AEN-148

University of Kentucky
College of Agriculture,
Food and Environment
Cooperative Extension Service

Considerations in Goat Barn Design

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Introduction

Farmers who raise goats for meat or milk need guidance in the interrelated tasks of choosing a barn design and managing temperatures for their herd. Barn orientation, ventilation design, and stocking density are all important considerations which impact goats socially and physiologically, potentially impacting production. While other species are relatively well studied in these areas, research on goats is somewhat limited. The goal of this publication is to provide recommendations drawn from research in goats and sufficiently similar species.

Stocking Density and Internal Layout

Stocking density can be highly variable between operations, often driven by management styles, for example, if the goats spend time predominantly on pasture vs. in a barn. Many goat spacing studies were run to determine pasture spacing. Pasture studies are likely excessively conservative (providing high square footage per goat) when applied to barns, since stocking density in a pasture impacts not only lying space and social constraints, but also dry matter availability and the probability of ingesting parasite eggs. Sheep literature is also limited in its application to goats. More aggressive behavior has been observed in kids than lambs (Mui and Ledin, 2007), and goats spend less time lying in close proximity to each other (Andersen and Bøe, 2007). Overall, Lyons et al. (1993) described goats as more individualistic in nature, preferring larger separation distances to other animals.

Behavioral considerations

Actual suggestions for spacing are variable, and may be attributed to behavioral differences of individual animals within groups under study. Toussaint (1997) suggested 16.1 ft^2 per goat in open housing with an exercise yard available, a minimum of 5.4 ft^2 per goat in individual stalls, and 3.2 ft^2 per kid pre-weaning. Several subsequent studies have used this stocking density as a general starting point for evaluating other stall design parameters.

Loretz et al. (2004) investigated the impact of horns on space requirements and interactions of late gestation does of medium- to large-size dairy breeds, when adjusting available space from 10.8 to 21.5 ft^2 per goat. The presence of horns and availability of feeding places both had a significant effect on feed bunk spacing and time spent eating, but not aggressive interactions. Also, lying time was not significantly influenced by horns, but it was influenced by space availability. With only 10.8 ft^2 per goat available, low-ranking goats spent less lying time regardless of the presence or absence of horns in the group. Lying time ranged from 66.8% to 79.6% of observation time.

Andersen and Bøe (2007) experimented with resting area size and layout for a Norwegian milking breed, keeping total space constant at 16.1 ft^2 per goat. Resting area varied from 5.4 to 10.8 ft^2 per goat, with the remainder of the area as an "activity" space where boards were strategically placed to discourage lying. Resting area was either all on one level, or with access to an "upstairs" lying area. They found resting pattern to be more dependent on area size than layout, whereas the opposite was true for social interactions. That is, lying time increased with increased resting space regardless of whether that resting space was on one or two levels, but fewer aggressive interactions were observed when goats had access to a second level. Interestingly, they noted much of the variation could only be explained by individual goat differences; individual goat aggressive initiations varied from none to >50 in six hours. The average within each group was less than two aggressive interactions initiated by each goat over those six hours. They also noted that their lying time observations were only 75% of those from Loretz et al. (2004) with a 21.5 ft^2 per goat resting space, suggesting that the environment is still not optimal.

Building on the idea that stall organization impacts aggressive interactions, Ehrlenbruch et al. (2010) added interior walls to pens using several different spatial layouts at a similar total space (stocking density) to that used by Andersen and Bøe (2007) and with the same breed. While goat preference to rest against a wall was better met, the additional walls had no effect on total resting time or social interactions in comparison to the control group. However, they noted it is not clear if their results can be extrapolated to larger groups than the four goats per pen used in the study. In addition, increasing total space may also impact interactions, potentially producing different results.

Vas et al. (2013) evaluated cortisol levels and kid weights for bred Norwegian dairy does provided 10.8, 21.5, and 32.3 ft^2 per goat. They observed more agonistic behaviors at high densities, but no impact on productivity. This contrasts much of the dairy cattle research in which excessive stocking density can have a measurable impact on profitability (De Vries et al., 2016). However, if agonistic behavior is a welfare sign, the frequently suggested 10.8 to 16.1 ft^2 per goat is likely inadequate (Vas et al., 2013).

In the United States, the Humane Farm Animal Care (HFAC) standards must be met by farms wishing to become certified humane, allowing for more marketing opportunities. Thus, these standards seem logical to investigate. HFAC (2005) suggests a total available floor space of 1.5 times that of lying space required, and references the lying space requirements found by Ensminger (2002). The adult doe lying space requirement of 18.3 ft^2 results in a total space requirement of approximately 27.4 ft^2. Conceptually, this result is similar to those of the previously referenced studies.

Recommendations

In consideration of these findings, it seems that a minimum stocking density of 27.4 ft^2 would be appropriate, but perhaps more importantly, barn layouts for goats should place greater emphasis on minimizing aggressive interactions. This should first be attempted by keeping group size small and minimizing relocations (Tennessen, 1989). Aggressive interactions could also be reduced by implementing a series of barriers, strategically placed without providing "corners" in which low-ranking animals may be targeted and trapped (Figure 1). Simultaneously, consideration should be given to the material composition and height of these barriers so as not to be detrimental to airflow. Orienting barriers parallel to the primary airflow, keeping barrier height approximate to goat height, and choosing a design permeable to air ought to provide a suitable result.

Thermal Comfort

There is a need for more producer-oriented publications related to thermal comfort of goats in the United States. While some goat-specific scientific papers exist, they are not well known throughout the general goat community. Many articles in the primary producer-targeted goat publications are recirculated old material, and the total volume of goat material in comparison to those developed for cows is notably small. Frequently, producers cite the lack of goat research in the United States as a limitation to the advancement of management practices. While this is true, much research from other species and geographical regions is applicable, given due regard to key physiological and environmental differences, respectively.

Using studies focused on goat thermal comfort in combination with existing dairy cattle studies, theoretical calculations could be useful in determining further steps under different conditions. Heat balance models (McGovern and Bruce, 2000; Turnpenny et al., 2000) may be applicable by altering the cattle components to better match those of goats. Nutrient requirements for the different groups and production stages have been widely studied and are readily available (Lachica and Aguilera, 2003; Sahlu et al., 2004)2003; Sahlu et al., 2004; feed efficiency for each energy use as found in Cannas et al. (2008) can be used to calculate the metabolic heat production based on age and production.

Table 1. Space requirements per goat

Type	Weight (kg)	Weight (lb)	Lying Space (m2)	Lying Space (ft2)	Total Space (m2)	Total Space (ft2)
Adult does	≤ 105	< 231	1.7	18.3	2.6	27.4
Kids under 5 months	4 – 34	9 – 75	0.7 – 0.9	7.5 – 9.7	1.1 – 1.4	11.3 – 14.5
Bucks	75 – 120	165 – 265	2.8 – 3.7	30.1 – 39.8	4.2 – 5.6	45.2 – 59.7

Source: Ensminger, 2002.

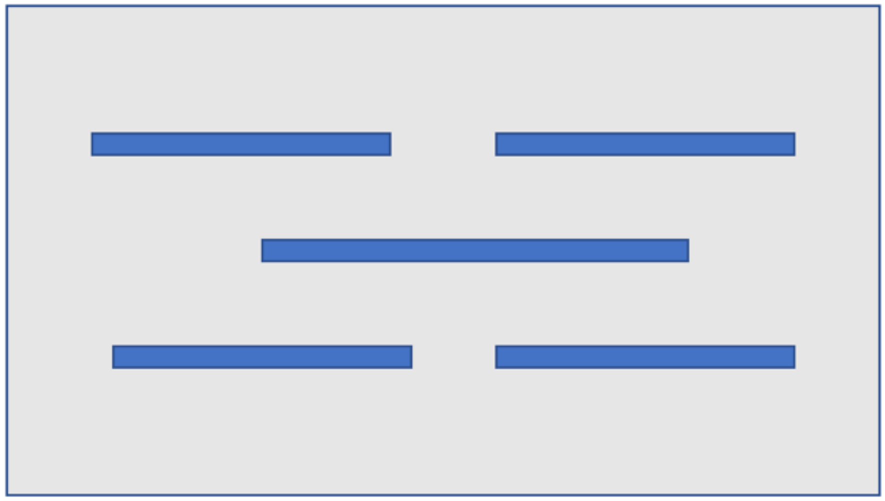

Figure 1. Example of barrier design to reduce line of sight and aggressive interactions without creating corners.

Cold stress

Goats tend to be more susceptible to cold stress compared to larger ruminants like cattle. This is partially due to greater surface area to body mass and their better feed efficiency compared to cattle. Wind speed and wet coats are particularly challenging for maintaining thermal comfort. In addition, kids have more susceptibility to cold stress compared to adult goats (Mellado et al., 2000). Cold stress reduced both milk production and water intake at both mild and moderate cold stress levels (Thompson and Thompson, 1977).

Moreover, managing cold stress is important in disease prevention. Extreme cold temperatures and poor ventilation can disrupt respiratory defense mechanisms, increasing the ability of pathogens to cause disease (Brogden et al., 1998). Pneumonia in livestock is generally multifaceted; infection with one organism increases susceptibility to others. Thus, working with the immune system by reducing stress and providing a good environment with appropriate ventilation are important aspects of reducing the "snowball" effect that results in respiratory disease. Barns provide an opportunity to reduce air speeds across the goats and keep them dry.

Heat stress

Heat stress is prevalent in most livestock species including goats. Metabolic heat results from the inefficiencies of using feed for physiological processes such as lactation, gestation, growth, and maintenance; as more feed is consumed, more heat must be dissipated. It follows that groups with different metabolic requirements also have different heat dissipation needs. Livestock dissipate heat via conduction from the core to the skin through blood circulation, convection from the skin, and evaporative cooling via the skin and respiratory system (McGovern and Bruce, 2000). In a shaded environment, evaporative and convective heat transfer are the primary pathways of interest for managing heat stress (Maia et al., 2005).

Heat stress is often undermanaged, with some farmers not realizing that a comfortable temperature for humans may not be a comfortable temperature for their animals. Observing goats' physiological responses, like panting, or changes in eating and drinking behaviors can help in identifying heat stress. More details about heat stress are included in *Heat Stress in Goats* (AEN-149).

Recommendations

Many studies have utilized a temperature humidity index (THI) and regressions of physiological responses to determine different thresholds for several levels of heat or cold stress. The combination of humidity level and temperature provides a better idea of how an animal responds to its environment than temperature alone. Ideally, thermal environment management would be adequate to prevent reaching these thermal stress levels; however, that is not always possible. Based on the studies described in *Heat Stress in Goats* (AEN-149), Table 2 with a range of temperatures and relative humidity has been developed for identifying combinations that are considered potentially a concern for heat or cold stress. Table 2 is based upon the THI equation developed by (Salama et al., 2014) and used specifically for goats.

Tdb °C	Tdb °F	Relative Humidity 10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
5	41	49.8	49.3	48.8	48.3	47.9	47.4	46.9	46.4	45.9	45.4	44.9	44.4	43.9	43.4	43.0	42.5	42.0	41.5
6	43	50.7	50.3	49.8	49.4	49.0	48.5	48.1	47.6	47.2	46.8	46.3	45.9	45.4	45.0	44.6	44.1	43.7	43.2
7	45	51.6	51.2	50.8	50.5	50.1	49.7	49.3	48.9	48.5	48.1	47.7	47.3	46.9	46.6	46.2	45.8	45.4	45.0
8	46	52.5	52.2	51.9	51.5	51.2	50.8	50.5	50.2	49.8	49.5	49.1	48.8	48.4	48.1	47.8	47.4	47.1	46.7
9	48	53.4	53.2	52.9	52.6	52.3	52.0	51.7	51.4	51.1	50.8	50.5	50.2	49.9	49.7	49.4	49.1	48.8	48.5
10	50	54.4	54.1	53.9	53.6	53.4	53.1	52.9	52.7	52.4	52.2	51.9	51.7	51.5	51.2	51.0	50.7	50.5	50.2
11	52	55.3	55.1	54.9	54.7	54.5	54.3	54.1	53.9	53.7	53.5	53.3	53.1	53.0	52.8	52.6	52.4	52.2	52.0
12	54	56.2	56.0	55.9	55.7	55.6	55.5	55.3	55.2	55.0	54.9	54.7	54.6	54.5	54.3	54.2	54.0	53.9	53.7
13	55	57.1	57.0	56.9	56.8	56.7	56.6	56.5	56.4	56.3	56.2	56.1	56.1	56.0	55.9	55.8	55.7	55.6	55.5
14	57	58.0	57.9	57.9	57.9	57.8	57.8	57.7	57.7	57.6	57.6	57.6	57.5	57.5	57.4	57.4	57.3	57.3	57.2
15	59	58.9	58.9	58.9	58.9	58.9	58.9	58.9	58.9	58.9	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0
16	61	59.8	59.9	59.9	60.0	60.0	60.1	60.1	60.2	60.3	60.3	60.4	60.4	60.5	60.5	60.6	60.6	60.7	60.7
17	63	60.7	60.8	60.9	61.0	61.1	61.2	61.3	61.5	61.6	61.7	61.8	61.9	62.0	62.1	62.2	62.3	62.4	62.5
18	64	61.6	61.8	61.9	62.1	62.2	62.4	62.6	62.7	62.9	63.0	63.2	63.3	63.5	63.6	63.8	63.9	64.1	64.2
19	66	62.5	62.7	62.9	63.1	63.4	63.6	63.8	64.0	64.2	64.4	64.6	64.8	65.0	65.2	65.4	65.6	65.8	66.0
20	68	63.4	63.7	64.0	64.2	64.5	64.7	65.0	65.2	65.5	65.7	66.0	66.2	66.5	66.7	67.0	67.2	67.5	67.7
21	70	64.4	64.7	65.0	65.3	65.6	65.9	66.2	66.5	66.8	67.1	67.4	67.7	68.0	68.3	68.6	68.9	69.2	69.5
22	72	65.3	65.6	66.0	66.3	66.7	67.0	67.4	67.7	68.1	68.4	68.8	69.1	69.5	69.8	70.2	70.5	70.9	71.2
23	73	66.2	66.6	67.0	67.4	67.8	68.2	68.6	69.0	69.4	69.8	70.2	70.6	71.0	71.4	71.8	72.2	72.6	73.0
24	75	67.1	67.5	68.0	68.4	68.9	69.3	69.8	70.2	70.7	71.1	71.6	72.0	72.5	72.9	73.4	73.8	74.3	74.7
25	77	68.0	68.5	69.0	69.5	70.0	70.5	71.0	71.5	72.0	72.5	73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5
26	79	68.9	69.5	70.0	70.6	71.1	71.7	72.2	72.8	73.3	73.9	74.4	75.0	75.5	76.1	76.6	77.2	77.7	78.3
27	81	69.8	70.4	71.0	71.6	72.2	72.8	73.4	74.0	74.6	75.2	75.8	76.4	77.0	77.6	78.2	78.8	79.4	80.0
28	82	70.7	71.4	72.0	72.7	73.3	74.0	74.6	75.3	75.9	76.6	77.2	77.9	78.5	79.2	79.8	80.5	81.1	81.8
29	84	71.6	72.3	73.0	73.7	74.4	75.1	75.8	76.5	77.2	77.9	78.6	79.3	80.0	80.7	81.4	82.1	82.8	83.5
30	86	72.5	73.3	74.0	74.8	75.5	76.3	77.0	77.8	78.5	79.3	80.0	80.8	81.5	82.3	83.0	83.8	84.5	85.3

Table 2. THI for goats based on dry bulb temperature (temperature measured by a thermometer) and relative humidity. Blue indicates potential cold stress, red indicates potential heat stress, green indicates preferred temperature, humidity combinations.

Better thermal management could include adding a number of additional systems to a barn. Adding propane or natural gas fired heaters would provide additional heat in barns during winter months without reducing ventilation to the point where respiratory diseases thrive. Adding fans and/or sprinkle cooling systems would provide additional cooling capacity during the heat of summer. All of these systems require additional infrastructure and management, but they provide better control of barn temperatures.

Ventilation

Ventilation is important for the removal of heat, moisture, and detrimental gases such as ammonia. The variable we wish to control may change with environmental conditions; typically, in summer conditions, heat removal is the top priority, but in winter it may be moisture or ammonia. The goal is to maintain an environment close to physiological optimum, however that is not always financially possible. Thus, it will be necessary to determine a maximum practical ventilation rate and size heaters if minimum ventilation in winter conditions is expected to significantly reduce barn temperature below acceptable conditions

There are two basic ventilation categories: mechanical and natural. Mechanical ventilation utilizes fans in conjunction with specific inlets and outlets to mix and deliver air appropriately. Natural ventilation uses thermal buoyancy and wind, resulting in larger ventilation rates than can easily be obtained through mechanical ventilation. Air enters the barn through inlets (either by design or by default), exiting through outlets. Direction of airflow (and whether inlets become outlets) is dependent on pressure differences throughout the barn. Airflow can also be controlled by adjusting openings, such as curtains and louvered vents. In a mechanically ventilated barn, adjusting fan speed allows control of air flow rate, especially important in cold weather when a balance between moisture loss and heat retention must be obtained.

Inlet placement is vital to air mixing (Albright, 1990). When there are obstructions like trusses just inside the inlet or when inlets are too large, which makes airflow move too slowly through the inlet, the momentum of the air entering the barn is affected, potentially resulting in a failure to adequately mix. When barns have pockets of stale air or cold drafts across animals it is usually an indicator that inlets are improperly designed. A properly designed ventilation system can move enough air without exceeding the maximum air velocity for animal comfort at any location.

Zhang et al. (2001) noted that in a survey of livestock buildings less than 15 years old, ventilation rates ranged from half to three times the recommended ventilation rates of two to eight air changes per hour (ACH). Random air movement due to leaks through the walls can significantly reduce ventilation effectiveness, possibly resulting in failure to control the indoor environment. Thus, it is vital for producers to work with engineers in facility design. Moving forward, computational fluid dynamics (CFD) software may be useful as a way of enabling better visualization of heat and ventilation for producers.

Managing the Goat Barn

Goats are particularly sensitive to rapid changes in weather, especially with large temperature swings. Finding the balance between maintaining stable temperatures and keeping barn air clean is a challenge, especially in the spring and fall seasons when goats may not yet be adjusted to the extreme temperatures. Adjustable sidewall openings (like curtains or roll up doors) can be used to both reduce ventilation rates on cold nights and allow maximum ventilation on hot days. Additional considerations include the use of heaters and appropriate bedding. With an adequately insulated barn, heaters may only be needed for a few weeks out of the year; heaters can be sized according to the controlling winter ventilation rate. Bedding can be variable by region, but generally pine shavings are adequate for summer conditions; dry straw is often a better option for winter conditions as it insulates the animals and provides nesting opportunities. A common bedding method in winter involves a layer of shavings under a straw bed, providing greater absorption than straw alone and more insulation than just wood shavings.

Conclusion

While the research on goats is limited compared to most other species in the United States, there is an abundance of relevant information which can be applied from other species. In cases where enough data exists to construct a model, such models may prove useful for producers to estimate design requirements to better manage their herd.

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Issued 3-2020