Field survey to evaluate space allowances for dairy cows in Great Britain

J. S. Thompson,¹ J. N. Huxley,² C. D. Hudson,¹ J. Kaler,¹ J. Gibbons,³ and M. J. Green^{1*}

¹School of Veterinary Medicine and Science, University of Nottingham, Sutton Bonington Campus, Leicestershire, LE12 5RD, United Kingdom

²School of Veterinary Science, Massey University, Palmerston North, 4474, New Zealand

³Agriculture and Horticulture Development Board (AHDB), Stoneleigh, Kenilworth, CV8 2TL, United Kingdom

ABSTRACT

Housing conditions can affect health of cows by increasing exposure to biological, chemical, and physical hazards, resulting in increased disease. A report in 2014 indicated that 99% of UK dairy cows are housed during winter months and that an increasing number of farms are committing to year-round indoor-housing management systems. Current literature does not provide a clear understanding of the relationship between cow health, welfare, and production, and the housing environment. Loafing space, in this case defined as non-feed, non-lying, and non-high traffic areas of the housed environment, is considered an important component of housing for dairy cows; however, the scientific literature associated with this subject is sparse internationally. The aim of this research was to explore current housing of dairy cows across Great Britain, with specific focus on understanding the practices and variability associated with space allowance. A secondary aim was to explore farmer opinions and knowledge on the value of living space. A single researcher visited 53 randomly selected farms, from a representative sample group, once during the winter housing period 2017–18. Data collection consisted of 3 elements: collation of basic farm details, precise measurement of adult dairy cow accommodation, and a questionnaire to capture farmer opinions on space allowances. Statistical analysis was undertaken to assess variation among farms in total space, loafing space, and living space per cow. A new metric, termed “living space,” was defined to describe the additional space availability for dairy cows above that deemed to be a baseline requirement. Large variability was identified between farms in total space available per cow, with a range from 5.4 to 12.7 m² [mean = 8.3 m², median = 8.2 m², interquartile range (IQR) = 1.9 m²]. The mean living space was 2.5 m², with a range of 0.5 m² to 6.4 m² (median = 2.4 m², IQR = 1.6 to 3.2 m²). Responses from a farmer questionnaire on importance

of loafing space revealed that farmers felt it was essential for cow welfare, over half of farmers scoring this ≥ 8 on a 0 to 10 scale. Farmers were categorized into 4 latent classes based on their attitudes toward the importance of loafing space. In a linear model to predict the “living space” provided on each farm, geographical location and latent class of farmer attitude were covariates significantly associated with the amount of space provided. This study is the first worldwide to quantify variability in loafing and living spaces for dairy herds; further research is required to evaluate the extent to which variation in quantity and quality of space influences cow health, welfare, and productivity, as well as farm economics and emissions.

Key words: dairy cow, housing, health and welfare, loafing space, living space

INTRODUCTION

The human literature reports important links between the physical and mental health of people and their built environment (Gan et al., 2017); the housing in which people spend the majority of their time has been shown to be particularly important for human health (Hancock, 2002). Housing conditions can affect the health of inhabitants by increasing exposure to biological, chemical, and physical hazards, resulting in increased disease (Bonnefoy, 2007; Jacobs, 2011). Populations of humans with the worst-quality built environments (measured by assessing access to amenities, air quality, and building design or layout) are known to be associated with greater incidence of disease (Hood, 2005), especially respiratory disease, which has been highlighted as a key outcome measurement of housing quality (Krieger and Higgins, 2002). Inadequate space allowance in human housing is considered the most important factor when assessing housing poverty (Blake et al., 2007; WHO, 2016), with overcrowding increasing the likelihood of disease transmission (WHO, 2016).

The housed environment is also of great importance to the dairy industry worldwide. A consensus panel (comprising the National Agricultural Statistics Service and the Animal and Plant Health Inspection Service)

Received May 22, 2019.

Accepted November 15, 2019.

*Corresponding author: martin.green@nottingham.ac.uk

in the United States in 2013 reported that more than 80% of dairy cattle in lactation are housed permanently indoors (USDA, 2016), and North American systems are continuing to move toward indoor housing systems rather than extensive outdoor environments (Barkema et al., 2015). A report in 2014 indicated that 99% of UK dairy cows are housed during winter months and that an increasing number of farmers are committing to year-round indoor-housed management systems (March et al., 2014). Notably, this trend toward increased year-round housing of cows is occurring despite recognition that grazing is perceived to be important by consumers (Ventura et al., 2016). Farmers who continuously house cows are reported to have larger average herd sizes (March et al., 2014), suggesting a move toward intensification of the sector and increased output per farm. It is recognized that the housed environment needs to be suitable to guarantee a sustainable, welfare-friendly industry (Place and Mitloehner, 2014), and the requirement for interdisciplinary research to investigate the relationship between animal welfare and the environment has been highlighted (Place and Mitloehner, 2014).

Since the 1960s, housing of lactating dairy cows in freestalls has become the most commonly used system in dairy nations worldwide (Bewley et al., 2017). Two recent reviews of the housed environment of adult dairy cows demonstrate the lack of research on loafing space allowances for cows in freestall accommodation and a lack of knowledge on its influence on cow health, welfare, and productivity (Bewley et al., 2017; Smith and Cook, 2019). It has also been suggested that overcrowding could be a stressor to cows with an effect on behavior (Templeton et al., 2014). Research on space allowances for adult cows has mainly focused on proxies such as stocking density (the number of cows per freestall; Hill et al., 2009; Krawczel et al., 2012; Wang et al., 2016; Witaifi et al., 2018; Krawczel and Lee, 2019), feed face measurements (DeVries et al., 2004; Crossley et al., 2017), and stall size (Bickert, 2000), but these do not necessarily reflect the space available for cows to live in, such as areas for lying, standing, eating, and drinking, as well as space to move between these areas. Surprisingly, loafing space allowances have remained relatively unstudied.

Current recommendations for cow housing space allowance in the UK are widely varied, also suggesting a poor scientific basis. A minimum guideline of 6.5 m² per cow (total area that cows can access, including bedded areas) is reported in UK British Standard laws, BS5502 (British Standards, 1990) and in the UK national “Red Tractor” farm assurance standards (Red Tractor, 2014). Other industry stakeholders such as AHDB (Agriculture and Horticulture Development Board, the UK dairy farmer Levy board) and RSPCA (Royal Society

for the Prevention of Cruelty to Animals) have published recommendations that exceed these minimum guidelines, at 10.5 m² and 10 m², respectively (AHDB, 2018; RSPCA, 2018). In the United States the most recent recommendation of space per cow was edited to 7.4 m² in the 1980s, based mainly on shed design rather than cow health and welfare (Bickert and Light, 1982). More recent recommendations are sporadic but do appear in Federation of Animal Science Societies (FASS) in the United States and SPCA Certified standards in Canada, both recommending 11 m² per cow (FASS, 2010; BCSPCA, 2018). The Canadian Code of Practice does not set a minimum figure for total space allowance in freestall accommodation, instead using a stocking density minimum of 1.2 cows per stall (NFACC, 2009).

Loafing space (in this case defined as non-feed, non-lying, and non-high traffic areas of the housed environment) is considered an important component of housing for dairy cows; however, the scientific literature associated with this subject is sparse (Haskell et al., 2013). Although it is likely that the size and type of space in which cows live will affect their health and wellbeing, virtually no data are available on the amount of, and variability in, space allowances in commercial dairy herds globally. The aim of this research was to explore current housing of dairy cows across a random sample of farms in Great Britain, with a specific focus to provide underpinning evidence on the quantity and variability of space provision for dairy cattle, including areas for eating, lying, and passageways. A secondary aim was to explore farmer opinions and knowledge on the value of living space for dairy cows.

MATERIALS AND METHODS

Study Design

An observational, cross-sectional study was conducted to evaluate the variability in living space allowances for dairy cows in Great Britain and is reported in alignment with STROBE guidelines (von Elm et al., 2008; STROBE, 2019). Informed consent was obtained from all participants after they were provided with details about the study purpose and data capture. Ethical approval was obtained from the departmental Ethical Review Panel of the University of Nottingham, School of Veterinary Medicine and Science, before study commencement.

Farm Selection

A large British food retailer provided a list of their supplying dairy farms ($n = 739$; ~12% of all GB dairy farms), which comprised the target population for this

study. This pool of farms was originally selected by the retailer in 2007 based on milk tanker routes, meaning that no selection criteria based on farm characteristics were used, so the population was considered representative of dairy farms in Great Britain. Sample farms were selected at random from this group using random number generation in Microsoft Excel (Microsoft, 2016), and the researcher (JT) was blind to farm details during selection. Farmers were invited to participate in the study by letter and email, and participating farmers were telephoned to organize a date for visitation. Sample size calculations indicated that a sample of 50 farms would provide an estimate of the population mean total space allowance per cow, to be estimated with a 95% confidence interval (CI) of $\pm 0.5 \text{ m}^2$, and the population standard deviation (SD), also to be estimated with a 95% CI of $\pm 0.5 \text{ m}^2$. Initially, 100 farms were randomly selected and ordered using random number generation; farms were contacted and invited to participate in the order defined. An initial group of 50 farms was contacted for recruitment. A further 20 farms were selected for contact 2 weeks later based on the response rate of the initial group, to ensure a sample size greater than 50. Overall, of the 70 farms approached, 53 agreed to participate (75.7% response rate).

Data Collection

A single researcher (JT) visited all 53 farms once between Nov. 9, 2017, and Jan. 19, 2018, for approximately 3 h per farm; the data collection window occurred during the winter housing period for all farms. Data collection consisted of 3 elements: the collation of basic farm details, the precise measurement of all adult dairy cow accommodation, and a questionnaire to capture farmer opinions on space allowances for cows, as follows.

Farm Characteristics

Farmers provided detail about the management of the farm, including breed of cows, calving pattern, and number of adult dairy stock. Details on the management of cows during the housed period were obtained, including how cows were grouped and duration and timing of groupings. Milk sold per cow per year and the most recently recorded bulk milk SCC were also obtained.

Housing Area Dimensions

Measurements of all accommodation used for adult dairy cows in lactation were taken using a Leica Disto D510 laser measuring device (Heerbrugg, Switzerland;

range 200 m, tolerance $\pm 0.10 \text{ mm}/10 \text{ m}$ between 10 and 30 m). Measurements were recorded on a standardized data capture form for each building or group of animals. Dimensions recorded comprised all areas available to cows: feed passageways, stall passageways, crossover passageways with and without water areas, collecting yards (if accessible to cows in addition to the time waiting for parlor entry), bedded areas, loafing areas, and any other living areas available to the lactating herd.

Loafing Space Opinion

An 11-question, face-to-face interview was conducted with the main herdsman or farm owner. Closed questions were styled to gain understanding of farmer views about loafing space and housing conditions for dairy cows. Farmers were asked to rank the overall importance of loafing space, as well as importance in terms of production, health, and welfare, on a scale from 0 to 10. Farmers were asked to indicate their preferred option for floor surface in loafing space areas. Farmers also ranked the importance of outdoor access for housed dairy cows. Finally, farmers were asked how much total space and loafing area space they believed housed dairy cows require, as a minimum and as an optimum.

Study Definitions

Total Area. This incorporated all floor and bedded areas that a group of dairy cows had access to while housed. This included cow access areas only, such as stall bedding area, all passageways, and indoor and outdoor loafing spaces, excluding areas in a building that did not permit cow entry, such as feed alleys for tractor use only.

Passageways. Areas used by cows to move through the accommodation; these comprised stall passageways, feed passageways, and crossover passageways.

Loafing Space. Non-bedded, non-passageway areas where cows can roam freely, including indoor or outdoor areas. Examples include (a) parlor collecting yards that are open and available to cows for a minimum of 4 h/d, excluding the time before milking, and (b) indoor or outdoor concrete, sand, straw, or woodchip pad or pasture areas, not used for bedding and that do not act as access areas between the stalls and feed-face.

Living Space. A novel bespoke definition of the space within the dairy cow accommodation that was greater than that considered a baseline requirement for movement and feeding within the overall accommodation area, excluding lying areas. The calculation of this definition was based on bespoke parameters for this study and was estimated as follows:

Total feed passageway area over and above a baseline allocation of 2.4 m² per cow + Total stall passageway area over and above a baseline allocation of 1.32 m² per stall + Total loafing space area (defined above),

for which the 2.4-m² feed passageway was deemed to be a minimal baseline space required for a cow to move into and stand at the feed-face, and the 1.32-m² stall passageway was defined in this study to be a minimal baseline passageway requirement for a cow to move in and out of a freestall (calculated using an estimated stall width of 1.10 m × half a minimum width deemed necessary for a stall passageway of 1.20 m).

These calculations mean that a minimum stall passageway width is taken to be 2.4 m (to allow simultaneous exit from opposing stalls), and the minimum feed passageway, which includes access to stalls, is 3.6 m wide (to allow for simultaneous entry to or exit from to a stall while another cow is feeding).

Maximum Pen Stocking Density. This was defined as a farmer-stated figure for the maximum number of cows that would ever be accommodated in a defined area of the farm.

Statistical Analysis

Data analysis was carried out using the R statistical package, version R-3.5.2 (R Core Team, 2018). Data were restructured to consist of farm averages for milking cows in stalls across all cow groups housed in stalls on farm. Three farms were omitted from analysis because all milking cows were housed exclusively in straw yards. Descriptive analysis was undertaken to visualize data, and linear models were used to explore the relationships between farm building features and farmer opinions with living space measurements.

Descriptive Analysis. Variability between herds was evaluated using summary statistics to evaluate distributional characteristics. Histograms, scatterplots, and box-and-whisker plots were used to visualize the data. Conventional bootstrapping (Kuhn and Johnson, 2016) of the building measurement data was carried out to estimate the 95% CI of the mean, median, and interquartile ranges (IQR).

Model 1: Estimation of Living Space from Housing Features

The aim of model 1 was to evaluate the associations between the area defined as “living space” and other

measurements of the housed environment. The purpose was to evaluate whether total area per cow and total stall area per cow (total base area: bedded area + lunge area) would provide a good estimate of total living space.

The linear regression model took the following form:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i,$$

where subscript *i* denoted the *i*th farm, Y_i was the living space area per cow for farm *i*, β_0 was the intercept, x_{1i} was the total building space allowance area per cow for the *i*th farm, β_1 was the coefficient for x_{1i} , x_{2i} was the stall area per cow (total base area: bedded area + lunge area) for the *i*th farm, β_2 was the coefficient for x_{2i} , and ε was the residual error, assumed to have a mean of 0 and variance σ^2 .

To explore the potential for generalizability of this model to new data, a leave-one-out cross-validation (LOOCV; Kuhn and Johnson, 2016) was performed. Model predictions were assessed using R^2 and mean absolute error (MAE). Fit was also assessed using conventional residual analysis and Cook's distance (Petrie and Watson, 2006).

A latent class analysis of farmer opinions on loafing space was conducted using the Mclust package (Scrucca et al., 2016) in R, to explore whether farmers tended to be grouped within the data in terms of their views. Data from all 53 farmers surveyed were used for analysis. The following 5 themes were used to evaluate farmer opinions: (1) importance of loafing space in general for housed dairy cows, (2) importance of loafing space for productivity, (3) importance of loafing space for health, (4) importance of loafing space for welfare, and (5) importance of outdoor areas for housed dairy cows. All 5 questions were presented to participants on an 11-point scale (0 = completely unimportant to 10 = critically important). The unsupervised latent class analysis was conducted using model-based clustering. The method comprised 3 elements: (1) initialization using model-based hierarchical agglomerative, (2) use of an expectation-maximization algorithm for likelihood, and (3) cluster selection using Bayesian information criterion approximation (Fraley and Raftery, 2002). Using this technique, first the number of clusters within the data was identified, and, second, the posterior probability of each farmer being in each latent class was estimated. Farmers were allocated to a cluster based on the maximum posterior probability; the Bayesian information criterion was used to identify the best model and hence the optimum number of latent classes (Fraley and Raftery, 2002).

Model 2: Factors Associated with Availability of Living Space

A second generalized linear model (Marschner, 2018) was built using living space at maximum stocking density for cows in milk as the outcome variable. The aim was to explore which farm- and farmer-related variables were associated with availability of living space. Predictor variables tested were milk sold per cow per year, age of building, maximum number of milking cows on farm, duration of housing period, cow breed, calving pattern, farm region, and latent class of farmer opinion. A forward stepwise procedure was undertaken with each variable tested and retained in model when $P \leq 0.05$. One farm was omitted from this model due to missing data for one of the covariates. The model took the following form:

$$Y_i = \beta_0 + \beta_n x_n + \varepsilon_i,$$

where subscript i denoted the i th farm, Y_i was the living space area per cow for farm i , β_0 was the intercept value, x_n were model covariates for i th farm, β_n were the coefficients for x_n , and ε was the residual error, assumed to have a mean of 0 and variance σ^2 .

Model predictions were assessed using R^2 and MAE. Model fit was evaluated using conventional residual analysis and Cook's distance, and LOOCV was performed to assess potential for generalizability of the model.

RESULTS

Farm Characteristics

Fifty-three farms participated in the study, giving a response rate of 75.7%. Three farms were removed from the data for assessment of space allowances because they did not house cows in freestalls during lactation. Consequently the minimum target sample size, which was prospectively estimated by power analysis before commencing the study, was fulfilled. The 50 farms were spread across Great Britain as shown in Figure 1, with the majority of farms within the South-West (18) or Midlands (19) areas. The main breed identified on each farm were Holsteins (18) or Holstein-Friesian types (27), with the remaining 5 consisting of crossbreeds or a mix of breeds without a majority. Twenty-eight farms contained between 201 and 400 adult dairy stock; 4, 10, and 8 farms had <100, 101 to 200, and >400, respectively (minimum = 60, maximum = 901, mean = 288, median = 265). Most farms stocked all of their cows in lactation in freestall buildings (26), with 2 farms housing <75% of their milking cows in freestalls (in

these herds, cows were divided between freestall and straw yard accommodation). For herds with a proportion of cows in non-freestall accommodation, calculations were based solely on measurements of, and cow numbers in, the freestall accommodation only. Calving patterns were split into 3 groups, block calving, double-block calving, and year-round, with 9, 2, and 39 farms respectively. Nineteen farms housed the milking herd year-round, with 23 farms housing cows for 6 mo or less in an average year. The highest-yielding herd sold 12,650 L per cow per year, the lowest 5,850 L, with a mean of 8,979 L and median of 9,150 L (the national UK mean annual milk yield in 2017 was 7,893 L, according to AHDB, 2019). Ten of the herds produced over 10,000 L per cow per year.

Housing Areas

Total area per cow showed large variability between farms, with a minimum of 5.4 m² and maximum of 12.7 m², mean = 8.3 m² (95% CI = 7.90 to 8.80), median = 8.2 m² (95% CI = 7.8 to 8.8), SD = 1.64 m² (95% CI = 1.26 to 1.96), and IQR 1.85 m² (95% CI = 1.25 to 2.70).

Specific loafing space per cow across the farms also varied, with a minimum observed of 0 m² and a maximum of 5.4 m². The mean loafing space was 1.1 m² (95% CI = 0.76 to 1.54), median 0.5 m² (95% CI = 0.0 to 1.3), SD = 1.44 m² (95% CI = 1.06 to 1.77), and IQR 1.9 m² (95% CI = 1.2 to 2.65). Approximately one-third of farms were above a specific UK recommended target of 3 m² for loafing space (Red Tractor, 2014).

The mean living space across the 50 farms was 2.5 m² per cow at maximum stocking density (95% CI = 2.15 to 2.92), with a minimum of 0.5 m² and maximum of 6.4 m². The median was 2.4 m² (95% CI = 1.95 to 2.75), SD = 1.40 m² (95% CI = 1.07 to 1.68), and IQR 1.6 m² (95% CI = 1.08 to 2.30). The association between total space available per cow and living space per cow at maximum stocking is illustrated in Figure 2.

The variability in living space between geographical regions is illustrated in Figure 3; 7 out of 10 farms with the most living space area per cow were in the South West of England. All farms in the north of England and Scotland were in the bottom 50% of study farms for amount of living space area per cow.

Farmer Opinion Questionnaire: Descriptive Results

Results of the farmer opinion questionnaire are summarized in Figure 4. In general, answers to the 5 11-point questions were relatively high, indicating that farmers valued loafing space and outdoor access as relatively important for housed dairy cows. The impor-

Figure 1. Geographical location of 53 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain (Google Maps, 2019).

tance of loafing space for cow welfare received the highest score, with a median of 8 and IQR of 8 to 10. The importance of outdoor access for housed dairy cows had most variation in scores (minimum = 0, maximum = 10, IQR = 5 to 8).

Questions about the definitions of space yielded substantial disagreement between respondents: 22 of 53 farmers (42%) stated that they thought all passages (stall, feed, and crossover passages) were defined

as loafing space, whereas 16 farmers stated that none of these comprised loafing space.

Twenty-one farmers (40%) identified grooved concrete as the best surface for a loafing space, 16 (30%) farmers stated this should be rubber matting, and the remaining farmers selected either pasture, sand, slatted rubber matting, straw, or woodchip pads.

Seventeen (50%) of the farmers responded that housed dairy cows should have greater than 2 m² as a

minimum loafing space [min = 0.00 m²; median = 2.00 m²; mean = 2.65 m²; max = 8.00 m²; IQR 1.40 to 4.00 m²; NA (farmer declined to state an answer for this question) = 20] but thought that ideally cows would be given more loafing space, with a median of 5.00 m² stated as the ideal situation (Figure 5; min = 0.57 m²; mean = 5.04 m²; max = 12.00 m²; IQR 2.95 to 6.13 m²; NA = 21).

Model 1: Estimation of Living Space from Housing Features

The final model to predict living space from total area per cow and stall bedded area per cow, both at maximum stocking was the following:

$$\text{Living Space at Maximum Stocking} = 0.83T - 1.28C - 0.79,$$

where T was the total area per cow at maximum stocking and C was the stall bedded area per cow at maximum stocking.

This model has an MAE of 0.39 m and an R^2 of 0.87. Results of the LOOCV are illustrated in Figure 6. The LOOCV model produced an MAE of 0.42 m and an R^2 of 0.85.

The 52 farms were categorized into 4 latent classes, as illustrated in Figure 7. The classes contained 22, 6, 13, and 11 farms, respectively. Latent class 2 contained farmers who gave the lowest scores for the importance of loafing space and outdoor access; conversely, latent class 4 farmers gave the highest score for all 5 questions. Farmers in latent class 1 gave intermediate scores for loafing space importance but rated loafing space more highly than did latent class 3 farmers, who rated outdoor access more highly than did latent class 1 farmers.

Model 2: Factors Associated with Availability of Living Space

Results of model 2 are presented in Table 1. Region and farmer latent class were significant variables, with farms in the South West, Wales, and the South East being associated with greater amounts of living space per cow than farms in Northern England and Scotland.

Figure 2. Scatterplot (with associated histograms) of total housing area per cow (m²) associated with freestall accommodation against living space area per cow at maximum stocking in 50 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain. The surrounding histograms show the number of farms in each 1-m² block of space for both measurements used in the scatterplot.

Figure 3. Living space available per cow per farm, arranged in ascending order, and how space varied by geographical region, across 50 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain.

Farmer opinion latent class 3 (higher outdoor access importance answers but lower loafing space importance answers) had farms with more living space per cow than did farmer latent class 1 (higher loafing space importance answers with lower outdoor access importance answers; $P < 0.05$). The mean absolute error for the model was 0.78 m, and $R^2 = 0.39$. Post-fit analyses indicated that model fit was good.

DISCUSSION AND CONCLUSIONS

Evidence for the effects of living space allowance on health and well-being of housed dairy cows appears to be very limited globally. This study is the first worldwide to report the magnitude of variation in living space availability for dairy herds. The variation in space allowance spanned all current recommendations for Great Britain: 10% of farms exceeded the highest

GB guideline (10.5 m², set by AHDB), and 1 farm was below the minimum guideline set in British standards (6.5 m²). Farms with higher space allowance and living area per cow typically had outdoor loafing or feeding areas as well as wider passageways. Farms with accommodations with the least space had narrow passageways and fewer crossover passages. Given the extent of variation observed, (SD was 20% of the mean for total space allowance per cow), the biological importance of the distribution of data is potentially of great significance although its effects are currently uncertain.

Although measurement of health outcomes was not an objective of this study, previous research suggests that living conditions are likely to influence the health of inhabitants (Bonnetfoy, 2007; Jacobs, 2011). It has been hypothesized that variation in the housed environment on farms has a relationship with health, welfare, and productivity of cows; a study looking into

Figure 4. Boxplots showing the spread of answers by the 53 participant dairy farmers in Great Britain, to five 11-point questions asking for their opinions on the importance of loafing space and outdoor access for housed dairy cows. Boxplots show the median value (midline) and 25th and 75th percentiles (boxes). The whiskers contain data within $1.5 \times$ interquartile range, with outlying data shown as individual points.

alternative housing systems for dairy cows has shown that the environment could influence SCC, mastitis infection rates, and reproductive performance (Barberg et al., 2007). Housing has been reported to influence lameness incidence through inappropriate design as a risk factor that could predispose cows to white line lesions, sole hemorrhage (Flower et al., 2007), or digital dermatitis (Endres, 2017). Milk production and quality have been reported to be influenced by space allowance via competition for resources, for example at the feed-face or stocking density in automatic milking systems (Deming et al., 2013; Crossley et al., 2017); however the short-term nature of such trials make these results difficult to interpret. Space availability is likely to influence cow behavior; spatial distribution analysis has shown dominant cows to have lower cow-to-cow distances and indicates that lower-ranking cows may want to space themselves further from other animals within a group (Syme et al., 1975). More recently, stocking density (defined as the number of cows to stall spaces) has been shown to decrease lying times and cause cows to spend more time in passageways and alter their social struc-

ture (Hill et al., 2009; Krawczel et al., 2012). Therefore current literature suggests that stocking density and feed-face and shed design can influence cow health, welfare, and production. Surprisingly, no studies to date have evaluated the direct effects of living space allowance on cow health and welfare.

This study proposes “living space” as a novel and valuable measure of space availability to cows on farm. Many farm regulatory bodies and assurance schemes have recommendations for loafing space availability in freestall systems; however, imprecise definitions of loafing space make it difficult for assessors to measure and for farmers to modify their buildings appropriately, and, to some extent, the sparsity of research into loafing areas may be caused by the ambiguity around its definition. We propose that our new definition of living space, an area above that considered essential to gain access to lying and feeding areas, provides a more intuitive framework to define space availability for cows. This definition of living space encompasses all fundamental areas of a freestall building, including accounting for wider passageways and additional outdoor

Figure 5. (A) Boxplots showing the answers given by 53 dairy farmers in Great Britain when asked how much loafing space should be given to housed dairy cows. Left boxplot: in an ideal scenario [NA (farmer declined to state answer for this question) = 20/53]. Right boxplot: as a minimum (NA = 21/53). Boxplots show the median value (midline) and 25th and 75th percentiles (boxes). The whiskers contain data within $1.5 \times$ interquartile range, with outlying data shown as individual points. (B) Scatterplot comparing the actual living space available per cow per farm from the 50 farms recruited to the investigation of space allowance studies and how this figure compared with the farmer-stated minimum amount for loafing space for housed dairy cows as part of the loafing space questionnaire.

and indoor areas, thus providing a useful estimate of the true available space from a single measurement. Importantly, this study identified that the definition of living space could be accurately estimated from 2 simple measurements: total housed area and total stall bedding area (model 1), which means it can be readily estimated under commercial conditions using a standard laser measurer. Because indoor-housed freestall systems are used across many large dairying nations, this definition of living space is likely to be widely useful for assessing the housed environment for freestall buildings, including the standardization of research studies.

Farmers who participated in this survey considered loafing space to be relatively important to the health, welfare, and productivity of their herds, as observed in the questionnaire results. However, answers to questions based around farmers' knowledge of loafing space

were highly variable; for example, 38% (20 out of 53) were unable to give an answer for the minimum amount of loafing space requirements (range: 0.3 to 8 m² per cow), suggesting poor knowledge of this topic. Some of this variation could arise from different perceptions of what constitutes loafing space, especially given the different views identified in the survey on whether all passageways should be counted as part of loafing space or not. Currently, farmer attitudes toward loafing space have not been widely investigated; it would be of interest to understand whether farmer views about the importance of loafing space are markedly different in different cultures and countries.

The observed living space measured on each farm was noticeably different to farmers' stated minimum acceptable loafing space, with around half of farmers providing their cows less than their cited minimum value. This is an example of cognitive dissonance, where a

Figure 6. Scatterplot comparing the observed living space availability per cow per farm across the 50 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain against the predicted living space availability per cow per farm from leave-one-out cross-validation (LOOCV) predictions (model 1); $R^2 = 0.85$.

belief does not match with behavior (Bandura, 2000); evidence shows that behavior does not always match with cognitive components of belief (LaPiere, 1934). A previous example of this has been shown with footrot management in sheep (O’Kane et al., 2017), when farmer behavior was identified to be affected by many factors, such as habit, emotions, social norms, and social capital (O’Kane et al., 2017; Shortall et al., 2018). This raises questions as to what the social norm for provision of loafing space to dairy cows is within the industry or, in terms of perceived behavioral control, how difficult farmers believe the provision of extra space to be in relation to its benefits. Our results indicate that many farmers believe loafing space is important for

their cows, but barriers must exist that prevent implementation. Further exploration of these barriers would be beneficial, but they are likely to include cost and practical difficulties associated with making significant changes to existing building and farm layouts. Plausible theories as to what prevents farmers from moving between the stage of wanting to implement change to actually undertaking it may include motivation, competition with other initiatives on farm, or anticipation of potential difficulties (Green et al., 2012).

Region and latent classes of farmer beliefs were both factors associated with the amount of living space per cow actually provided on farm. Farms in the south of England provided more living space than did those in

the north. A possible explanation for this may be that farms with greater amounts of space tended to have additional outdoor loafing areas. Further meteorological investigation revealed that the farms in this study from the more northern areas of Great Britain generally had higher rainfall on average than those located in the southern parts. Farms in the Northern England and Scotland region grouping may be less likely to opt for outdoor loafing areas due to the higher average rainfall recorded in these areas, as this could increase the vol-

ume of slurry and therefore time and expense to manage it. Farmers in latent class 3 (intermediate loafing space importance scores, higher outdoor access scores) provided more living space for cows than did those in latent class 1 (intermediate loafing space scores, lower outdoor access scores). The main difference between these 2 classes was the stated importance of outdoor access for housed dairy cows, with latent class 3 farmers scoring this feature higher. Therefore, it is more likely that farmers in this group would commit to provid-

Figure 7. Mean farmer opinion scores of the five 11-point questions (Q2, Q5, Q6, Q7, and Q8a) used to form the 4 latent classes analyzed from the loafing space farmer questionnaire completed by 53 dairy farmers in Great Britain. Latent class 1: $n = 22$; all farmers gave intermediate scores for the 4 loafing space importance questions but scored the importance of outdoor access for housed dairy cows low in comparison to latent class 3. Latent class 2: $n = 6$; farmers ranked the 4 loafing space importance questions and importance of outdoor access lowest of all 4 latent classes. Latent class 3: $n = 13$; farmers gave intermediate scores to all the questions but a higher score for importance of outdoor access for housed dairy cows compared with latent class 1. Latent class 4: $n = 11$; farmers scored all 5 questions highly compared with the other latent classes.

ing outdoor areas for their livestock and consequently specific loafing spaces, which tend to inflate the total living space availability.

A limitation associated with the questionnaire is the potential for social desirability bias; it was known to respondents that the researcher was from a university and that loafing space was a key theme of the study. Therefore, farmers may have believed that loafing space should be important for housed dairy cows and may have inflated their scores in response to this. Although a high response rate (76.7%) was achieved from study farms, we cannot be sure that non-responders would be the same as those responding. Reasons given for non-participation included time availability ($n = 2$), exiting the dairy business ($n = 2$), illness ($n = 2$), biosecurity ($n = 1$), and non-interest ($n = 5$). Three of the selected farmers were uncontactable despite at least 3 attempts at contact via email and telephone, and the remaining farmers did not provide a reason for non-participation. It is likely that the sample group was representative of the target sample because of the robust randomization method of selection and very high response rate; however, data protection issues meant it was not possible to compare demographics of the non-responder group and the study participant group, meaning that a degree of selection bias cannot be ruled out.

The target population in this study was all dairy producers supplying a large British retailer, and it is unclear how this group relates to other British farmers. How this sample relates to other dairying nations is also unknown, due to differences in management practices and legislation and guidelines.

This research has demonstrated that important variation exists in the housing conditions of dairy cows

across Great Britain. It is unknown to what extent this variation affects health, welfare, and productivity, and we believe this should be the subject of further research. It will also be important to greatly improve the understanding of the quality of space provided to cows. For example, this could include investigations of the types of spaces required for displaying natural behaviors, improving access to feed and lying areas, design of freestall layouts, and quality of floor surfaces for walkability. By combining assessment into quantity, quality, and types of space provided to indoor-housed dairy cows, the influence of building design should be evaluated in the context of ammonia emissions and cow health, welfare, and productivity. Such research would provide a scientific basis to advise international industry standards on the quantity and quality of living space for dairy cows.

ACKNOWLEDGMENTS

This work was funded by the Agriculture and Horticulture Development Board (AHDB) Dairy Division (Kenilworth, UK), a levy board, not-for-profit organization working on behalf of British dairy farmers. The author Dr. J. Gibbons is an employee of AHDB Dairy Division. We also acknowledge the retailer for access to their supplier records and all of the selected farmers for giving up their time and welcoming the researcher onto their farms for data collection. The authors have not stated any conflicts of interest.

REFERENCES

- AHDB (Agriculture and Horticulture Development Board) Dairy. 2018. Technical information: Buildings. Accessed Jul. 24, 2018. <https://dairy.ahdb.org.uk/technical-information/buildings/#.W1hx6dJKjDc>.
- AHDB (Agriculture and Horticulture Development Board) Dairy. 2019. Average milk yield. Accessed Oct. 3, 2019. <https://dairy.ahdb.org.uk/market-information/farming-data/milk-yield/average-milk-yield/#.XZXWKUZKhPZ>.
- Bandura, A. 2000. Health promotion from the perspective of social cognitive theory. <https://psycnet.apa.org/record/2001-16477-012>.
- Barberg, A. E., M. I. Endres, J. A. Salfer, and J. K. Reneau. 2007. Performance and welfare of dairy cows in an alternative housing system in Minnesota. *J. Dairy Sci.* 90:1575–1583. [https://doi.org/10.3168/jds.S0022-0302\(07\)71643-0](https://doi.org/10.3168/jds.S0022-0302(07)71643-0).
- Barkema, H. W., M. A. G. von Keyserlingk, J. P. Kastelic, T. J. G. M. Lam, C. Luby, J.-P. Roy, S. J. LeBlanc, G. P. Keefe, and D. F. Kelton. 2015. Invited review: Changes in the dairy industry affecting dairy cattle health and welfare. *J. Dairy Sci.* 98:7426–7445. <https://doi.org/10.3168/jds.2015-9377>.
- BCSPCA. 2018. Standards for the Raising and Handling of Dairy Cattle. Accessed Feb. 18, 2019. <https://spca.bc.ca/wp-content/uploads/SPCA-Certified-Dairy-Standards-2012-v.4.pdf>.
- Bewley, J. M., L. M. Robertson, and E. A. Eckelkamp. 2017. A 100-year review: Lactating dairy cattle housing management. *J. Dairy Sci.* 100:10418–10431. <https://doi.org/10.3168/jds.2017-13251>.
- Bickert, W. G. 2000. Dairy Freestall Housing and Equipment. Midwest Plan Service, Ames, IA.

Table 1. Results of a statistical model (model 2) assessing factors associated with the amount of living space available for lactating cows on farm, in a study investigating space allowance in dairy cow housing in Great Britain

Item	Coefficient		
	Estimate	SE	P-value
Intercept	0.84	0.51	0.1119
Farm region			
Northern England and Scotland	(Referent)		
Midlands	0.83	0.55	0.1356
South East	1.51	0.84	0.0796†
South West	2.01	0.52	0.0004***
Wales	3.28	0.97	0.0017**
Farmer opinion latent classes			
Latent class 1	(Referent)		
Latent class 2	0.34	0.60	0.5743
Latent class 3	1.03	0.44	0.0238*
Latent class 4	0.59	0.46	0.2098

† $P < 0.10$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

- Bickert, W. G., and R. G. Light. 1982. Housing systems. *J. Dairy Sci.* 65:502–508. [https://doi.org/10.3168/jds.S0022-0302\(82\)82224-8](https://doi.org/10.3168/jds.S0022-0302(82)82224-8).
- Blake, K. S., R. L. Kellerson, and A. Simic. 2007. Measuring overcrowding in housing. U.S. Department of Housing and Urban Development Office of Policy Development and Research. Accessed Feb. 5, 2019. https://www.huduser.gov/publications/pdf/measuring_overcrowding_in_hsg.pdf.
- Bonnefoy, X. 2007. Inadequate housing and health: An overview. *Int. J. Environ. Pollut.* 30:411. <https://doi.org/10.1504/IJEP.2007.014819>.
- British Standards. 1990. British Standards Relevant to Agriculture: BS5502:40, Cattle Buildings. Accessed Feb. 5, 2019. <http://adlib.eversite.co.uk/adlib/defra/content.aspx?id=000HK277ZW.0A774HQ2BI6TZX>.
- Crossley, R. E., A. Harlander-Matauschek, and T. J. DeVries. 2017. Variability in behavior and production among dairy cows fed under differing levels of competition. *J. Dairy Sci.* 100:3825–3838. <https://doi.org/10.3168/jds.2016-12108>.
- Deming, J. A., R. Bergeron, K. E. Leslie, and T. J. DeVries. 2013. Associations of housing, management, milking activity, and standing and lying behavior of dairy cows milked in automatic systems. *J. Dairy Sci.* 96:344–351. <https://doi.org/10.3168/jds.2012-5985>.
- DeVries, T. J., M. A. G. von Keyserlingk, and D. M. Weary. 2004. Effect of feeding space on the inter-cow distance, aggression, and feeding behavior of free-stall housed lactating dairy cows. *J. Dairy Sci.* 87:1432–1438. [https://doi.org/10.3168/jds.S0022-0302\(04\)73293-2](https://doi.org/10.3168/jds.S0022-0302(04)73293-2).
- Endres, M. I. 2017. The relationship of cow comfort and flooring to lameness disorders in dairy cattle. *Vet. Clin. North Am. Food Anim. Pract.* 33:227–233. <https://doi.org/10.1016/j.cvfa.2017.02.007>.
- FASS (Federation of Animal Science Societies). 2010. Guide for the Care and Use of Agricultural Animals in Research and Teaching. 3rd ed. Federation of Animal Science Societies, Champaign, IL.
- Flower, F. C., A. M. de Passillé, D. M. Weary, D. J. Sanderson, and J. Rushen. 2007. Softer, higher-friction flooring improves gait of cows with and without sole ulcers. *J. Dairy Sci.* 90:1235–1242. [https://doi.org/10.3168/jds.S0022-0302\(07\)71612-0](https://doi.org/10.3168/jds.S0022-0302(07)71612-0).
- Fraley, C., and A. E. Raftery. 2002. Model-based clustering, discriminant analysis, and density estimation. *Journal of the American Statistical Association*. Accessed Mar. 11, 2019. <https://www.stat.washington.edu/raftery/Research/PDF/fraley2002.pdf>.
- Gan, W. Q., W. T. Sanderson, S. R. Browning, and D. M. Mannino. 2017. Different types of housing and respiratory health outcomes. *Prev. Med. Rep.* 7:124–129. <https://doi.org/10.1016/j.pmedr.2017.05.018>.
- Google Maps. 2019. Accessed Mar. 5, 2019. <https://www.google.co.uk/maps/>.
- Green, M., A. Bradley, J. Breen, L. Green, A. Hayton, H. Higgins, C. Hudson, J. Huxley, and J. Statham. 2012. Dairy Herd Health. CABI, Wallingford, UK. <http://www.cabi.org/cabebooks/ebook/20123387548>.
- Hancock, T. 2002. Indicators of environmental health in the urban setting. *Can. J. Public Health* 93(Suppl. 1):S45–S51. <https://doi.org/10.1007/BF03405118>.
- Haskell, M. J., K. Maslowska, D. J. Bell, D. J. Roberts, and F. M. Langford. 2013. The effect of a view to the surroundings and microclimate variables on use of a loafing area in housed dairy cattle. *Appl. Anim. Behav. Sci.* 147:28–33. <https://doi.org/10.1016/j.applanim.2013.04.016>.
- Hill, C. T., P. D. Krawczel, H. M. Dann, C. S. Ballard, R. C. Hovey, W. A. Falls, and R. J. Grant. 2009. Effect of stocking density on the short-term behavioural responses of dairy cows. *Appl. Anim. Behav. Sci.* 117:144–149. <https://doi.org/10.1016/j.applanim.2008.12.012>.
- Hood, E. 2005. Dwelling disparities: How poor housing leads to poor health. *Environ. Health Perspect.* 113:A310. <https://doi.org/10.1289/ehp.113-a310>.
- Jacobs, D. E. 2011. Environmental health disparities in housing. *Am. J. Public Health* 101(Suppl. 1):S115–S122. <https://doi.org/10.2105/AJPH.2010.300058>.
- Krawczel, P. D., L. B. Klaiber, R. E. Butzler, L. M. Klaiber, H. M. Dann, C. S. Mooney, and R. J. Grant. 2012. Short-term increases in stocking density affect the lying and social behavior, but not the productivity, of lactating Holstein dairy cows. *J. Dairy Sci.* 95:4298–4308. <https://doi.org/10.3168/jds.2011-4687>.
- Krawczel, P. D., and A. R. Lee. 2019. Lying time and its importance to the dairy cow: Impact of stocking density and time budget stresses. *Vet. Clin. North Am. Food Anim. Pract.* 35:47–60. <https://doi.org/10.1016/j.cvfa.2018.11.002>.
- Krieger, J., and D. L. Higgins. 2002. Housing and health: Time again for public health action. *Am. J. Public Health* 92:758–768. <https://doi.org/10.2105/AJPH.92.5.758>.
- Kuhn, M., and K. Johnson. 2016. Applied Predictive Modeling. Springer Science and Business Media, New York, NY.
- LaPiere, R. T. 1934. Attitudes vs. actions. *Soc. Forces* 13:230–237. <https://doi.org/10.2307/2570339>.
- March, M. D., M. J. Haskell, M. G. G. Chagunda, F. M. Langford, and D. J. Roberts. 2014. Current trends in British dairy management regimens. *J. Dairy Sci.* 97:7985–7994. <https://doi.org/10.3168/jds.2014-8265>.
- Marschner, I. 2018. Fitting generalized linear models [R package glm2 version 1.2.1]. Accessed Mar. 25, 2019. <https://cran.r-project.org/web/packages/glm2/index.html>.
- Microsoft. 2016. Microsoft Excel. Accessed Feb. 25, 2019. <https://products.office.com/en-gb/excel>.
- NFACC (National Farm Animal Care Council). 2009. Code of Practice for the Care and Handling of Dairy Cattle. Dairy Farmers of Canada, Ottawa, ON, Canada.
- O’Kane, H., E. Ferguson, J. Kaler, and L. Green. 2017. Associations between sheep farmer attitudes, beliefs, emotions and personality, and their barriers to uptake of best practice: The example of footrot. *Prev. Vet. Med.* 139:123–133. <https://doi.org/10.1016/j.prevetmed.2016.05.009>.
- Petrie, A., and P. Watson. 2006. Statistics for Veterinary and Animal Science. Blackwell Publishing, Hoboken, NJ.
- Place, S. E., and F. M. Mitloehner. 2014. The nexus of environmental quality and livestock welfare. *Annu. Rev. Anim. Biosci.* 2:555–569. <https://doi.org/10.1146/annurev-animal-022513-114242>.
- R Core Team. 2018. R: A Language and Environment for Statistical Computing. Accessed Feb. 12, 2019. <https://www.r-project.org/>.
- Red Tractor. 2014. Red Tractor: Dairy Standards. Accessed Feb. 12, 2019. https://assurance.redtractor.org.uk/contentfiles/Farmers-6802.pdf?_=637060417378500869.
- RSPCA (Royal Society for the Prevention of Cruelty to Animals). 2018. RSPCA welfare standards for dairy cattle, January 2018. <https://www.berpscaassured.org.uk/media/1283/rspca-welfare-standards-dairy-cattle-jan-2018.pdf>.
- Scrucca, L., M. Fop, T. B. Murphy, and A. E. Raftery. 2016. mclust 5: Clustering, classification and density estimation using Gaussian finite mixture models. *R J.* 8:289–317. <https://doi.org/10.32614/RJ-2016-021>.
- Shortall, O., L.-A. Sutherland, A. Ruston, and J. Kaler. 2018. True cowmen and commercial farmers: Exploring vets’ and dairy farmers’ contrasting views of “good farming” in relation to biosecurity. *Sociol. Ruralis* 58:583–603. <https://doi.org/10.1111/soru.12205>.
- Smith, R. A., and N. B. Cook. 2019. Housing to Optimize Comfort, Health, and Productivity of Dairy Cattle. Elsevier, Amsterdam, the Netherlands.
- STROBE. 2019. STROBE Statement: Available checklists. Accessed Apr. 30, 2019. https://www.strobe-statement.org/fileadmin/Strobe/uploads/checklists/STROBE_checklist_v4_cross-sectional.pdf.
- Syme, L. A., G. J. Syme, T. G. Waite, and A. J. Pearson. 1975. Spatial distribution and social status in a small herd of dairy cows. *Anim. Behav.* 23:609–614. [https://doi.org/10.1016/0003-3472\(75\)90138-4](https://doi.org/10.1016/0003-3472(75)90138-4).
- Templeton, S., R. Black, and P. Krawczel. 2014. The effects of overcrowding on the behavior of lactating dairy cows in free-stall housing systems. *J. Dairy Sci.* 97(E-Suppl. 1):10. (Abstr.)
- USDA. 2016. Dairy 2014 Dairy Cattle Management Practices. USDA-APHIS-VS-CEAH-NAHMS, Fort Collins, CO.

- Ventura, B. A., M. A. G. von Keyserlingk, H. Wittman, and D. M. Weary. 2016. What difference does a visit make? Changes in animal welfare perceptions after interested citizens tour a dairy farm. *PLoS One* 11:e0154733. <https://doi.org/10.1371/journal.pone.0154733>.
- von Elm, E., D. G. Altman, M. Egger, S. J. Pocock, P. C. Gøtzsche, and J. P. Vandenbroucke. 2008. The Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *J. Clin. Epidemiol.* 61:344–349. <https://doi.org/10.1016/j.jclinepi.2007.11.008>.
- Wang, F. X., D. F. Shao, S. L. Li, Y. J. Wang, A. Azarfar, and Z. J. Cao. 2016. Effects of stocking density on behavior, productivity, and comfort indices of lactating dairy cows. *J. Dairy Sci.* 99:3709–3717. <https://doi.org/10.3168/jds.2015-10098>.
- WHO (World Health Organization). 2016. What are the health risks related to overcrowding? Accessed Feb. 5, 2019. https://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa9/en/.
- Witaifi, A. A., A. B. A. Ali, and J. M. Siegford. 2018. Stall and feed bunk stocking rates impact cows' diurnal behavior and activity in automatic milking system farms. *J. Vet. Behav.* 24:48–55. <https://doi.org/10.1016/j.jveb.2018.01.004>.

ORCIDS

- J. S. Thompson <https://orcid.org/0000-0002-7443-2709>
 J. N. Huxley <https://orcid.org/0000-0002-1149-2480>
 C. D. Hudson <https://orcid.org/0000-0003-4777-062X>
 J. Kaler <https://orcid.org/0000-0002-3332-7064>
 J. Gibbons <https://orcid.org/0000-0001-7719-1587>
 M. J. Green <https://orcid.org/0000-0002-6408-6443>