Effect of group size-floor space allowance and floor type on growth performance and carcass characteristics of heavy pigs

R. Rossi, MSc, PhD; A. Costa, MSc, PhD; M. Guarino, MSc, PhD; F. Laicini, MSc; G. Pastorelli, MSc, PhD; C. Corino, MSc

Summary

Objective: To evaluate the effects of group size-space allowance and floor type on growth performance and carcass characteristics in pigs slaughtered at 160 kg live weight (LW).

Materials and methods: (Landrace × Large White) × Duroc pigs (N = 216), averaging 89.8 ± 0.4 kg LW at approximately 6 months of age, were evenly distributed among 18 pens (six pens per room, equal numbers of barrows and gilts per pen). Nine pens provided a low space allowance (LSA; k = 0.033; 1.0 m^2 per animal; 126 pigs), and nine pens provided a high space allowance (HSA; k = 0.047; 1.4 m^2 per animal; 90 pigs). After 90 days, six pigs per pen were slaughtered (total 108 pigs; 156 ± 1.4 kg LW). The proportion of floor contaminated with manure, urine, or both, and environmental parameters, were recorded during the observation period.

Results: Pigs on all floor types tended to gain more weight with HSA than with LSA (P = .08) days 46 to 90. Average daily gain (ADG) and final LW were higher for barrows than gilts (P < .05). Feed conversion ratio tended to be lower (P < .10) for HSA than LSA animals. Backfat thickness was higher for HSA and rooms with totally slatted floors. Contaminated floor area was smaller with totally slatted floors.

Implications: Increasing space allowance from k = 0.033 to k = 0.047 is associated with better ADG at LW > 120 kg, suggesting that this change might be of benefit to the heavy-pig industry.

Keywords: swine, performance, carcass, housing, space allowance

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Resumen - Efecto del espacio de piso según el tamaño del grupo y el tipo de piso en el desempeño del crecimiento y las características de la canal en cerdos pesados

Objetivo: Evaluar los efectos del espacio de piso según el tamaño del grupo y el tipo de piso en el desempeño del crecimiento y en las características de la canal en cerdos sacrificados a 160 kg de peso vivo (LW por sus siglas en inglés).

Materiales y métodos: Cerdos (Landrace × Blanco Grande) × Duroc (N = 216) promediando aproximadamente 89.8 ± 0.4 kg LW a los 6 meses de edad, se distribuyeron equitativamente en 18 corrales (seis corrales por sala, igual número de castrados y primerizas por corral). Nueve corrales proveyendo poco espacio (LSA; k = 0.033; 1.0 m^2 por animal; 126 cerdos), y nueve corrales proveyendo mucho espacio (HSA; k = 0.047; 1.4 m^2 por animal; 90 cerdos). Después de 90 días, seis cerdos por corral fueron sacrificados (total 108 cerdos; 156 ± 1.4 kg LW). La proporción de piso contaminado con excremento, orina o ambos, y los parámetros medioambientales, se registraron durante el periodo de observación.

Resultados: Sin importar el tipo de piso, los cerdos en el tratamiento HSA tendieron a ganar más peso que en el LSA (P = .08) entre los días 46 a 90. La ganancia diaria promedio (ADG por sus siglas en inglés) y el LW final fueron mayores para los castrados que para las primerizas (P < .05). La conversión alimenticia tendió a ser más baja (P < .10) para los animales en el tratamiento HSA que para los del LSA. El grosor de grasa dorsal fue más alto para el tratamiento HSA y para las salas con piso de slat total. El área de piso contaminada fue más baja con pisos de slat total.

Implicaciones: El aumento de espacio de k = 0.033 a k = 0.047 se asocia con mejor ADG en LW > 120 kg, sugiriendo que este cambio puede ser de beneficio para la industria de cerdo pesado.

RR, AC, MG, GP, CC: Department of Veterinary Sciences and Technologies for Food Safety, University of Milan, 20133 Milan, Italy.

FL: Associazione Regionale Allevatori della Lombardia, Via Kennedy 30, 26013 Crema, Italy.

Corresponding author: Dr Raffaella Rossi, Department of Veterinary Sciences and Technologies for Food Safety, University of Milan, Via Celoria, 10, 20133 Milan, Italy; Tel: +39250315758; Fax: +39250315746; E-mail: raffaella.rossi@unimi.it.

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Résumé - Effet de l'attribution de la superficie de plancher selon la taille du groupe et le type de plancher sur les performances de croissance et les caractéristiques des carcasses de porcs lourds

Objectif: Évaluer les effets de l'attribution de la superficie de plancher et du type de plancher sur les performances de croissance et les caractéristiques des carcasses de porcs abattus à un poids vif (LW) de 160 kg.

Matériels et méthodes: Des porcs croisés (Landrace × Large White) × Duroc (N = 216), pesant en moyenne 89.8 ± 0.4 kg LW à environ 6 mois d'âge, ont été répartis également dans 18 enclos (six enclos par chambre, nombres égaux de cochettes et mâles castrés par enclos). Dans neuf enclos l'espace plancher alloué était faible (LSA; k = 0.033; 1.0 m^2 par animal; 126 porcs) et dans les neuf autres enclos l'espace plancher était élevé (HSA; k = 0.047, 1.4 m^2 par animal; 90 porcs). Après 90 jours, six porcs par enclos ont été euthanasiés (total de 108 porcs; 156 ± 1.4 kg LW). La proportion de plancher contaminé par du fumier, de l'urine ou les deux, ainsi que les paramètres environnementaux ont été notés pour la durée de la période d'observation.

Résultats: Les porcs sur tous les types de plancher avaient tendance à prendre plus de poids entre les jours 46 à 90 avec HSA plutôt qu'avec LSA (P = .08). Le gain quotidien moyen (ADG) et le LW final étaient plus élevés pour les mâles castrés que pour

les cochettes ($P < .05$). Le taux de conversion alimentaire avait tendance à être plus bas ($P < .10$) pour les animaux avec HSA plutôt que ceux avec LSA. L'épaisseur du gras dorsal était plus grand pour HSA et les chambres avec planchers complètement lattés. La surface de plancher contaminé était plus petite avec les planchers complètement lattés.

Implications: Une augmentation de la superficie de plancher allouée de k = 0.033 à k = 0.047 est associée avec un meilleur ADG à un LW > 120 kg, ce qui suggère que ce changement pourrait être bénéfique pour l'industrie du porc lourd.

Space allowance is one of the most important variables in pork production, affecting productivity and animal welfare.[1,2] Inadequate floor-space allowance causes stress and diminishes growth rate in growing and finishing pigs.[3,4] Productivity decreases as crowding increases,[5] but production per unit area rises,[6] improving profitability. Animal welfare and profitability are thus inversely related.

The static space requirement for pigs is based on body size. Petherick and Baxter[7] proposed that space allowance should be based on surface area in lateral recumbency, correlated with live weight (LW) (space allowance = $0.047 \times LW^{0.667}$). The allometric approach was proposed by Petherick[1] and Baxter[8] and applied by Edwards et al[6] and Gonyou and Stricklin.[5] In this approach, $A = k^*LW^{0.667}$, with A representing floor-space allowance and k representing a space-allowance coefficient. The European Union has established space allowances for several LW ranges that approximate k values of 0.033 for finisher pigs in the weight class > 100 kg.[9] Italian swine production focuses primarily on heavy pigs, slaughtered at 160 kg ± 10% LW, in order to produce carcasses destined for Denomination of Protected Origin products such as Parma ham (Council Regulation [EEC] N°2081/92).[10] However, studies concerning pig space requirements and their effects on growth performance have been limited to lighter-weight pigs.[11-13]

Proportion of slatted flooring may affect growth performance and welfare, since pigs prefer different pen areas for different behaviors and activities and use different strategies to maintain pen hygiene when space allowance is limited, depending on the type of flooring.[1,14]

According to available data,[15] about 60% of growing-finishing pigs in Italy are housed in pens with partially slatted floors, 25% in pens with totally slatted floors, and 15% in pens with solid floors and no bedding. To our knowledge, no studies have determined the impact of different floor types and group size-space allowance on growth performance and carcass characteristics of heavy pigs.

The objectives of this study were to determine the effects on heavy pig growth performance, carcass characteristics, and meat quality of two group size-space allowance treatments and three housing systems differing in types of flooring and ventilation systems, representing housing systems traditionally present in Italy.

Materials and methods

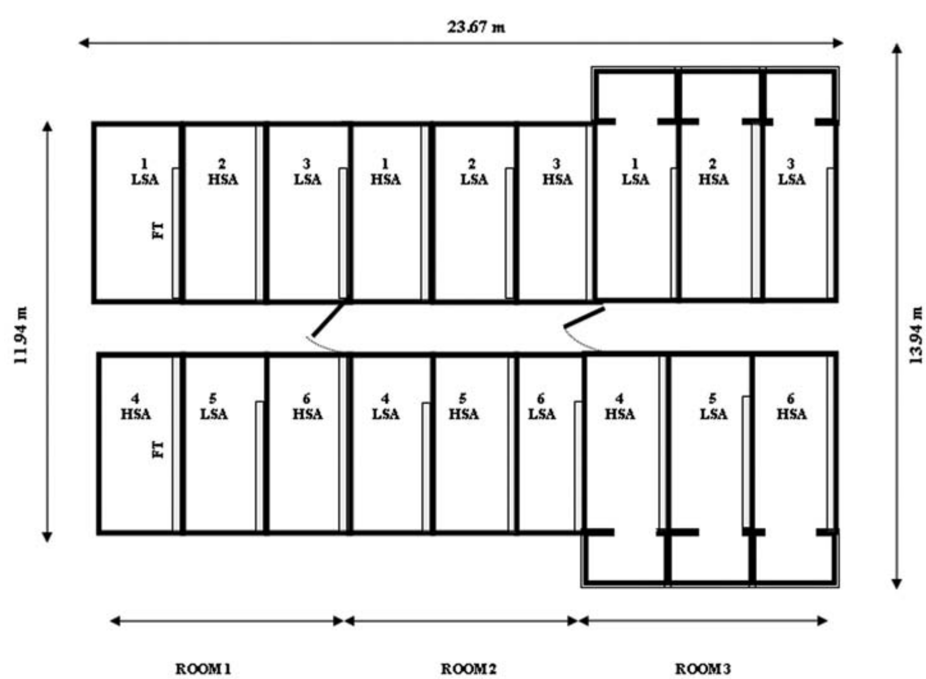
Housing and environmental parameters

The trial was conducted in the spring in a swine stock farm in Northern Italy ("Le Cerchie" experimental swine housing, Curtatone, Mantova, Italy), which conformed to Italian commercial practice. The building had 2.05-m high concrete block walls, with or without air inlets, and a roof of pre-fabricated concrete sheets with an approximate 30° slope. A 1.3-m passage the length of the building was used both for access and for moving pigs to the weighing system. The floor was concrete, with pen fronts and sides constructed of pre-cast concrete blocks, approximately 1 m high. The building was divided into three rooms, each subdivided into six pens 5.32 m × 2.63 m, including feeding troughs (38 cm per pig). Each room had a different floor type and ventilation system. Figure 1 shows the top view of the three pig rooms and Figure 2 shows a cross section of each room, including the flooring type and the ventilation system.

Room One (Figure 2A) had a 20% slatted floor, with 10-cm slats and 2-cm gaps, and was cross-ventilated mechanically. Incoming air was fed through ceiling inlets, and air was exhausted by an axial fan placed in the middle of the front wall.

Room Two (Figure 2B) had a totally slatted floor with 10-cm slats and 2-cm gaps, and was mechanically ventilated, with air exhausted from under the slatted floor.

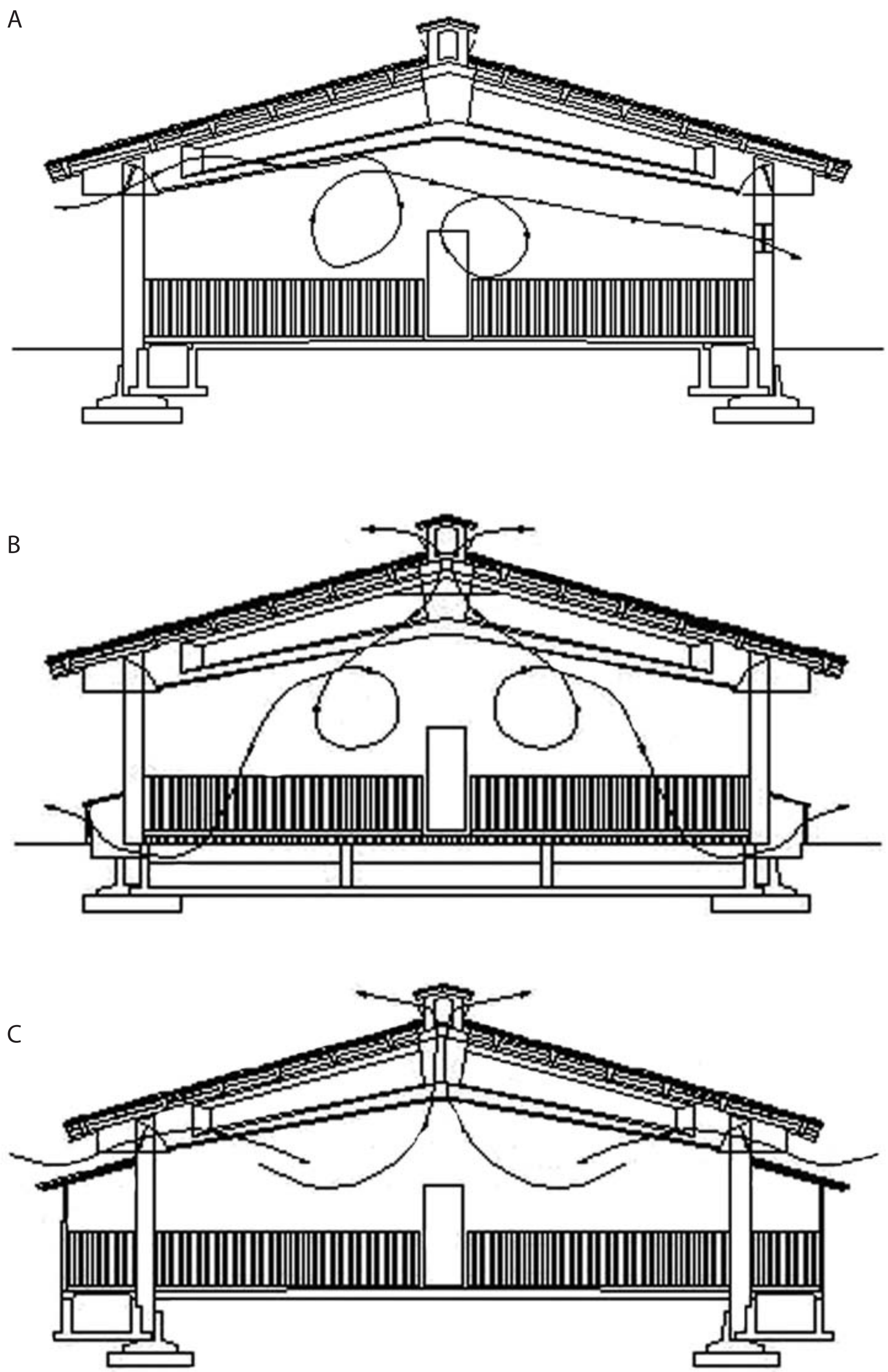
Figure 1: Floor plan of three pig housing rooms in a study on the effects of group size-space allowance and floor type on growth performance and carcass characteristics in finishing pigs in Italy. Room One: partially slatted floor, mechanically cross-ventilated; Room Two: totally slatted floor, mechanically ventilated; Room Three: solid floor, natural ventilation. LSA, low space allowance of 1.0 m² per animal; HSA, high space allowance of 1.4 m² per animal; FT, feeding trough.



Room Three (Figure 2C) had a solid floor with an external dunging area (1m × 2.63 m) and natural ventilation. Air entered through the dunging-area doors and was exhausted through ceiling inlets and a chimney placed in the middle of the roof.

Temperature and relative humidity in the rooms and outside the building were measured continuously at 1-minute intervals by Dataloggers (Babuc M; Lsi Instruments, Milan, Italy). Probes were positioned in the centre of and immediately outside each room. In all three rooms, ammonia levels were detected once a week by Draeger Tubes (Draeger Safety Inc, Pittsburgh, Pennsylvania) placed at a height of 20 cm from the floor. The threshold value for ammonia for this instrument is 2 ppm.

Figure 2: Cross sections of three pig housing rooms in the study described in Figure 1. A) Room One, partially slatted floor, mechanically cross-ventilated, with air entering via ceiling inlets and exhausted by an axial fan in the middle of the front wall; B) Room Two, totally slatted floor, mechanically ventilated, with air exhausted under the slatted floor; C) Room Three, solid floor with external dunging area, naturally ventilated, with air entering through the dunging area doors and exhausted through ceiling inlets and a chimney placed in the middle of the roof.



Floor contamination

The amount of manure on the floor inside the building was estimated visually twice weekly as an assessment of animal space availability and air quality in the three housing systems. Conditions of floor contamination were expressed as the proportions of the pen floor surface that were covered by solid manure, urine, and solid manure plus urine. The same person made the assessment weekly. Decimal values between 0 (clean floor) and 1 (floor completely covered by manure or urine) were assigned, then the contaminated areas were mapped and recorded on paper to evaluate the individual percentages in the three rooms.[16]

Animals and stocking density

A total of 216 pigs, (Landrace × Large White) × Duroc, with an average body weight of 89.8 ± 0.4 kg (mean ± SEM) and average age 6 months, were selected on the basis of gender and weight uniformity. The animals were distributed among 18 pens (six pens per room). Nine pens (three pens per room) housed a total of 126 pigs (equal numbers of barrows and gilts) with a low space allowance (LSA) of 1.0 m^2 per animal. The other nine pens (three pens per room) housed a total of 90 pigs (equal numbers of barrows and gilts) with a high space allowance (HSA) of 1.4 m^2 per animal. Group sizes were selected to provide these specific floor-space allowances. A group size of 14 pigs per pen provided 1.0 m^2 per pig (LSA), which conformed to the minimum space allowance for pigs of LW > 100 kg as stipulated in Directive 2001/88/ec.[9] Using the allometric approach, k stipulated by the European Union for pigs of 160 kg LW is equal to 0.033. A group size of 10 pigs per pen provided 1.4 m^2 per pig (HSA), which was calculated on the basis of the space occupied by a laterally recumbent animal[7] with k = 0.047 for LW 160 kg. Thus, group size and floor-space allowance are confounded, and we refer to these treatments as group size-space allowance.

Live weights and feeding

The pigs were individually weighed on Day 0 (the beginning of the trial), Day 46, and Day 90 (the end of the trial). The trial was divided into two feeding phases: Phase One included Days 0 through 45 and Phase Two included Days 46 to 90. Mean body weights (± SEM) on Days 46 and 90 were 119.4 ± 0.6 kg and 146.2 ± 0.8 kg, respectively.

The Phase One and Phase Two diets were formulated to meet the National Research Council's nutrient requirements of growing-finishing pigs,[17] as prescribed by Parma ham regulation (Council Regulation [EEC] N°2081/92).[10] Three times daily, animals were fed a liquid feed with a water:concentrate ratio of 3:1, with free-choice access to drinking bowls located at the corner of each pen. Feed was restricted to 9% of metabolic weight ($LW^{0.75}$) on a dry matter basis. The feed conversion ratio (FCR) was calculated as the ratio between the amount of feed offered (dry matter basis) and weight gained between Days 0 and 90.

The animals used in this experiment were cared for in accordance with European Union guidelines (N. 86/609/EEC)[18] approved by the Italian Ministry of Health (DLgs116/92).[19]

Carcass measurement and meat quality

On Day 90, all pigs were weighed and 108 pigs with a weight close to the mean for the group (± 10%) were selected, including six pigs per pen and equal numbers of barrows and gilts, and were transported to a commercial abattoir. Carcass and ham weights were recorded. Backfat, longissimus dorsi thickness, and meat percentage were measured using a Fat-O-Meter (SFK Technology A/S, Herlev, Denmark) immediately after slaughter.

Meat quality was evaluated 45 minutes and 24 hours post mortem using pH (HI 9023, microcomputer; Hanna Instruments, Vila do Conde, Portugal) and color measurements on the caudal portion of the semimembranosus muscle, as described by the Italian Scientific Association for Animal Production.[20] Reflectance measurements were performed when measurements had stabilized, ie, after the samples had oxygenated in air for at least 30 minutes. Tristimulus color coordinates (lightness, redness, yellowness) were recorded using a Chroma meter (CR-300; Minolta Cameras, Osaka, Japan). The instrument was calibrated using a white calibration plate (Calibration Plate CR-A43; Minolta Cameras) at the beginning of each session. The colorimeter had an 8-mm measuring area and was illuminated with a pulsed xenon arc lamp (Illuminant C) at 0° viewing angle. Reflectance measurements were obtained at a viewing angle of 0° and the spectral component was included.

Statistical analysis

Data were analyzed as a split-plot design using the GLM procedure of SAS (SAS version 8; SAS Institute, Cary, North Carolina). Room (floor type) was the main plot, and pen (group size-space allowance) and gender were considered subplots. The variables analyzed were body weight, ADG, FCR, percentage of contaminated solid-floor area, carcass characteristics, and meat-quality parameters. No significant interaction among gender, floor type, and space allowance-group size were observed. The environmental parameters (temperature and relative humidity) were not significantly associated with the dependent variables and were dropped from the statistical analysis. The data are presented as means ± SEM. An effect was considered significant at $P < .05$.

Results

Environmental parameters

The mean external temperature and relative humidity were 13.90°C and 75%, respectively, for Phase One, and 21.49°C and 80%, respectively, for Phase Two. Mean internal temperature on Days 0 through 90 was numerically higher in Room Two (23.6°C) than in either Room One (22.0°C) or Room Three (22.1°C). Mean daily temperature variation on Days 0 through 90 was numerically higher in Room One than in the other two rooms (Room One, 5.9°C; Room Two, 5.5°C; Room Three, 5.5°C). Mean internal relative humidity on Days 0 through 90 was numerically higher in Room One than in Rooms Two and Three (Room One, 68.5%; Room Two, 54.9%; Room Three, 63.2%).

Group size-space allowance and period were not associated with proportions of manure, urine, or manure plus urine on the floor (Table 1). The amount of manure on the floor was significantly associated with housing system. There was a higher percentage of solid manure on the Room One floor during both Phase One and Phase Two ($P < .001$). There was a lower percentage of solid manure on the Room Two floor than on the Room Three floor during Phase Two (Table 1). There was significantly more urine ($P < .001$) on the Room Three floor than on the Room One floor during Phase Two. Percentages of solid manure and urine were lower ($P < .001$) in Room Two than in the other two rooms during both phases. Percentage of manure mixed with urine was higher in Room One during both phases ($P < .001$).

Ammonia levels (Draeger tubes) were not detectable in either phase of the trial, ie, ammonia concentration was < 2 ppm.

Growth performance

All animals were in good health throughout the trial and no mortality was recorded. All feed was consumed and no wastage was observed. Average daily gain, final LW, and carcass weight were not associated with floor type or group size-space allowance (Table 2). However, pigs in HSA tended to gain more weight than pigs in LSA ($P = .08$) during Phase Two. No significant interactions between floor type and group size-space allowance ($P = .63$) were observed for final LW of pigs (HSA: 148.8 kg, 148.1 kg, and 146.0 kg in Rooms One, Two, and Three, respectively; LSA: 144.1 kg, 146.0 kg, and 145.2 kg in Rooms One, Two, and Three, respectively). No significant interactions between floor type and group size-space allowance ($P = .58$) were observed for ADG throughout the trial (HSA: 651 g, 645 g, and 624 g per day in Rooms One, Two, and Three, respectively; LSA: 603 g, 625 g, and 619 g per day in Rooms One, Two, and Three, respectively). Feed conversion ratio (Table 2) was not associated with floor type, but tended to be lower ($P < .10$) in the HSA pigs than in LSA animals. Average daily gain throughout the trial and the final LW of gilts was lower ($P < .05$) than that of barrows.

Carcass characteristics

Carcass weight, meat percentage, longissimus dorsi muscle thickness, and ham weight did not differ significantly with floor type or group size-space allowance (Table 3). Backfat

Table 1: Proportion of floor space contaminated with manure, urine, or both in three rooms housing finishing pigs*

	Space allowance†		Housing system‡			SEM
	High	Low	Room One	Room Two	Room Three	
Phase One (0-45 days)						
Solid manure (%)	20.28	20.22	33.05[a]	10.92[b]	16.78[b]	3.70
Urine (%)	5.52	2.42	4.13	2.07	5.71	3.36
Solid manure and urine (%)	15.09	20.14	23.93[a]	1.71[b]	27.21[a]	2.78
Phase Two (46-90 days)						
Solid manure (%)	15.58	20.91	30.00[ax]	7.31[by]	17.43[c]	4.26
Urine (%)	4.5	2.37	1.18[a]	3.00[ab]	6.12[b]	2.64
Solid manure and urine (%)	20.75	22.62	29.00[a]	1.00[b]	35.06[a]	3.65

* Means ± SEM. Data were analyzed by analysis of variance using a split-plot design. The model included the effects of floor type and group size-space allowance and their interaction. Pigs entered the study at approximately 6 months of age.

† Low space allowance, 1.0 m^2 per animal; high space allowance, 1.4 m^2 per animal.

‡ Room One: partially slatted floor, mechanically cross-ventilated; Room Two: totally slatted floor, mechanically ventilated; Room Three: solid floor with external dunging area, natural ventilation.

[ab] Values with different superscripts within a row and within a category differ significantly ($P < .001$).

[xy] Values with different superscripts within a row and within a category differ significantly ($P < .05$).

Table 2: Effects of group size-space allowance, floor type, and gender on growth performance and average daily gain (ADG) of heavy pigs*

Variable	Group size-space allowance		Housing system†			Gender	
	High	Low	Room One	Room Two	Room Three	Barrow	Gilt
Initial weight (kg)	90.0 ±1.20	89.7 ± 0.94	89.9 ± 0.72	89.8 ± 1.00	89.7 ± 0.73	90.4 ± 0.98	89.3 ± 1.11
CV (%)	7.3	6.8	6.8	7.3	6.9	6.5	7.4
Final weight (kg)	147.6 ± 2.55	145.1 ± 1.88	146.0 ± 1.51	146.9 ± 1.45	145.6 ± 1.82	149.8 ± 2.00[a]	142.6 ± 2.16[b]
CV (%)	8.7	8.4	8.8	8.3	9.5	8.0	9.1
ADG (g/day)							
0-45 days	657 ± 15.16	644 ± 14.15	642 ± 19.83	662 ± 17.25	644 ± 16.77	691 ± 13.67[a]	608 ± 14.62[b]
46-90 days	632 ± 19.40	587 ± 17.35	608 ± 22.71	601 ± 24.10	608 ± 20.67	629 ± 17.20[a]	583 ± 19.36[b]
0-90 days	640 ± 14.13	615 ± 9.99	623 ± 13.83	633 ± 13.84	621 ± 15.57	659 ± 11.19[a]	592 ± 11.42[b]
FCR 0-90 days	4.51 ± 0.18	4.88 ± 0.19	4.63 ± 0.20	4.83 ± 0.21	4.61 ± 0.19	ND	ND

* Means ± SEM. Study design and housing described in Table 1. A total of 216 pigs were individually weighed on Day 0 (approximately 6 months old) and at slaughter on Day 90. A total of 126 pigs (equal numbers of barrows and gilts) were housed in six pens per room (low space allowance, 1.0 m^2 per animal). A total of 90 pigs (equal numbers of barrows and gilts) were housed in three pens per room (high space allowance, 1.4 m^2 per animal). Group sizes of 14 and 10 pigs per pen, respectively, provided 1.0 m^2 and 1.4 m^2 per pig.

CV% = coefficient of variation; FCR = feed conversion ratio (feed offered ÷ gain); ND = not done.

[ab] Values with different superscripts within a row and within a category differ significantly ($P < .05$).

thickness was significantly higher ($P < .05$) for pigs in the HSA and in Room Two. There were no significant interactions between floor type and group size-space allowance ($P = .73$) for mean backfat thickness in pigs in the HSA (29.70 mm, 31.40 m, and 27.35 mm in Rooms One, Two, and Three, respectively) or in the LSA (24.64 mm, 28.8 mm, and 25.04 mm in Rooms One, Two, and Three, respectively). Ham weight was higher in barrows than in gilts ($P < .05$).

The meat quality of the semimembranosus muscle, assessed using pH and color indices at 45 minutes and 24 hours, was not associated with group size-space allowance and floor type. More yellowness was observed in the semimembranosus muscle in barrows than in gilts at 24 hours post mortem ($P < .05$).

Discussion

The microclimates in all three rooms of the building were classified within the "comfort zone" for finishing swine.[21,22] Relative humidity was numerically lowest and internal temperature was numerically highest in

Table 3: Effects of group size-space allowance, floor type, and gender on carcass characteristics and meat quality of semimembranosus muscle*

Variable	Group size-space allowance		Housing system†			Gender	
	High	Low	Room One	Room Two	Room Three	Barrow	Gilt
Carcass weight (kg)	126.0 ± 1.32	123.9 ±1.28	126.1 ± 1.87	125.4 ± 1.54	123.5 ± 1.47	122.9 ± 1.24	126.57 ± 1.34
Meat (%)	48.85 ± 0.62	49.55 ± 0.45	50.11 ± 0.71	49.30 ± 0.63	48.80 ± 0.57	49.19 ± 0.55	49.32 ± 0.48
Backfat thickness (mm)‡	29.44 ± 1.13[a]	26.42 ± 0.78[b]	26.75 ± 1.26[a]	29.97 ± 1.30[b]	26.00 ± 0.87[a]	28.22 ± 0.96	27.18 ± 0.98
LD thickness (mm)§	60.93 ± 0.59	62.78 ± 0.62	61.95 ± 1.01	61.78 ± 0.71	62.27 ± 0.90	61.70 ± 0.59	62.31 ± 0.71
Ham weight (kg)	16.7 ± 0.19	16.7 ± 0.21	16.7 ± 0.34	16.9 ± 0.21	16.4 ± 0.22	16.9 ± 0.20[a]	16.4 ± 0.19[b]
Trimmed ham weight (kg)	13.9 ± 0.15	13.9 ± 0.18	14.0 ± 0.26	14.0 ± 0.18	13.7 ± 0.18	14.0 ± 0.16	13.8 ± 0.16
Semimembranosus muscle at 45 minutes¶							
pH	6.34 ± 0.04	6.34 ± 0.03	6.31 ± 0.05	6.29 ± 0.04	6.40 ± 0.04	6.31 ± 0.03	6.37 ± 0.03
Lightness	38.16 ± 0.35	38.66 ± 0.36	38.72 ± 0.52	38.10 ± 0.36	38.64 ± 0.45	38.40 ± 0.35	38.51 ± 0.37
Redness	7.09 ± 0.24	6.97 ± 0.19	7.17 ± 0.34	6.79 ± 0.20	7.15 ± 0.26	7.05 ± 0.20	6.99 ± 0.22
Yellowness	2.25 ± 0.13	2.09 ± 0.10	2.20 ± 0.17	2.02 ± 0.11	2.26 ± 0.14	2.20 ± 0.10	2.11 ± 0.12
Semimembranosus muscle at 24 hours¶							
pH	5.47 ± 0.01	5.49 ± 0.01	5.49 ± 0.03	5.47 ± 0.02	5.49 ± 0.01	5.48 ± 0.01	5.48 ± 0.01
Lightness	49.41 ± 0.39	50.01 ± 0.40	49.58 ± 0.62	49.97 ± 0.45	49.67 ± 0.46	50.03 ± 0.31	49.51 ± 0.40
Redness	10.49 ± 0.26	9.88 ± 0.19	10.45 ± 0.35	9.73 ± 0.23	10.33 ± 0.25	10.51 ± 0.25	9.78 ± 0.18
Yellowness	6.33 ± 0.19	6.01 ± 0.15	6.45 ± 0.24	5.91 ± 0.16	6.21 ± 0.22	6.46 ± 0.18[a]	5.85 ± 0.15[b]

* Means ± SEM. Data were analyzed by analysis of variance with split-plot design. The model included the effects of floor type and group size-space allowance and their interaction.

† Room One: partially slatted floor, cross-ventilated mechanically; Room Two: totally slatted floor, mechanically ventilated; Room Three: solid floor with external dunging area, natural ventilation. High and low space allowances provided 1.4 m^2 and 1.0 m^2 per pig, respectively.

‡ Backfat thickness between the third and fourth last ribs measured 8 cm off the midline of the split carcass.

§ Longissimus dorsi (LD) muscle thickness between the third and fourth last ribs measured 8 cm off the midline of the split carcass.

¶ pH and colour measurements at 45 minutes and 24 hours post mortem on the caudal portion of the semimembranosus muscle. Tristimulus color coordinates (lightness, redness, yellowness) were recorded using a Chroma meter (CR-300; Minolta Cameras, Osaka, Japan).

[ab] Values with different superscripts within a row and within a category differ ($P < .001$).

Room Two throughout both study phases, probably because of the position of this room in the middle of the building.

The amount of manure on the floor was not associated with group size-space allowance throughout the trial period, but was associated with floor type. As expected, the lowest proportion of solid manure was found in Room Two, which had a totally slatted floor. Also as expected, the floor of the room with the external dunging area (Room Three), was less contaminated than the floor in Room One.

There was no difference in proportion of floor contamination between Phase One and Two. The soiled area was numerically larger in Phase Two, probably due to increased animal weight, in agreement with the results of Aarnink et al[23] in a study on pigs reared to 105 kg LW, and as previously reported.[24,25] This difference was more marked in Room Three (27.21% versus 35.06%), the room with a solid floor and an external dunging area, perhaps because animals tended to stay in the room to avoid high outdoor temperatures. Voermans and Hendriks[26] noted that finishing pigs fouled pens more in summer than in winter.

Hoeksma et al[27] found that in pig barns with manure pits, as in our study, about two thirds of ammonia emissions come from the pit and one third from the pen floor. A previous study focuses attention on the strong relationship between degree of fouling and environmental ammonia, and thus poor air quality, in swine houses.[25]

Several studies have shown that restricted space allowances are associated with poorer growth rate in growing and finishing pigs.[3,4] A recent review by Gonyou et al[28] showed a significant effect of space allowance on ADG. In that study, the authors used an allometric approach to express space allowance ($A = k^* LW^{0.667}$). Use of this expression allows comparison of studies in animals with different end weights. Moreover, Gonyou et al[28] reported that a critical k value, below which a decrease in ADG occurred, varied from 0.031 to 0.034. In Phase Two of our study, ADG tended to be higher in the HSA (k = 0.047) than in the LSA (k = 0.033) These results agree with those of a study[29] that reported an improvement in growth performance when the available space was increased from k = 0.029 to k = 0.042. Hacker et al[24] reported an improvement in growth rate when space allowance was increased from k = 0.031 to k = 0.049, and Massabie and Granier[30] reported higher ADG in pigs reared to 110 kg LW when k was increased from 0.030 to 0.039.

In the current study, floor type was not associated with growth performance of heavy pigs, in agreement with results of the studies by Guingand and Granier[31] and Spoolder et al.[2] In contrast, Courboulay[32] reported that pigs reared on a partially slatted floor gained more than pigs on a totally slatted floor (851 g per day versus 831 g per day).

In the current study, final weight and ADG throughout the trial were lower in gilts than barrows, in agreement with previous reports.[32,33]

Carcass characteristics in this study are in agreement with those reported for heavy pigs.[34] Carcass characteristics are slightly affected by rearing methods, as reviewed by Millet et al.[35] Brumm[12] found that in finishing pigs (120 kg LW), backfat increased from 19.4 to 21.4 mm when available space increased from k = 0.023 to k = 0.030. Moreover Brumm et al[13] also reported that when space allowance was decreased from k = 0.032 to k = 0.024, backfat thickness was lower in pigs slaughtered at 120 kg LW. In contrast, Hamilton et al[33] reported no differences in fat depth in pigs slaughtered at 120 kg LW and reared in restricted or unrestricted conditions (k = 0.022 versus k = 0.038).

In the current study, backfat thickness was significantly higher in Room Two, where the floor was totally slatted, than in the other two rooms. This might be related to the limiting effect of the totally slatted floor on movement of the animals, as observed daily by the producer. Lewis et al[36]reported that backfat thickness was higher in inactive pigs than in pigs receiving exercise. Mattiello et al[37] observed that finishing pigs housed on fully slatted floors spent more time lying on the floor than pigs in other housing systems. Guy et al[38] reported that finishing pigs housed on fully slatted floors spent more time lying down than pigs housed in pens bedded with straw. Candotti et al[39] reported that leg weakness syndrome was more severe and occurred in significantly more pigs housed on a totally slatted floor than in pigs in other housing systems. Examination of the joints at necropsy showed no differences associated with floor type that were likely to have caused clinical signs, ie, clinical signs did not predict gross lesions in the joints. Clinical signs can be influenced by several conditions other than the severity of articular cartilage damage. Candotti et al[39] hypothesized that totally slatted floors might influence the incidence of abnormal leg conformation, increasing static overload and reducing locomotory ability. Ruiterkamp[14] observed that pigs on fully slatted floors are frequently motionless and suggested that this abnormal behavior is a form of apathy ie, animals show no interest in the environment.

In agreement with a previous study,[40] semimembranosus muscle quality in pigs slaughtered at 120 kg LW did not differ with floor type and group size-space allowance.

Increasing floor space per pig from the k indicated by European Union to a k = 0.047 was associated with positive effects on FCR and ADG only in the final phase of the finishing period (animals > 120 kg LW), in agreement with previous studies[29,30] that compared pigs at a lighter weight. In the heavy-pig industry, feed conversion is recognized as an important indicator of profitability for pork producers. In Italy, feed costs represent approximately 61.4% of the total cost of pork production[15] in pigs raised to 160 kg LW.

Further studies are needed to confirm optimal heavy-pig space allowance based on static spatial requirements[41] (animal length, width, and height) and to determine the effects of the housing system, including floor and ventilation type, on welfare, growth performance, and meat quality.

Implications

- Under the conditions of this study, increasing space allowance from k = 0.033 to k = 0.047 is associated with an increase in ADG in pigs > 120 kg LW.
- Under the conditions of this study, backfat thickness is higher in heavy pigs reared on totally slatted floors at a high space allowance (k = 0.047).
- Under the conditions of this study, meat quality is not affected by group size-space allowance or floor type.

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References

*1. Petherick JC. A Biological Basis for the Design of Space in Livestock Housing. Farm Animal Housing and Welfare. A Seminar in the CEC Programme of Coordination of Research on Animal Welfare. Aberdeen, Scotland. 1983;103–120.

2. Spoolder HAM, Edwards SA, Corning S. Legislative methods for specifying stocking density and consequences for the welfare of finishing pigs. *Livest Prod Sci.* 2000;64:167–173.

3. Kornegay ET, Meldrum JB, Chickering WR. Influence of floor space allowance and dietary selenium and zinc on growth performance, clinical pathology measurements and liver enzymes, and adrenal weights of weanling pigs. *J Anim Sci.* 1993;71:3185–3198.

4. Hyun Y, Ellis M, Riskowski G, Johnson RW. Growth performance of pigs subjected to multiple concurrent environmental stressors. *J Anim Sci.* 1998;76:721–727.

5. Gonyou HW, Stricklin WR. Effects of floor area allowance and group size on the productivity of growing/finishing pigs. *J Anim Sci.* 1998;76:1326–1330.

6. Edwards SA, Armsby AW, Spechter HH. Effects of floor area allowance on performance of growing pigs kept on fully slatted floors. *Anim Prod.* 1988;46:453–459.

*7. Petherick JC, Baxter SH. Modelling the static spatial requirements of livestock. In: McCormack JAD, ed. *Modelling, Design and Evaluation of Agricultural Buildings*. CIGR Section II Seminar. Bucksburn, Aberdeen. 1981;75–82.

8. Baxter S. *Intensive Pig Production: Environmental Management and Design*. London, UK: Granada Publishing Ltd; 1984:210–254.

9. Council Directive 2001/88/EC of 23 October 2001 amending Directive 91/630/EEC laying down minimum standards for the protection of pigs. Available at: `http://www.legaltext.ee/text/en/U61132.htm`. Accessed 26 June 2008.

10. Parma Ham. Protected Designation of Origin. Specifications and Dossier Pursuant to Article 4 of Council Regulation (EEC) N°2081/92 dated 14th July 1992. Available at: `http://www.parmaham.org/quality/guarantee-specifications.pdf`. Accessed 26 June 2008.

11. Edmonds MS, Baker DH. Effect of dietary protein fluctuations and space allocation on performance and carcass traits of growing-finishing pigs. *J Anim Sci.* 2003;81:3783–3791.

12. Brumm MC. The effect of space allocation on barrow and gilt performance. *J Anim Sci.* 2004;82:2460–2466.

13. Brumm MC, Miller PS, Thaler RC. Response of barrows to space allocation and ractopamine. *J Anim Sci.* 2004;82:3373–3379.

14. Ruiterkamp WA. A comparative study of the wellbeing of fattening pigs. *Tijdschr Diergeneeskd*. 1987;111:520–552.

15. Directorate General for 'Health and Consumers' of European Commission. Study on the socio-economic implications of different aspects of farming weaners and pigs kept for fattening. 2006. Available at: http://ec.europa.eu/food/animal/welfare/farm/farming_pigs_finalreport_en.pdf. Accessed 26 June 2008.

16. Ni JQ, Vinckier C, Coenegrachts J, Hendriks J. Effect of manure on ammonia emission from a fattening pig house with partly slatted floor. *Livest Prod Sci.* 1999;59:25–31.

17. National Research Council. *Nutrient Requirements of Swine*. 9th rev ed. Washington, DC: National Academy Press; 1988.

18. Council Directive 86/609/EEC of 24 November 1986 on the approximation of laws, regulations and administrative provisions of the Member States regarding the protection of animals used for experimental and other scientific purposes. Available at: http://ec.europa.eu/food/fs/aw/aw_legislation/scientific/86-609-eec_en.pdf. Accessed 26 June 2008.

19. Decreto legislativo n 116 of 27 Gennaio1992 (in Suppl. ordinario alla Gazz. Uff. No. 40, del 18 Febbraio). Attuazione della direttiva (CEE) n. 609/86 in materia di protezione degli animali utilizzati a fini sperimentali o ad altri fini scientifici. Istituto Poligrafico e Zecca dello Stato, Rome, Italy. Available at: http://www.antaonlus.org/leggi/DLGS116-92.doc. Accessed 26 June 2008.

20. Italian Scientific Association of Animal Production. Metodiche per la determinazione delle caratteristiche qualitative della carne. Perugia, Italy: Press agency of the University of Perugia; 1996:61–65.

21. Commission Internationale Du Genie Rural (CIGR). 2002. 4th Report of Working Group on Climatization of Animal Houses. Heat and moisture production at animal and house levels. Pedersen S, Sällvik K, eds. Horsens, Denmark. Available at: http://www.cigr.org/documents/CIGR_4TH_WORK_GR.pdf. Accessed 3 July 2008.

22. Massabie P, Granier R, Le Dividich J. Influence de la température ambiante sur les performances zootechniques du porc à l'engrais alimenté ad libitum. *Journées Recherche Porcine.* 1996;28:189–194.

*23. Aarnink AJA, Schrama JW, Verheijen RJE, Stefanowska J. Pen fouling in pig houses affected by temperature. *Livestock Environment VI. Proc 6th Int Symp*. Louisville, Kentucky. 2001;180–186.

24. Hacker RR, Ogilvie JR, Morrison WD, Kains F. Factors affecting excretory behavior of pigs. *J Anim Sci.* 1994;72:1455–1460.

25. Aarnink AJA, Swierstra D, Van den Berg AJ, Speelman L. Effect of type of slatted floor and degree of fouling of solid floor on ammonia emission rates from fattening piggeries. *J Agric Eng Res.* 1997;66:93–102.

26. Voermans JAM, Hendriks JGL. Report P4.9 of the Research Institute for Pig Husbandry. Pit or roof ventilation for growing finishing pigs [in Dutch; abstract in English]. 1995. Available at: http://library.wur.nl/file/wurpubs/pv/rapport/var/9.pdf. Accessed 5 September 2008.

27. Hoeksma P, Verdoes N, Oosthoek J, Voermans JAM. Reduction of ammonia volatilization from pig houses using aerated slurry as recirculation liquid. *Livest Prod Sci.* 1992;31:121–123.

28. Gonyou HW, Brumm MC, Bush E, Deen J, Edwards SA, Fangman T, McGlone JJ, Meunier-Salaun M, Morrison RB, Spoolder H, Sundberg PL, Johnson AK. Application of broken-line analysis to assess floor space requirements of nursery and grower-finisher pigs expressed on an allometric basis. *J Anim Sci.* 2006;4:229–235.

29. Courboulay V. Effect of increasing the floor space allowance on performance, skin lesions and behaviour of growing-finishing pigs. *Journées Recherche Porcine.* 2005;37:465–470.

30. Massabie P, Granier R. Comparaison de deux densités animales en porcherie d'engraissement pour une température ambiante de 20 ou 24°C. *Journées Recherche Porcine.* 2003;35:171–178.

31. Guingand N, Granier R. Comparaison caillebotis partiel et caillebotis integral en engraissement. Effets sur les performances zootechniques et sur l'émission d'ammoniac. *Journées Recherche Porcine.* 2001;33:31–36.

32. Courboulay V. Effect of floor type (slatted/partly slatted) and pen size on the welfare of growing/finishing pigs. *Journées Recherche Porcine.* 2003;35:163–170.

33. Hamilton DN, Ellis M, Wolter BF, Schinckel AP, Wilson ER. The growth performance of the progeny of two swine sire lines reared under different floor space allowances. *J Anim Sci.* 2003;81:1126–1135.

34. Corino C, Magni S, Pastorelli G, Rossi R, Mourot J. Effect of conjugated linoleic acid on meat quality, lipid metabolism, and sensory characteristics of dry-cured hams from heavy pigs. *J Anim Sci.* 2003;81:2219–2229.

35. Millet S, Moons CPH, Van Oeckel MJ, Janssens GPJ. Welfare, performance and meat quality of fattening pigs in alternative housing and management systems: a review. *J Sci Food Agric.* 2005;85:709–719.

36. Lewis PKJ, Rakes LY, Brown CJ, Noland PR. Effect of exercise and preslaughter stress on pork muscle characteristics. *Meat Sci*. 1989;26:121–129.

37. Mattiello S, Tosi MV, Heinzl E, Carenzi C. Il benessere del suino pesante: effetto della densità e del sistema di stabulazione. *Rivista di Suinicoltura*. 2003;10:157–161.

38. Guy JH, Rowlinson P, Chadwick JP, Ellis M. Behaviour of two genotypes of growing–finishing pig in three different housing systems. *Appl Anim Behav Sci.* 2002;75:193–206.

*39. Candotti P, Rota Nodari S, Archetti I, Pezzotti R, Caldara G, Lazzarini C, Borghetti P. Influence of floor type on the incidence of leg weakness and on the frequency and severity of articular osteochondrotic lesions in Italian heavy pigs [in Italian]. *Proc XXIXth Ann Meet Italian Soc Swine Pathol Breeding*. Salsomaggiore Terme, Italy. 2003:223–234. Available at: http://www.agricoltura.regione.lombardia.it/admin/rla_Documenti/1-2350/sipas_artic.doc. Accessed 28 July 2008.

40. Geverink NA, De Jong IC, Lambooij E, Blokhuis HJ, Wiegant VM. Influence of housing conditions on responses of pigs to preslaughter treatment and consequences for meat quality. *Can J Anim Sci.* 1999;79:285–291.

41. Pastorelli G, Musella M, Zaninelli M, Tangorra F, Corino C. Static spatial requirements of growing-finishing and heavy pigs. *Livest Sci.* 2006;105:260–264.

* Non-refereed references.