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The design of modern housing systems for farm animals calls for cooperation between scientists within different disciplines. This article describes the design of a new production system for weaned and growing pigs, as well as the analyses and working processes behind its development. The aim of the study was to develop an economically competitive system that also provided better welfare for the animals and a healthier environment for the workers. Analyses were carried out with emphasis on behavioral needs and building design and economy. The resulting system, the "safari system," consists of a number of straw flow pens of increasing size. Pigs are moved to larger and larger pens each week until slaughter. The main advantage is that pigs are not mixed during the growth period and that they are given more space, especially toward the end of the growth period when their space demand is high. Furthermore, the provision of straw for comfort and exploration and of wallow basins for cooling in the pens for the larger pigs were considered significant welfare improvements. An analysis revealed that the safari system would be economically competitive in comparison to traditional intensive systems.

Pig production today is a result of technical developments throughout several decades (Baxter, 1984). During the last 30 years this process has become faster and been based on an interaction between new research results and the contributions from competent companies, advisors, and farmers. Nevertheless, during the last 15 years modern production systems for pigs have been widely criticized for lack of concern for the welfare of the animals (Vestergaard, 1990).

In this article we use the term intensive production systems to refer to such modern production systems, characterized by high stocking density, slotted floors, a large number of animals, a high degree of mechanization, little labor per animal

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and, usually, a total absence of litter. These systems restrict the behavioral repertoire, which in turn results in behavioral abnormalities, for example redirected activities such as tail biting (e.g., van Putten, 1969) and increased belly nosing in weaned piglets and growing pigs (Petersen, Simonsen, & Lawson, 1995; Schmidt & Adler, 1980). Similarly, sows housed in intensive systems show increased numbers of stereotypies as a consequence of crating (Cronin & Wiepkema, 1984; Vestergaard & Hansen, 1984).

Some of these behaviors may cause damage, and in addition they are generally an expression of psychological problems and stress (Menuier-Salaun, Vantrimponte, Raab, & Danzer, 1987; Worsaae & Schmidt, 1980). Further, the behavioral abnormalities may lead to reduced productivity and health of the animals; for example, piglets reared by tethered sows as compared to loose sows may have a reduced survival rate (Hansen & Vestergaard, 1984), and pyaemia may develop as a result of tail biting (Anonymous, 1990; see also Arey, 1991).

The aim of this article is to present a new, alternative production system, the "safari system," which may provide better welfare for weaned pigs (5–8 weeks old) and growing pigs from 8 weeks old and until slaughter. Furthermore, we present the analyses and the working processes behind its development. Before doing so, however, it is relevant to characterize the background and rationale for the existing intensive production systems as well as some of their consequences.

The development of these systems has primarily been aimed at improved feed efficiency, weight gain, health control, carcass quality, and reduction in the use of labor, and it has resulted in systems with a high dependency on technology. This development has had three main consequences: (a) a high capital cost (Sørensen, 1985), (b) an unhealthy working environment, mainly because of dust (Rylander, Donham, Hjort, Brouwer, & Heederick, 1989), and (c) systems in which the welfare of the pigs is reduced. In such systems pigs have only minimum floor area and are kept without straw, which is detrimental to their welfare (van Putten, 1969; Warnier & Zayan, 1985). Obviously, this development has reached a point where it is no longer possible to reduce the space allowance and increase the use of expensive technology. The public and the farmers want systems with a higher degree of welfare both for the pigs and for the workers. Consequently there is a need to develop economically competitive systems that improve the conditions for both.

Within the last 15 years other attempts have been made to create production systems with a higher degree of welfare for the pigs. One of the best known examples is the family pen system (Stolba, 1985; Stolba & Wood-Gush, 1984). The development of the family pen is based on studies of normal behavior of pigs kept in a seminatural environment. This system is an integrated system for all classes of pigs: sows, piglets, growing pigs, and boars. Other examples are the labyrinth pen (Nehring, 1981) and the multiactivity pen (Lund & Simonsen, 1995; Simonsen, 1990), which are both for growing pigs only.

Some of these systems improve the welfare of the pigs over the usual intensive systems because they allow more of the pigs' normal behavior. One major problem,
however, is that such systems may be unable to compete economically with the intensive systems. For example, economic calculations based on Danish prices show that the price needs to be 40% higher per kg pork in the family pen system (Stolba, 1985) if the production results are to be equal in the two systems (Bjerg, 1992).

The development of new economically competitive housing systems with improved welfare for animals and people is an important challenge to agricultural engineers and scientists working in animal behavior and welfare. Considering that intensive systems have usually been developed by technicians and alternative systems by ethologists, it is obvious that cooperation between such experts is called for to solve problems related to housing design and production as well as to animal behavior and welfare. Therefore, a research project to develop a new and better housing system for pigs was carried out at The Royal Veterinary and Agricultural University in Copenhagen by a group of scientists with expertise in both animal housing and animal behavior. The project was based on theoretical analysis, combining existing knowledge of animal behavior with knowledge of building planning, construction, materials, and prices.

In the development of the safari system, the fundamental demands were that (a) the pigs should be given more pen area than in intensive systems, (b) there should be no mixing of pigs, (c) straw should be used, and (d) the production system should be able to compete with the intensive systems economically. In other words, compared to that of intensive systems, it should result in a lower or equal cost per pig produced.

The project was divided into two steps. The first step consisted of the analysis of animal welfare related to behavioral needs and analysis of building design. The second step consisted of the design of a new production system based on the results collected during the first step.

**ANIMAL WELFARE: POSSIBILITIES AND CONSTRAINTS**

Potentially, animal welfare can be improved for weaned and growing pigs by reducing social and environmental stressors provided that such stressors can be identified. At least some of them have been revealed. For example, social stressors caused by high stocking density are known to increase aggression and retaliations in pigs and thereby distort social stability (Ewbank & Bryant, 1972).

Furthermore, these social stressors may lead to reduced weight gain as a consequence of reduced feed intake (Edwards, Armsby, & Spechter, 1988; Kornegay & Notter, 1984).

High stocking density also aggravates the adverse effects of heat stress (Götze & Rist, 1987). The optimum stocking density, as seen from an animal welfare point of view, is not known; possibly it is very low. Additionally, the mixing of strange individuals is associated with much aggression (Symoens & Van Den Brande,
1969), physiological stress (Blecha, Pollmann, & Nichols, 1985), and decreased weight gain (Danzer, 1970; Graves, Graves, & Sherritt, 1978). The reduced weight gain may only be seen during the first week after regrouping (McGlone & Curtis, 1985), but if regrouping occurs within the 14 days prior to slaughter a deleterious effect on weight gain due to fighting and social stress has been documented (Stookey & Gonyou, 1994). Furthermore, recent studies on pigs kept under free-range conditions have indicated that stable social relationships between individuals develop early in life, preferably before 5 to 7 weeks old, whereas there is much less willingness to initiate social contacts and make social relationships later on (Petersen, Vestergaard, & Jensen, 1989).

Mixing of strange animals after about 5 weeks may therefore be especially stressful. It may also be stressful later in life because sows and gilts that are introduced into an established group are met with aggression from the residents and form a subgroup for about 12 days (Moore, Gonyou, & Ghent, 1993). The continual mixing of strange pigs was one of the main ideas but also the major disadvantage in the labyrinth pen (Nehring, 1981). As a consequence of these social stressors, pigs should be given enough space to avoid excessive aggression and retaliations and furthermore, should not be mixed during the growing period.

There will always be spatial limitations for pigs because of economic constraints. On the other hand the reduction of stress may potentially improve production (Menuier-Salaun, Vantrimponte, Raab, & Danzer, 1987) as well as welfare. We present a solution to overcome the constraints on the allocation of more space. Furthermore, mixing of strange pigs can easily be avoided if the piglets are grouped in appropriate group sizes before transfer to the growing environment, and thereafter kept within the same group.

Environmental stressors may be divided into stressors caused by the climate and stressors due to the lack of essential key stimuli. Temperature extremes are obvious examples of environmental stress (see Close & Mount, 1978; Mount, 1979). Generally, the house protects pigs from low temperature stress, and the provision of straw may allow the pigs to maintain body temperature when it is cold. High temperatures may give rise to stress or hyperthermia (Mount, 1979), especially if no wet places are provided for wallowing. On the other hand, providing wallow facilities reduces stress and increases growth at high ambient temperatures (Heitman & Hughes, 1949).

Although the significance of essential key stimuli has been demonstrated by Stolba and Wood-Gush (1984) in their work on the development of the family pen for pigs, most growing pigs are still kept in barren pens without environmental stimuli (see Wood-Gush, Vestergaard, & Petersen, 1990). Nonetheless, straw, which was traditionally used for bedding in Danish farms and elsewhere, may provide key stimuli for a large number of behaviors in pigs. For example, straw is appropriate for foraging behavior, predatory behavior (a bundle of straw is being treated as prey; see Jensen, 1981), and for bedding and nest building (Fraser, 1975; Jensen, 1981; Stolba & Wood-Gush, 1984), as well as for exploration and play.
Finally, there is evidence that the provision of straw can reduce or prevent physiological stress responses in growing pigs (Warnier & Zayan, 1985). Straw may be especially significant for nest building because domesticated pigs under free range conditions are known to sleep in communal nests like their ancestor, the wild boar (Stolba & Wood-Gush, 1984), and nest-building behavior can be seen in young (wild boar) pigs from about one week of age (Gundlach, 1968).

Pigs are curious animals, which may be related to the fact that they are omnivores (Meynhardt, 1980). Furthermore, there is evidence that pigs possess inquisitive exploratory tendencies (i.e., they actively seek change and things to explore). This may lead to redirected behavior toward penmates when the environment is inappropriate for exploration (Wood-Gush & Vestergaard, 1991), and to injuries such as tail bites and ear bites (Algers, 1983a, 1983b; Petersen, 1995; van Putten, 1969). Furthermore, the lack of possibilities for exploration may be stressful in itself (Wood-Gush & Vestergaard, 1990), as for example documented by a rebound in both play and exploration when the opportunity to explore is given (Wood-Gush et al., 1990).

Some straw is also eaten, and this may be beneficial because it adds structure to the food (Fraser, 1975). In consequence, environmental stress may be reduced considerably for giving straw to the pigs. Branches may be an additional option to allow exploration (Lund & Simonsen, 1995; Stolba & Wood-Gush, 1984).

There are, however, some constraints to the use of straw. It is costly and may increase labor requirements (Møller & Johansen, 1989). On the other hand, paying the costs associated with straw may be worthwhile from a production point of view because growth may be improved when stress is reduced (Menuier-Salaun et al., 1987). The provision of branches is cheap and involves only a slight increase in labor requirements.

BUILDINGS: POSSIBILITIES AND CONSTRAINTS

As discussed previously, the available pen area is an essential factor from an animal welfare point of view. From an economic point of view a consideration of pen area is essential because of its crucial effect on building cost. Therefore, the following analyses concentrated on the use of pen area and the possibility of changing building design to allow a larger pen area without increasing the total building cost.

Use and Allocation of Pen Area

Based on the assumptions that small pigs have approximately the same geometrical shape and the same relative space demand as large pigs (see Discussion), the relation between body weight and pen area requirement can be expressed as \( A = k \cdot W^{0.67} \) (Baxter, 1984), where \( A \) is the pen area (m\(^2\)) per animal, \( W \) is the body weight (kg), and \( k \) is a constant that specifies the level for pen area assignment. In the left part
of Figure 1 the profile area of a pig is shown in relation to the pen area calculated using different values of the constant \( k \). It can be seen that the value \( k = 0.047 \) corresponds to the area of the body length multiplied by body height.

In intensive production systems in Denmark pigs are usually weaned at about 4 weeks old. After weaning they are expected to gain from about 7 to about 100 kg in a period of 18 to 20 weeks. In that period they are usually housed in two or three different housing units designed to fulfill the minimum pen area per pig required according to EEC Directive 91/630 on pig welfare. (EEC is now the European Union, EU.) In the right part of Figure 1 the value of the constant \( k \) for the required pen area per pig is shown together with an example of common practice for pen area assignment during the growth period (from 8 weeks). In the example, pigs are weaned at 4 weeks old and housed in a weaners’ unit for 7 weeks and expected to gain from 7 to 30 kg. Afterward the pigs are transferred and kept in the growing unit until slaughter. The figure shows that, for some part of the growing period, the pigs are given considerably more space per pig than the minimum requirement.

For the EU pen area requirement, Figure 1 shows that the calculated values for the constant \( k \) vary between \( 0.027 \) and \( 0.041 \) for pigs between 7 and 100 kg. In the example, the calculated values for the constant \( k \) vary between \( 0.030 \) and \( 0.082 \). Therefore, pigs have about 170% more space in one part of the growing period than in other parts. It is reasonable to expect that it would be advantageous for the pigs if the available area could be allocated according to the size (weight) of the pigs. It is calculated that the constant \( k \) as an average in the growing period is \( 0.043 \). If the pen area per animal could be adjusted continuously to this value during the growing period it would therefore be possible to reduce the relative animal density by about 30% in the most crowded periods.

There are two potential ways to practice pen area adjustment. One way is to keep pigs of different ages in the same pen. Every time some of the oldest pigs are removed from the pen a corresponding number of young pigs are put into the pen (Nehring, 1981). The problem with such a system is that the young pigs may be attacked and suppressed by the older ones. There may also be problems related to stress and the spreading of disease. Separation of the oldest pigs may also involve a considerable amount of labor. The other way of adjusting pen area per pig is to move the group of pigs into successively larger pens as they increase in weight. The possibilities and consequences of this are described in a later section.

**Building Layout**

The size of a building for pig production has a direct influence on the building cost per unit area. In the case of traditional constructions for Danish pig production, Bjerg (1992) has calculated that a building of 800 m\(^2\) is 14% cheaper per m\(^2\) than a building of 400 m\(^2\). This means that it is possible to assign a 16% larger pen area per animal in a 800 m\(^2\) building than in one of 400 m\(^2\) but at an equal building cost per animal. Furthermore, in a 1600 m\(^2\) building each pig can be given about 30%
FIGURE 1  To the left: The profile area of a pig in relation to the pen area calculated by using different values of the constant $k$. To the right: The calculated value of the constant $k$ as function of live weight for (a) the EU (EEC) pen area requirements per pig, (b) an example of common practice in Danish intensive systems, and (c) the safari system.
more space as compared to a building of 400 m² but at the same building cost per animal. The considerable influence that building size has on cost suggests that the use of large buildings is a method to achieve economic competitiveness for newer, more space-demanding production systems.

Sectioning

Including separate sections inside a finishing unit is usually motivated by concerns for animal health (Elbers, Tielen, & Hunneman, 1992). From an economic point of view, however, such considerations have to be balanced against the effects on building cost. To illustrate the relation between sectioning and building cost we calculated four combinations of sectioning and pen area that resulted in an equal building cost. The calculations were based on traditional constructions for Danish pig production, with production of 120 pigs per week housed in finishing units designed for a growing period of 12 weeks. The results presented in Figure 2 show that, with equal building cost, the pigs can be given 34% more space each in a building without sectioning than in a building with 12 sections. Thus a lower degree of sectioning may also allow a reduction in pig density. From an animal health point of view the reduced animal density is an advantage (Menuier-Salaun et al., 1987). However, this advantage has to be balanced against the disadvantage of having a larger number of animals in one room. Consequently, from an animal welfare point of view, the reduced animal density, and thereby the reduced stress and possibly better hygiene, has to be evaluated in relation to the total effect on animal health.

Group Size

Using the same conditions as described above under Sectioning, we calculated four combinations of numbers of animals per pen and pen area per animal with equal building cost. The results presented in Figure 3 show that without increasing building cost it is possible to increase the pen area by 30% when the number of animals per pen increases from 15 to 120. This calculation shows that increasing group size also may contribute to reduction in animal density. From an animal welfare point of view the advantages of reduced animal density have to be evaluated in relation to possible negative aspects of increased group size (see Discussion section).

Use of Slotted Floors

The wide use of slotted floors leads to an increase in the building cost per unit area in intensive production systems. In the finishing units illustrated in Figure 2 and 3
it is presumed that 100% of the pen area is covered with a slotted floor. Calculations showed that if the slotted pen area is reduced to 25% of the total pen area it is possible to increase the pen area by about 25% without increasing building costs. Reduced use of slotted floor may also tend to increase welfare (e.g., by reducing the risk of tail biting; Etter-Kjelsaas, 1986).

Relation Between the Use of Straw and the Demand for Insulation

Bruce and Clark (1979) calculated that the use of straw lowers the critical temperature for growing pigs by 5° to 6° C compared to pigs kept on a concrete floor without straw. The use of straw therefore makes it possible to reduce the indoor temperature. Reduction of the indoor temperature reduces the heat loss from the building and increases sensible heat production from the animal. It is calculated that the sensible

FIGURE 2 Combinations of pen area per pig and sectioning that results in equal building costs. The calculations were based on the use of fully slotted floors in the pens.
FIGURE 3  Combinations of pen area and number of pigs per pen that results in equal building costs. The calculations were based on the use of fully slotted floors in the pens.
heat production for a 50 kg pig increases from 116 to 130 W when the ambient temperature is reduced from 18° to 12° C (Anonymous, 1984). To illustrate the reduced demand for insulation, the size of the maximum allowable transmission heat loss from a building for pigs at 50 kg was calculated. The calculation was based on an outdoor temperature of -10° C, minimum ventilation rate of 10 m³ h⁻¹ pig⁻¹ and no additional heat supply, and showed that the maximum allowable transmission heat loss from the building is 0.8 W °C⁻¹ for a pig of 50 kg kept at an indoor temperature of 18° C. If the indoor temperature is reduced to 12° C, the maximum allowable transmission heat loss from the building is as high as 2.5 W °C⁻¹ pig⁻¹. This means that the use of straw makes it possible to use building construction with a lower insulation performance than would be necessary if no straw is used. Reduced demand for insulation will normally reduce the building cost.

For a finishing unit designed for 540 pigs it is calculated that it is possible with equal building cost to increase the pen area by 22% when the wall construction is changed from the usual double brick wall (including 75 mm insulation) to a single brick wall construction. This change will increase the heat transmission loss from 0.84 to 2.4 W °C⁻¹ pig⁻¹ and therefore result in nearly the same ventilation rate as would be required with an outdoor temperature of -10° C. But at outdoor temperatures between -10° and about 13° C the ventilation rate will be up to 140% higher. Under Danish temperature conditions (Andersen et al., 1982) and assuming a maximum ventilation rate of 75 m³ h⁻¹ pig⁻¹, it is calculated that the average ventilation rate over the year will increase about 50% and therefore the average air contamination will be reduced.

THE SAFARI SYSTEM: A NEW HOUSING SYSTEM FOR PIGS

The essential welfare demands that should be satisfied in the new system are: (a) more space for locomotion and other activities, (b) a stable social group (i.e., no mixing of pigs), and (c) possibilities for exploration. In addition we also attempted to solve temperature regulation problems that may arise during hot periods. To meet the demands for economic competitiveness the building design was based on: (a) frequent pen size adjustment, (b) relatively large pens and group sizes, (c) few and large rooms, (d) reduced use of slotted flooring, and (e) reduced insulation for the building.

Layout and Function

Figure 4 shows the layout of the safari system, which is comprised of a piglet and a finishing unit. Figure 5 shows a cross section. The house is designed to accommodate 120 4-week-old piglets per week. We suggest pens for 120 pigs until 8
FIGURE 4 Layout of the safari system. The first four sets of pens are for weaned pigs, whereas the remaining 12 sets are for growing pigs. In the two first sets of pens a part of the pen is covered with a plate above the floor to create a warmer resting area for the weaned pigs. 'Two-climate system'. In all pens feeders are placed on the pen partitions where branches can also be hung up to stimulate exploration. Note the wallow basins in the last seven sets of pens. The four last pens are smaller because some of the pigs will have been sent for slaughter. All dimensions are in mm.
FIGURE 5  A cross section of the safari system, showing the dimensions (in mm) and the solid floor sloping down to the slotted floor in both sides of the house. The corridor is in the center. Also note the ventilation system in the top of the house.
FIGURE 6  A perspective view of six pens. The feeders and the wallow basins are placed close to the wall. The drinking nipples are placed on the wall so that water runs into wallow basins. Movement of the pigs to the next pen once a week can be accomplished easily by using suitable gates between the pens and by providing fresh straw. A straw dispenser is seen in the corridor.
weeks old, because the pens would have been too narrow with a smaller number of pigs. After 8 weeks the weaned pigs are moved to two pens in the finishing unit with 60 pigs per pen. Figure 4 shows that the pens are of different sizes. The finishing pigs are moved once a week to the next pen after pigs are sent for slaughter from the last three pens (22- to 24-week-old pigs). Piglets are moved every 2 weeks. Each pen is designed to fulfill the requirements of the pigs in the week in which they are kept there. The last two sets of pens are smaller because by that time some pigs would have been sent for slaughter.

With a suitable gate design between the pens and by attracting the pigs into the empty pen with a bundle of fresh straw, it is expected that it will be a reasonable task to move all pigs every week (Figure 6). The fact that the pigs of a certain age are always kept in a certain pen provides an opportunity for different designs in the different pens. For instance: (a) two-climate systems for the youngest pigs, with cover above the resting area, (b) feeders and drinkers designed and placed in a way that suits pigs of different ages, and (c) wallow basins in pens for the oldest pigs. The pen partitions allow a large feeding space (see Figures 4 and 6), which may reduce aggression considerably (Hansen, Hagelso, & Madsen, 1982). Furthermore, they allow space for the placing of branches for exploration (see Simonsen, 1990; Stolba & Wood-Gush, 1984).

The large number of pigs per pen allows appropriate pen dimensions in a building with minimal allocation of alley area and with building dimensions that result in low building cost per unit area. A large number of animals per pen may also reduce the cost or make it possible to have special equipment such as wallow basins in the pens.

Figure 5 shows that the concrete floor slopes toward either side of the house (6% slope). The straw can be removed from the pen via a slotted floor and a dung channel with a mechanical manure scraper. The proposed system to handle the straw and manure in the pens is a modified version of the straw flow system (Bruce, 1990). The system will only require a limited amount of straw, and the pigs are usually able to move the dirty straw to the manure channel. Furthermore, it has been shown that, in this type of pen layout, tail biting is only a minor problem (Arey, 1991).

The ability to operate without the use of labor to remove dung from the laying area is important for a commercial production system for pigs. Bruce (1990) found that pigs in the straw flow system in general were able to keep the laying area clean except under certain conditions: (a) “When the pigs first entered the pen, the stocking rate was very low. In these circumstances the pigs sometimes, but not always, dunged on the free space available on the sloped lying area.” (b) “In hot summer conditions the pigs wallowed in the dunging area and dung spread to the lying area of the pen.” In the safari system these problems can be avoided by adjusting the stocking density to the size of the animals and by placing wallow basin in pens for the oldest pigs.

In the section Relation Between the Use of Straw and the Demand for Insulation, we discussed how the use of straw may reduce the demand for insulation. We
therefore suggest that the upper part of the walls and the upper part of the roof consist of glass panels controlled by an opening system used for natural ventilation in greenhouses. Such a solution is expected to provide daylight and a better working environment. Reduced insulation may increase the risk of condensation. The risk in the present system, however, is minimal because of the reduced indoor temperature that allows a higher level of ventilation. Additionally, the glass panels in the ceiling should be placed so that condensation water will flow to the outside of the building. Finally, because of the natural ventilation system a higher level of ventilation will be provided without increasing cost.

The lower temperature in the house may theoretically result in increased feed costs. However, as described in the section Relation Between the Use of Straw and the Demand for Insulation, pigs can remain within their thermoneutral zone in spite of the calculated drop in temperature by 50° to 6° C because of the straw and the solid floor; consequently, there will be no extra feed costs. In general, it is expected that the pigs can take better care of themselves in systems with a larger pen area and straw.

Animal Welfare

The main welfare improvements in the safari system compared to the traditional intensive systems are: (a) a larger pen area per animal that creates less stress and also allows more natural behavior, (b) the solid floor and the use of straw, which allow the pigs to perform more natural behaviors, (c) the minimization of mixing of pigs from different groups, and (d) the possibility of using a special pen layout for pigs of a certain age to achieve better welfare. An example is the wallow basin in pens for the oldest pigs.

Utilization of Building Area

As mentioned in the section Use and Allocation of Pen Area, the level for pen area assignment can be expressed by the constant $k$ in the formula $A = k \cdot W^{0.667}$.

In the safari system, as described previously, the constant $k$ varies between .043 and .062 (Figure 1). In an intensive production system with a piglet unit for pigs less than 30 kg and a finishing unit for pigs above 30 kg designed to fulfill the EU minimum pen area requirement, the lowest value for the constant $k$ is .030. The animals in the safari system are given a 43% larger pen area in the most crowded periods than in common practice.

Compared to a common practice-intensive system with the same production capacity the total pen area in the safari system is increased by only 4%, the area for passages and internal walls is reduced by more than 50%, and the total area is reduced by 7%.
Capital Demand for Investment

Table 1 shows an overview of the calculated capital demand for investment in the safari system as compared to a traditional production system with fully slotted floor, containing 8 sections with four pens for 30 weaned pigs, and a unit with 96 pens for 15 growing pigs. The calculation is based on Danish conditions and the total capital demand for investment in the intensive production system is set at 100%.

In the safari system, the total capital demand is reduced by 18% mainly because of the minimal use of slotted floors. The floor construction contributes to nearly half of this reduction. The considerable savings in the cost of walls and roof construction is primarily due to the reduced use of internal walls.

Production Costs

Table 2 shows an estimate for production costs in the two systems. The comparison is based on Danish conditions, and the production results are assumed to be equal. The total cost in the traditional production system is set at 100. The total cost in the safari system is calculated to be about 3% less than in the traditional system.

The interest level used is 10% per year, and the average write-off period for building and equipment is set to 20 years. The reduced capital demand for investment in the safari system is calculated to reduce the costs for interests and write-off corresponding to 3% of the total cost. Use of straw (0.1 kg per kg weight gain) and increased demand for labor in the safari system is calculated to be about 2% of the total production costs, but this is neutralized by reduced energy and maintenance costs.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Relative Capital Demand for Investment in Piglet and Finishing Unit</th>
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<tbody>
<tr>
<td></td>
<td>Designed for 120 Pigs Per Week</td>
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<tr>
<td></td>
<td><strong>Traditional System</strong></td>
</tr>
<tr>
<td>Floor constructions</td>
<td>19</td>
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<td>Walls and roof</td>
<td>27</td>
</tr>
<tr>
<td>Manure equipment and storage</td>
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<tr>
<td>Straw storage</td>
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<td>Pens</td>
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<td>Feeding system</td>
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<tr>
<td>Ventilation system</td>
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<td>Other installations and equipment</td>
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<td>Herd</td>
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<td>Total</td>
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TABLE 2
Relative Production Costs in Piglet and Finishing Unit Design for 120 Pigs Per Week

<table>
<thead>
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<th></th>
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<th>Safari System</th>
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</thead>
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<td>Feed</td>
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<td>46</td>
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<td>Straw</td>
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<td>&lt; 0.5</td>
</tr>
<tr>
<td>Investment, interests and write-off</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>97</td>
</tr>
</tbody>
</table>

DISCUSSION

Pigs can be provided with a higher degree of welfare in several ways. However, commercial pig production systems with a higher degree of welfare must be economically competitive with the traditional systems. Otherwise a higher degree of welfare will be introduced only by national or international requirements.

One of the difficulties in designing systems with a higher degree of welfare is prioritizing the different welfare elements. Does a larger pen area per pig provide more welfare value than the use of straw? Is the welfare of one group of pigs (dry sows, farrowing sows, boars, suckling piglets, weaned pigs, or growing pigs) improved more by a certain investment than another group? Answers to such questions are crucial to the future development of new production systems.

From studies of animal behavior it is known that pen area per pig and use of straw are very important elements in behavior and welfare for piglets and fattening pigs (e.g., Ewbank & Bryant, 1972; Simonsen, 1990; van Putten, 1969; Warnier & Zayan, 1985; Wood-Gush et al., 1990). In the proposed safari system straw can be used, and the animals are given a 40% larger pen area per pig in the most crowded periods than is common practice. The varying pen sizes are thought to accommodate space on an “even basis” for all age classes of growing pigs. The assumption made in the section Use and Allocation of Pen Area that small pigs have the same space demands as older pigs is based on the actual space demands when all pigs are lying (on their side). However, the level and type of activity must also be considered when allocating the available total space in the house to the various age classes (16 in total). Accurate figures cannot be given, but information from pigs kept under seminatural conditions may be useful and seems to support our decision: Piglets up to the age of 7 to 8 weeks old show a lower but increasing activity level as compared
to older pigs, but on the other hand they show more boisterous play. Later on there is less play but the activity level is higher and slowly increasing (Petersen, Vestergaard, & Jensen, 1989; Petersen, 1994). A similar age-related development in activity has been found for pigs kept indoors with and without straw, but the level of activity was lower (Petersen, Simonsen, & Lawson, 1995). We decided that, taken altogether, the activities would demand a similar space allowance in all our age classes, but more information—for example about aggression levels at various ages—may warrant a different space allocation for different age classes. The large groups that we propose seem to be only a minor disadvantage from a production point of view (see Kornegay & Notter, 1984); from a welfare point of view they may be advantageous in that they provide more total space.

Finally, it has been indicated that relocation in itself has adverse effects on production, but the effect of this is much smaller than that of the mixing of pigs (Douglas, Borell, Williams, & Stahly, 1993; 1994). Relocation effects might be alleviated in the safari system because of the increased space after relocation and because of possible adaptation to the frequent relocations. Furthermore, the pigs will always be moved to neighboring pens of which they may have some visual and olfactory experience, which may tend to reduce their fear.

It is normally accepted that the welfare effect of pen area is connected to the minimum area provided during the production periods. Therefore, there is no doubt that a higher minimum pen area during the whole production period gives a higher degree of welfare than in intensive systems. In addition, the total pen area in the proposed system is greater, and the pens give access to a relatively large area. Big pens by themselves increase free pen area and provide opportunities for the pigs to explore. The small pens and group sizes that are usually used have led to the mixing of pigs, and farmers have not been aware of the social organization and dynamics in groups of pigs and their effects on production.

In the safari system the design of the buildings is integrated into the proposed production system, but with special attention to building costs and labor requirements. The width of the building, for instance, corresponds to the desired size and form of the pens, to the need for a simple arrangement to move the pigs from one pen to another, and to a low square meter price of the building. The proposed width of the unit and the placing of ventilation openings also allow a good natural change of air. The straw flow system corresponds to the need for straw as an important welfare element, to a limited use of straw and labor, and to cheap floor construction. The poor insulation and the simple form of ventilation correspond to the fact that the animals are better able to protect themselves against semioptimal climatic conditions in a system with straw and good conditions for natural behavior. At the same time, the building costs can be kept low even though the total pen area is greater than in a traditional system.

Many of the improvements suggested for the safari system may also be applied in intensive systems to increase welfare and, possibly, production economy. The
unique advantage of the safari system is the "safari" itself: that the pigs are "traveling" through a number of pens of increasing size and on the way given space and facilities according to their age related demands, and without being mixed with strange pigs.

The safari system requires different management strategies than traditional systems. Health control and disease prevention also differ from the traditional systems. In this theoretical project it is not possible to evaluate these parameters. They need to be tested in large-scale experiments under practical conditions.

CONCLUSION

The analysis of animal welfare related to behavioral needs showed that the essential welfare demands for a new production system for growing pigs are (a) more space for locomotion and other activities, (b) a stable social group, (i.e., no mixing of pigs), and (c) good possibilities for exploration and wallowing.

The analysis of building design revealed five elements that contribute to economic competitiveness of new production systems for growing pigs: (a) frequent pen size adjustment, (b) relatively large pens and group sizes, (c) few and large rooms, (d) reduced use of slotted floors, and (e) reduced insulation of the building.

A theoretical analysis indicated that our new design for growing pigs, the safari system, could improve the welfare of the pigs and increase economic competitiveness because it accommodates the documented behavioral needs and also utilizes elements that reduce building costs.

We believe that pig producers want the best conditions possible for the animals. Therefore, it is an important challenge to agricultural engineers and scientists in animal behavior (and welfare) to work together to create comprehensive solutions that can be used under practical conditions. In general, the project showed that it is indeed valuable for the fields of animal behavior and animal housing to interact in developing new designs for improved farm animal housing.

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REFERENCES

PRODUCTION SYSTEM FOR WEANED AND GROWING PIGS


