiboerhoeve experimental farm has been composting wood chips and sawdust without aeration. The Wiersma farm is composting wood chips with an aeration system. The Hartman farm is experimenting on a small scale by extracting air and composting gently.

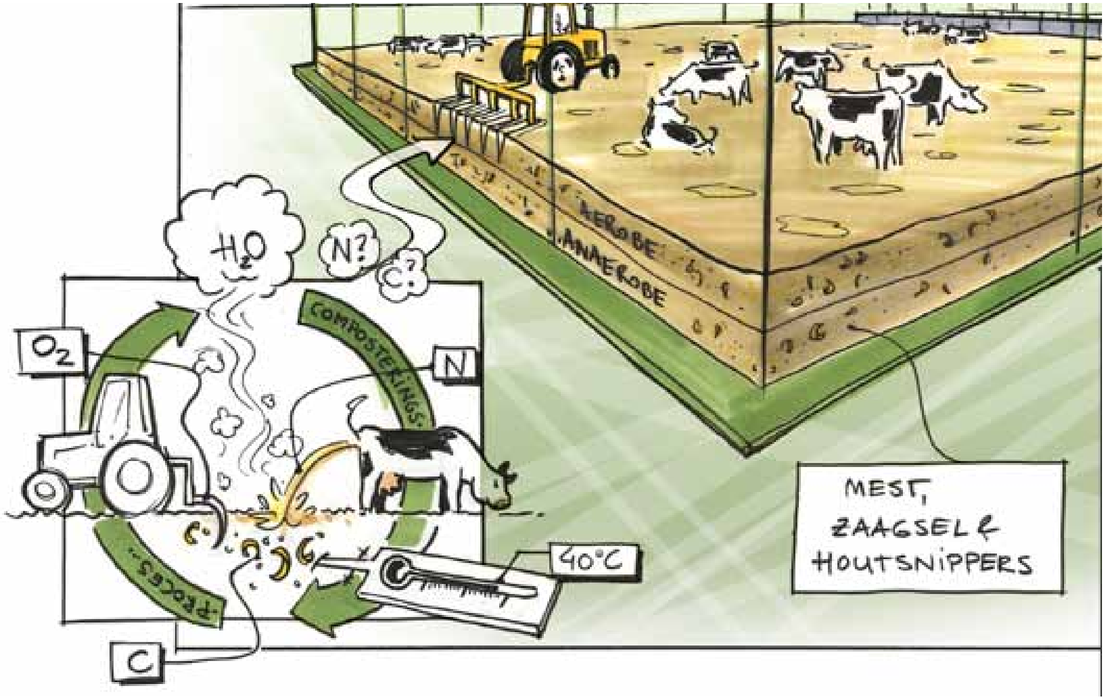


Figure 26. Control of composting process

- Pack thickness required is at least 50 cm, otherwise heat will disappear from the pack.
- Adequate C:N (>30:1) ratio; adding feed rests will help.
- Sufficient oxygen by aeration, cultivation, working or digging will help.
- Too much ventilation will cool down the pack.
- Too high a temperature will incur a risk of too high an ammonia emission.

By acquiring new knowledge in experiments and applying existing knowledge to the various packs, the differences are explained and questions answered, though new bottlenecks can be formed. That is a key to ideas about improvements that may be applied.

Studies, explore

The bedded pack barn aims at improving the sustainability as regards various aspects. There is a chance that trade-off occurs among sustainability aspects. The most prominent characteristic of the bedded pack barn is that it offers more space to the animals. That means more m2 per cow. In combination with upscaling, the houses will become much larger. Especially the space that is available per cow has a large effect on animal welfare, landscape, economics and environment. This is illustrated by figure 28.

More space is good for animal welfare, but will result in a larger soiled area and consequently a larger chance of increased ammonia emissions. The houses are becoming wider. Ridge height reduction requires a different superstructure, functional and aesthetic. A spacious house means more costs for the superstructure, whereas house layout and manure storage are simpler.

New concepts, design

Smart designs and management of houses are called for to prevent trade-off among sustainability aspects.

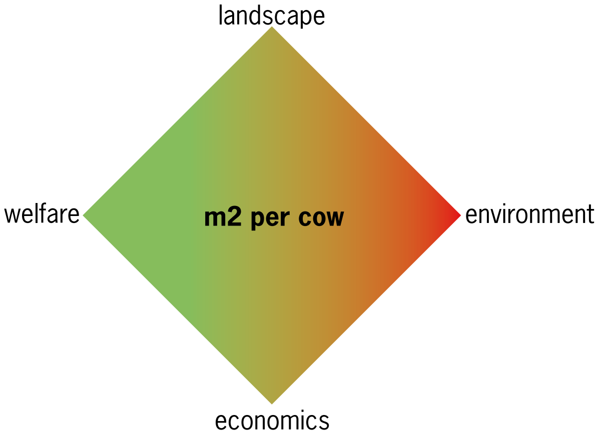


Figure 27. Space per cow (m^2) in relation to animal welfare, landscape, environment and economics

Tips for new designs:

- Different superstructure, such as a pagoda livestock house and a foil greenhouse (to make it blend in with the landscape)
- Circular house
- Inexpensive bedding material in combination with upgrading of waste from elsewhere
- Creation of 'controls' to manage bedding material quality, such as:
  - m^2 per cow
  - positioning of water basins
  - ventilation method
  - working method (cultivation, digging)
  - type of bedding material (drying of material outside the house (manure, digestate, biomass etc.))
  - aeration method to prevent adverse emissions
  - cleaning method sand bedded pack or synthetic floor
  - additives to reduce emissions
  - feeding system in combination with milking system (milking robots or no milking robots).

  Integrating these 'controls' into a total design.

Negotiate
Technical innovations and various sustainability aspects require continuous balancing of interests, for example:

- A soft airy bedded pack ensures proper absorption of urine, thereby reducing the chance of ammonia emission, but also reducing the cows' footing on the bedded pack.
- Upgrading of waste materials by third parties by mixing these with cow dung to achieve a valuable manure must not result in the introduction of other risk to animal health or food safety.
- More space per cow for a better animal welfare is to be weighed against landscape, environment and economics.

Example of learning cycle
Inspired by experiences in Minnesota (USA) the idea has occurred on the Wiersma farm to use in the composting process a material that is cheaper than sawdust, assisted by an aeration system (describe). Experts have been called in to design a good aeration system. The experiences since December 2009 are such that aeration for one hour per day has a favourable effect on the composting process. Over the time, however, the bedded pack of coarse wood chips will change into a fine material with a smaller volume that is becoming more and more difficult to aerate and consequently to keep dry. The effects of the aerated composting process on the ammonia emission, the temperature in the pack and the manure composition are measured and evaluated (explain). Based on experiences gained with aeration, space per cow and changes in the bedding material over the time, the system will be altered (explore). It is considered to start with a new pack with coarse wood chips in the autumn. In winter the pack material will be stored outside the house and applied in spring. Possibly more cows can be kept in the same space inside, though not at the cost of animal welfare (design). With this possibly new approach the learning cycle can be passed through again.

When more farmers are experimenting in various ways, the innovation process can be accelerated, provided there is sufficient attention to components of knowledge.

8 Discussion

The bedded pack barns have the potency to be a total integrated sustainable dairy farm system, but there are some concerns, especially about the environmental aspects.

What concerns and opportunities are left?
Some dairy farmers are engaged in experiments; in 2010 many are applying for building permits for bedded pack barns and still more dairy farmers are exploring possibilities. The following questions and chances come up from the various contacts with these dairy farmers, consultants (cattle house layout, composting) and authorities:

Sustainability
To get a total integrated sustainable system further substantiation of sustainability, verification of interactions and trade-off (if any) is necesary:

Environment
- How much and in what form does nitrogen (N_2 (nitrogen), NH_3 (ammonia), N_2O (nitrous oxide) disappear in the house and when it is applied to the field?
- How much and in what form does carbon (CH_4 (methane) or CO_2 (carbon dioxide)) disappear?
- Odour and fine dust

Animal welfare, animal health, animal performance and food safety
- Natural behaviour
- Claw health and udder health
- Production and life expectancy
- Microbial contamination

Faeces quality, fertilisation and soil fertility
- Value of manure enriched with organic pack material
- Value of separated manure fractions (solid and liquid fractions)

Landscape
- Ratio between length, width and height in relation to superstructure
- Fitting in the livestock house on farmyard and in surroundings

Further development

Further development of technical innovations regarding:

- Management of bedded pack, floor and cattle
- Relationship of pack / floor – type of manure / faeces quality – fertilisation / crop – soil fertility

Rules and regulations

- which ‘waste’ material from elsewhere is allowed to be used as a bedding material?
- what roof shapes are permitted?

9. Conclusions

All in all the following (preliminary) conclusions can be drawn:

1. The bedded pack barn offers opportunities to dairy farming to improve animal welfare, provided the basic condition of a clean (hygienic) and dry top layer (bedded pack or floor) has been met.

2. In the moist Dutch climate more attention must be paid to drying the top layer. Options are:
   Bedding material or floor type
   - allow for heat development by composting
   - drain moisture through sand bedded pack (not performing very well) or synthetic floor
   - absorption of moist by dry material

   Management
   - mechanical ventilation
   - natural ventilation through open side and front walls or open roof (e.g. foil greenhouse)
   - sufficient space (m^2) per cow
   - the pack is worked by cultivation or digging

3. The house design requires additional attention as more space per cow is needed. Livestock houses tend to become bigger and bigger in combination-with upscaling. This requires a different super structure, especially to reduce ridge height. A foil greenhouse or a gradual roof slope are options. It is also possible to think of several smaller (circular) houses.

4. Animal welfare in a bedded pack barn is mainly improved by more space, a softer bedded pack and the fact that it is easier for cows to get up and lie down than in a free stall barn. Effects on claw health, udder health and life expectancy have not been ascertained yet.

5. On the experimental farms no problems of mastitis, claw health or microbiological contami nation have been experienced on the three pack materials, being sand, composting bedded pack and bedded pack of dried clay or peat with reed. This, however, is a first indication.

6. The emission of ammonia per cow from a sand bedded pack is too high, probably because of a poor draining action and soiling. The ammonia emission from the composting bedded pack and the bedded pack of dried clay or peat with reed is a little bit higher (5 to 10%) then from a free stall barn with slatted floors. These, however, are tentative measurements. Especially the standard of the reference (slatted floor) needs more attention.

7. It is advisable to monitor the innovation cycle of DEED with those interested towards a total integrated sustainable housing system:

DEED:

- **D**escribe (description of novel packs and houses)
- **E**xplain (learning from experiments as regards sub-aspects and within the overall farming context)
- **E**xplore (exploration of alternatives and determination of trade-offs, if any)
- **D**esign (redesigning pack material, floor, house layout, superstructure etc. to integrated and sustainable dairy farming systems)

10. References

Bos, A.P., J.M.R. Cornelissen, P.W.G. Groot Koerkamp, M. Mittelmeijer. (2009)
Kracht van koeien: springplank naar een duurzame veehouderij: hoe dierenwelzijn, milieu en economie elkaar kunnen versterken in de melkveehouderij. Wageningen UR Livestock Research, Lelystad
Dooren van, H.J.C., P.J. Galama, M.C.J. Smits, W. Ouweltjes, F. Driehuis (NIZO), S. Bokma. (2011) Bodems voor vrijloopstallen. Report 411, Wageningen UR Livestock Research, Lelystad (in preparation)

Dooren van, H.J.C., P.J. Galama. (2009) Internationale verkenning van ervaringen met vrijloopstallen. Report 244, Wageningen UR Livestock Research. Lelystad, 25 pp.

Dooren van, H.J.C., G. Biewenga, A.G. Evers, P.J. Galama (2009) Economische aspecten van de vrijloopstal: kosten and baten in vergelijking met een ligboxenstal, Report 238, Wageningen UR Livestock Research, Lelystad, 21 pp.

Galama P.J., C. de Vries, H.J.C. van Dooren. (2009) 'Grensverleggend huisvesten van melkvee' (New horizons for dairy cattle housing), Cowfortable part 3. Courage, Zoetermeer, 103 pp.

Giller, K.E., C. Leeuwis, J.A. Andersson, W. Andriesse, A. Brouwer, P. Frost, P. Hebinck, I. Heitkönig, M.K. van Ittersum, N. Koning, R. Ruben, M. Slingerland, H. Udo, T. Veldkamp, C. van de Vijver, M.T. van Wijk, and P. Windmeijer. (2008). Competing claims on natural resources: what role for science?. Ecology and Society 13(2): 34. [online] URL: http://www.ecologyandsociety.org/vol13/iss2/art34/

Proceedings of the National Compost Dairy Barn Conference, June 21 & 22, 2007. Burnsville, Minnesota (USA)

Smits, M.C.J., F. Dousma, G.C.C. Kupers, K. Blanken. (2009) Oriënterend laboratorium-onderzoek naar ammoniakemissie uit bodempakketten voor vrijloopstallen. Report 231, Wageningen UR Livestock Research, Lelystad 18 pp.

Smits, M.C.J., A.J.A. Aarnink. (2009) Verdamping uit ligbodems van vrijloopstallen; oriënterende modelberekeningen. Report 230, Wageningen UR Livestock Research, Lelystad, 18 pp.

Colophon

Publisher: Wageningen UR Livestock Research

Title: Prospects for bedded pack barns for dairy cattle, publication 16

Author: Paul Galama
Telephone: +31 320-238238
Email: paul.galama@wur.nl

Editing, design and interviews: Wageningen UR, Communication Services

Photography: Wageningen UR, Communication Services

Contributions from (photographs and illustrations):
- Yehuda Sprecher, Architect Israel *www.sprecher-arch.com*
- Figures 10 t/m 19 originating from 'Grensverleggend huisvesten van melkvee' (New horizons for dairy cattle housing) commissioned by Courage (Cowfortable report, part 3) within the framework of the Dairy adventure project. For more information: *www.courage2025.nl*
- 3D drawings, JAM bureau voor visueel denken

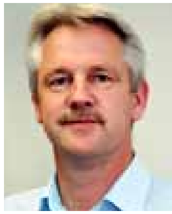
This publication was financed by TransForum through the Dairy adventure project.

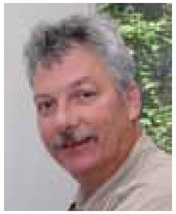
Ministerie van Economische Zaken, Landbouw en Innovatie

The research at experimental farms was financed by the Productschap Zuivel (PZ – Dairy Produce Board) and the Netherlands Ministry of EL&I.

The experiences from the farming practice are based on interviews with the dairy farmers who participate in experiments with bedded pack barns and synthetic floor houses:
- Pascal Peeters, dairy farmer in Dorst
- Meindert Wiersma, dairy farmer in Midwolde
- Marc Havermans, dairy farmer in Moerdijk
- Jeroen Groenewegen, dairy farmer in Kraggenburg
- Co Hartman, dairy farmer in Neer
- Jacob Noord, innovator in Zeijen
- Jan Pape, landscape gardener and innovator in Beltrum

The research has been carried out by the:
Project team for research on bedded pack barns of Wageningen UR Livestock Research:


Paul Galama


Sjoerd Bokma


Hendrik Jan van Dooren


Wijbrand Ouweltjes


Michel Smits

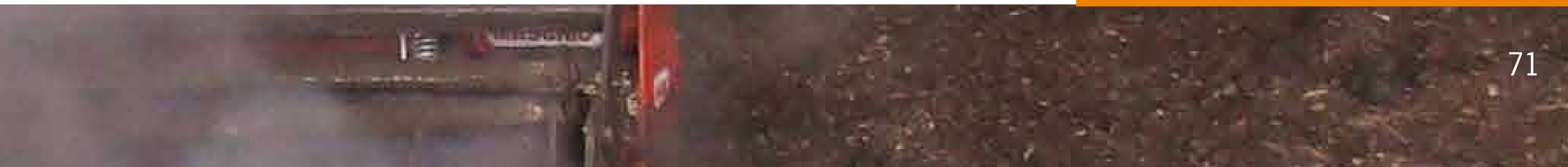

Frank Driehuis of
NIZO food research BV

LIVESTOCK RESEARCH
WAGENINGEN UR

Liability: Wageningen UR Livestock Research does not accept any liability for damages, if any, arising from the use of the results of this study or the application of the recommendations.

ISBN-nummer: 978-90-8585-947-1
First edition, July 2011

More information can be found here:
www.vrijloopstallen.wur.nl



Wageningen UR Livestock Research
P.O. Box 65, 8200 AB Lelystad, The Netherlands
Telephone: +31 320-238238
Email: info.livestockresearch@wur.nl
Internet: www.livestockresearch.wur.nl