ABSTRACT

Cold stress negatively affects the welfare of calves in outdoor hutches. No studies have examined the potential benefits of pair housing calves to buffer against cold stress. Our study evaluated the effects of pair versus individual housing on thermoregulatory, behavioral, and growth performance responses of calves in outdoor hutches during a Wisconsin continental winter. Forty-eight Holstein-Friesian heifer calves were enrolled into 1 of 2 housing treatments: individually (n = 16 calves) or pair housed (n = 16 pairs; 32 calves). Calves were fed milk twice daily, with ad libitum access to starter and water. Step-down weaning began on d 42 of life, and all milk was removed on d 54. Data collection continued through d 59. Calves were restricted inside a hutch (pair-housed calves in the same hutch) for 1 h during wk 4, 6, and 9 of life; internal hutch air temperature (T) was recorded with data loggers, and rectal temperature (RT) was recorded outside the hutch before and after restriction. On the subsequent 3 d in those weeks, calves’ locations (outside or inside a hutch) were recorded at 15-min intervals using time-lapse cameras. Linear mixed models (change in T and RT after 1 h) and generalized linear mixed models with a β distribution (proportion of time spent inside hutches) were used to evaluate the fixed effects of housing treatment, the models for BW included birth weight as a covariate. All mixed models included a random term for housing unit (individual or pair of calves) nested within treatment. Hutch T increased more after 1 h with pair-housed calves inside than with those housed individually (+2.3 vs. 1.4°C, respectively; standard error of the mean = 0.26°C). However, no treatment differences were detected in RT. Individually housed calves spent more time inside the hutches than pair-housed ones (93.9 vs. 90.7% of total time, respectively; standard error of the mean = 0.8%), and the latter chose to be together most of the time, regardless of location (90.0 ± 1.3%, 88.6 ± 1.2%, and 79.4 ± 4.2% in wk 4, 6, and 9 of life, respectively). After weaning, there was some evidence suggesting that pair-housed calves had greater starter DMI than those housed individually. No effects of housing type were found on FCR, BW, or ADG. Our study is the first to explicitly examine the potential benefits of pair housing for alleviating cold stress in outdoor-housed dairy calves, and we found limited evidence in support of our hypotheses. Key words: social housing, thermal comfort, cold stress

INTRODUCTION

Approximately 38% of US dairy operations house preweaning calves in individual outdoor hutches (USDA, 2021). Depending on the region, calves housed this way are exposed to environmental extremes, including cold temperatures. When the lower critical temperature (8–10°C for calves up to 8 wk of age; Webster et al., 1978; Gebremedhin et al., 1981) is reached, a calf must expend energy to produce heat and maintain body temperature (Nonnecke et al., 2009). In much of the United States from fall to early spring, calves will experience some degree of cold stress. Cold stress has been documented to have negative effects on the immune system and growth performance (Olson et al., 1980; Godden et al., 2005; Holt, 2014). One study reported winter morbidity and mortality rates of 52% and 21%, respectively, compared with 13% and 3% during the summer, when housed in individual...
pens inside calf barns in central Minnesota and fed 4 L/d of pasteurized milk (Godden et al., 2005). Compared with older cattle, preweaning calves have a larger body surface-to-mass ratio, which leads to greater heat loss, and an undeveloped rumen, which does not produce the body heat associated with ruminal fermentation (Collier et al., 1982). Therefore, calves are limited to producing body heat through the metabolism of the brown adipose tissue, shivering, physical activity, or from the feed they consume (Vermorel et al., 1983).

To date, the most common methods of cold stress abatement in calves focus on making up the energy lost for thermoregulation. Even in the context of traditional, limited milk allowances (10% of BW), the amount of milk recommended during winter was 15% to 20% of BW (Anderson and Bates, 1984). The addition of fat in milk replacer has been reported to help calves in cold stress conditions achieve ADG similar to those raised in thermoneutral conditions (Scibilia et al., 1987; Nonnecke et al., 2009). However, the addition of fat to starter has often shown the opposite effects, with reduced DMI and ADG (Fallon et al., 1986; Hill et al., 2015; Ghasemi et al., 2017). Another method is to prevent heat loss using calf jackets. Inside a barn, nonjacketed calves ate more and had more unrewarded visits to the automatic milk feeder compared with those with jackets, but ADG was equivalent (Scoley et al., 2019); this indicates that the former had to increase their intakes to maintain energy requirements. Additionally, some producers provide insulative bedding material in winter, which allows the calves to nest and conserve body heat (Nordlund, 2008).

Recently, a wealth of literature has documented the benefits of housing calves in social groups (pairs or groups; reviewed by Costa et al., 2016). Social housing of calves has resulted in greater DMI and ADG in numerous studies (e.g., De Paula Vieira et al., 2010; Jensen et al., 2015). In addition, improvements in welfare associated with social housing include reduced neophobia to unfamiliar calves (Jensen et al., 1997) and greater cognitive and behavioral flexibility (Meagher et al., 2015; Horvath et al., 2017). A novel potential benefit of pair housing in hutches is that calves can huddle together for warmth, which may help alleviate cold stress. In a Canadian study with calves pair housed in connected hutches in winter, calves were observed inside the same hutch more than 80% of their total time inside the hutches (Wormsbecher et al., 2017). Similarly, group-housed calves increased the amount of time spent near another calf as the ambient temperatures decreased inside an uninsulated barn (Boe and Havrevoll, 1993). In addition, there is the potential for social facilitation (imitating the current behavior of others; Clayton, 1976) to help calves maintain homeothermy during cold stress. Specifically, calves have been documented to display local enhancement, in which the behavior of one calf brings the attention of another from the group to the same food source (De Paula Vieira et al., 2012), which could result in calves increasing DMI during times of cold stress.

The objective of this study was to evaluate the effects of pair versus individual housing on thermoregulatory, behavioral, and growth performance responses of dairy calves in outdoor hutches during a Wisconsin winter. We hypothesized that pair-housed calves would show lesser thermoregulatory responses than individually housed ones and would thus outperform them in terms of greater ADG, BW, DMI, and a lower (more desirable) feed conversion ratio (FCR; DMI of starter/ADG). We also predicted that pair-housed calves would prefer to spend the majority of their time together.

MATERIALS AND METHODS

The study was conducted during the winter (December 2019 to March 2020) at the University of Wisconsin–Madison (UW–Madison) Emmons Blaine Dairy Cattle Research Center located in Arlington, Wisconsin, with all procedures approved by the Institutional Animal Care and Use Committee (protocol #A006133).

Animals, Treatments, and Housing

Forty-eight Holstein-Friesian dairy heifer calves were enrolled into 1 of 2 housing treatments: individually (n = 16 calves) or pair housed (n = 16 pairs; 32 calves) in outdoor hutches. Treatments were assigned in a balanced fashion across sequential hutches.

Power Calculation. The sample size was determined based on expected housing treatment differences between individually and pair-housed calves for DMI of starter and ADG during the first 9 wk of life. Previous studies of individually versus pair-housed calves in indoor pens found medium to very large (Cohen’s d ≥0.5 and ≥1.2) effect sizes for these variables (Bernal-Rigoli et al., 2012; Costa et al., 2015; Jensen et al., 2015). Based on these effect sizes, power analyses indicated sample sizes of n = 5 to 16 experimental units would be required per treatment. Therefore, to confidently achieve a power of 0.8 or higher, we chose to use 16 experimental units per housing condition (individually vs. pair-housed).

Enrollment Criteria. Within 6 h of birth (d 1 of life), calves were separated from their dam, weighed, had their navels dipped with iodine solution, and were fed 3.8 L of colostrum. They also received *Clostridium perfringens* types C and D antitoxin. Calves weighing <30 or >48 kg at birth were excluded from the trial.
(more than ±2 SD from the mean birthweights of the farm’s calves in the 12 mo preceding the start of the trial). If weight criterion was met, calves were then temporarily (1 ± 1 d, mean ± SD) housed in individual straw-bedded pens inside the barn to await final confirmation of enrollment. To test for failure of transfer of passive immunity, blood samples were collected from the jugular vein within 48 h after the first colostrum feeding using 10.0-mL 16 × 125 mm BD vacutainer venous blood collection tubes with clot additive. After collection, tubes were stored at room temperature for 30 min to allow for clotting. Tubes were then centrifuged at room temperature for 15 min at 1,545 × g. Serum was analyzed using a Premiere RHC-200-ATC refractometer (C & A Scientific Co. Inc.). Only calves with serum protein >5.1 g/dL (Elsohaby et al., 2019) were enrolled in the trial. All calves wore calf jackets (C27111N; Nasco) from birth to d 21 ± 1 (mean ± SD) of life. Calves were assigned to hutches sequentially by birth order, with the exception that to be assigned to the same pair, calves’ birthweights had to be within 10 kg of each other (final difference = 1.8 ± 3.9 kg within pairs). Within a given pair, the difference in age was 2 ± 1 d (range: 0–4 d). Average birthweight for individually versus pair-housed calves was 39.7 ± 4 versus 38.7 ± 4 kg (mean ± SD). Once enrollment criteria were met, calves were moved to their treatment housing (at d 2 ± 1 of life).

**Experimental Housing.** Individually housed calves had a single hutch (Calf-Tel Deluxe II, 1.1 m wide × 2.1 m long × 1.2 m high, inside dimensions, 2.3 m³; Hampel Corp.) with an outdoor area (1.2 m wide × 1.8 m long) enclosed with wire fencing (1.0 m tall; 2.2 m² enclosure; 4.5 m² total space). Pair-housed calves had 2 adjacent hutches connected with a white plastic board (0.6 m wide × 1.2 m high, 9.5 mm thick; high density polyethylene sheet; Hemisphere Design Works) and an outdoor area (2.7 m wide × 1.8 m long) enclosed with wire fencing (1.2 m tall; 4.9 m² enclosure; 9.5 m² total space, 4.7 m³ per calf). All hutches were south facing and deep bedded with straw, with additional bedding added according to farm staff judgment based on weather conditions. Pair-housed calves were initially separated with an additional wire fencing panel (1.2 m tall) dividing the outdoor enclosure until both calves were determined by farm staff to be drinking milk consistently; this period lasted 7 ± 1 d (mean ± SD; range: 5–10 d).

**Management**

**Feed and Water.** For all calves, drinking water was offered from birth. Once calves moved to treatment housing, hot water was offered inside each hutch in a plastic pail (C18933, 8-L capacity; Nasco) and was checked 3 times daily (0600, 1300, and 1800 h) for freezing. If the water was frozen, the bucket was removed, replaced with a new bucket, and filled with hot water.

All calves were fed pasteurized whole milk in the outdoor enclosure twice daily between 0400 and 0530 h and 1500 and 1600 h. All calves were initially hand fed 1.9 L at each feeding by bottle (C14766; Nasco). Once calves were determined by farm staff to be drinking sufficiently (at d 5 ± 1 of life, mean ± SD), milk volume was increased to 2.8 L per feeding, with the bottles hung on the fence. When calves reached d 14 ± 1 of life, milk allowance was increased to 3.8 L per feeding using larger bottles (Milk Bar Vitality System; The Coburn Company) hung from the fence. Calves were started on a softer colostrum nipple (Milk Bar Colostrum Teat for calves, 265–0001) for 4 d before changing to a slow-flow nipple (Milk Bar Teat for calves, 265–0002) at d 17 ± 1 of life. All bottles were brought indoors and scrubbed with a foaming cleanser. All calves were weaned in a step-down fashion based on age; for pair-housed calves, this was determined based on the younger calf in the pair. First, milk allowance decreased to 1.9 L twice daily at d 42 of life (average among all pair-housed calves: d 43 ± 1 of life), then to 1.9 L once daily (afternoon only) on d 49 of life (pairs: d 50 ± 1 of life). Milk was completely removed on d 53 of life (pairs: d 54 ± 1 of life). Calves remained in their hutches for at least 6 more d after weaning (9 ± 2 d), moving to postweaning group housing no earlier than d 60 of life.

Beginning on d 3 of life, calves were given texturized starter (BSF 18; Vita Phs) composed of corn (43.5%), soybean meal (28.5%), cottonseed hull pellets (12.5%), molasses (5.0%), roasted soybeans (2.8%), wheat middlings (2.2%), calcium carbonate (1.6%), a mineral and vitamin premix (1.0%), dicalcium phosphate (0.6%), and salt (0.5%). Starter was fed in a plastic bucket (C18933; Nasco) inside each hutch, adjacent to the water pail. Starter was topped up twice daily (0600 and 1300 h) and fully replaced at least twice per week (more frequently if frozen). To ensure ad libitum availability, the amount of starter offered was increased daily based on consumption (>5% refusals by weight).

**Disbudding and Health Monitoring.** Calves were hot-iron disbudded, in conjunction with administration of a lidocaine cornual nerve block and oral meloxicam, at d 10 ± 2 of life; this age was chosen so the procedure would not coincide with the beginning of data collection.

Calf health was evaluated weekly by recording rectal temperature (RT) with a digital thermometer, along with cough, nasal discharge, and eye, ear, and fecal scores using the UW–Madison School of Veterinary Medicine Calf Health Scorer application.
Sick calves were treated following the farm’s standard operating procedures. In addition, when calves drank less than half of their milk meal (as determined by visual assessment) for any reason including illness, electrolytes were delivered by bottle and provided to both calves within pairs. Across the entire study, 4 calves were treated for health conditions, and 15 calves were given electrolytes (detailed in Table 1).

Data Collection

**Feed Intake and Growth Performance.** Daily pasteurized milk samples from the afternoon milk feeding were collected and analyzed (AgSource, Verona, WI) for composition [butterfat: 3.6 ± 0.4%; protein: 3.4 ± 0.2%; lactose: 4.5 ± 0.1%; SNF: 9.1 ± 0.2%; MUN: 13.6 ± 1.5%; SCC (×1,000): 682.4 ± 152.4; mean ± SD].

Starter intake was assessed by weighing cumulative refusals twice per week in wk 2 to 9 of life. Weights were converted to a DM basis using the DM% of 4 handfuls from samples of the refusals and fresh feed (collected weekly), respectively, which were oven (Isotemp Oven, Fisherbrand) dried at 105°C for 24 h. For pair-housed calves, starter intake was determined at the pair level and averaged to report a per-calf basis. Calves were measured weekly for BW by haltering and walking them individually approximately 9 m to a portable scale (sw300; Digistar).

**Thermoregulatory Responses and Hutch Use.** Calves were habituated to temporary restriction within their hutch on 6 consecutive days (beginning on d 15 ± 1 of life; mean ± SD) between 0800 and 1030 h by affixing a 2- by 1-m wire panel over the entrance to the hutch with a bungee cord (Figure 1). This allowed for ventilation while standardizing the amount of time calves were inside the hutch. To ensure familiarity with each of 4 conditions for later behavioral monitoring, pair-housed calves were restricted in a 2 × 2 factorial design in a balanced order: individually or in pairs in the left or right hutch (2 conditions/d, with approximately 1 min spent outside between consecutive sessions). Individually housed calves were restricted in-

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**Table 1.** All recorded illnesses and treatments provided to calves (n = 16 individually housed, n = 32 housed in 16 pairs) across the entire study (d 1–60 of life)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Treatment 1</th>
<th>Pair-housed calves</th>
<th>Individually housed calves</th>
<th>Age of calves (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infected inner ear</td>
<td>Tulathromycin</td>
<td>1</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Cryptosporidiosis</td>
<td>Oral electrolytes</td>
<td>0</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>Tulathromycin, flunixin (transdermal)</td>
<td>1</td>
<td>1</td>
<td>28–34</td>
</tr>
<tr>
<td>Milk refusal</td>
<td>Oral electrolytes</td>
<td>10 (5)</td>
<td>5</td>
<td>15–30</td>
</tr>
</tbody>
</table>

1Tulathromycin was administered as Draxxin (Zoetis Animal Health, Parsippany, NJ); flunixin was administered as Banamine (Merck Animal Health, Rahway, NJ).

2The number of pair-housed calves receiving each treatment are given, with the number of unique pairs in parentheses.

3Electrolytes were provided when calves drank less than half of their milk meal, as assessed visually; both calves within a pair were given electrolytes if at least 1 of the bottles was less than half finished.

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Figure 1. Calves were restricted inside hutches for 1 h using wire fencing and a bungee cord to collect data on changes in internal hutch microclimate and calves’ thermoregulatory responses. For pair-housed calves, both were placed together in 1 of their 2 adjacent hutches.
side their hutch for 2 consecutive sessions per day and brought outside for 1 min between sessions to mimic the experience of pair-housed calves. The initial restriction periods lasted 10 min on d 1 and 2, 20 min on d 3 and 4, and 30 min on d 5 and 6.

The restriction procedure, including the balanced exposure in a 2 × 2 factorial arrangement for pair-housed calves, was repeated in wk 4, 6, and 9 of life (d 23 ± 2, 38 ± 1, and 55 ± 1 of life, respectively; mean ± SD), but with 1-h periods inside the hutch. These 3 wks of life (wk 4, 6, and 9) were chosen to represent different time points in the calves’ development: by wk 4 of life, calves had received peak milk allowance for at least a week, wk 6 of life was before weaning started, and wk 9 of life was postweaning, when calves were fed only starter. We chose not to restrict calves during the weaning period to avoid additional stress and potential effects on growth performance data. Data were collected only before and after the first weekly exposure (1100 to 1200 h) in which both pair-housed calves were restricted inside the same hutch, and for the equivalent session for the individually housed calves. Pilot testing revealed that opening the bedding door on the back of the hutch immediately reset the hutch microclimate to baseline conditions. Only 1 min outdoors between consecutive sessions may not have been long enough to return calves’ thermoregulatory responses to baseline values, which is why only the first session was used to evaluate thermoregulatory responses. Nonetheless, to protect the calves’ welfare, we limited their duration of exposure to outdoor winter conditions. The other 3 weekly restriction sessions served to remind pair-housed calves of all possible conditions inside each hutch, separately or together, for subsequent behavioral monitoring.

Immediately before and after the focal 1 h restriction period, RT, skin temperature (ST), and ocular temperature (OT) were recorded while calves were outside the hutch. Due to space constraints inside the hutch, the left vs. right hutch was noted) were recorded by loggers (Kestrel DROP D2AG; Kestrel Meters) placed in suet cages (EZ Fill Suet Basket Bird Feeder; C & S Products) to prevent tampering by calves and hung inside the hutches at 1.1 m high for each data collection period in wk 4, 6, and 9. The internal hutch conditions are descriptively summarized by week of life and housing treatment in Table 2. A portable weather station (HOBO U30-NRC, ONSET Computer Corporation) was placed in the vicinity of the hutches to record ambient conditions at 5-min intervals: T, solar radiation (W/m²), and wind speed (m/s). The 24-h weather conditions are summarized in Table 3. Wind chill (WC) was calculated by the following equation from Oszczewski and Bluestein (2005):

\[
WC = 13.12 + 0.6215 \times T - 11.37 \times (V^{0.16}) + 0.3965 \times T \times (V^{0.16}),
\]

where V = wind velocity (km/h).

**Bedding DM.** Bedding samples were taken from 5 locations (corners and middle) in each hutch at the beginning and end of each 3-d behavioral observation period in wk 4, 6, and 9. The top 8 cm of bedding in each location was collected and combined to represent the hutch. Samples were converted to a DM basis using the DM% of 4 handfuls from the collected bedding in each hutch and from fresh straw (collected weekly), respectively, which were oven (Isotemp Oven, Fisherbrand) dried at 105°C for 24 h.
Statistical Analysis

Excluded and Missing Data. After reviewing the ST data, this measure was not analyzed, as the low values suggested an instantaneous drop in ST occurred when calves were removed from the hutches to collect the measurements. Two values for internal hutch temperature during restriction were missing due to logger malfunction: 1 for a pair-housed hutch in wk 6 of life and 1 for an individual hutch in wk 9. For OT in wk 6, three data points were missing due to camera malfunction: 1 for an individually housed calf and 1 each for both calves within a single pair.

Bedding DM% was calculated only descriptively by week of life and housing treatment (Table 4). For pair-housed calves, values are reported separately for the more-used and less-used hutch in each week. The farm staff topped up the bedding every Sunday and Wednesday and as needed when they deemed the bedding was becoming too damp. Therefore, no statistical analyses were performed on this measure, as bedding was occasionally added during the observation periods.

Standardizing Growth Performance by Day of Life. Due to logistical constraints, starter intake and BW were collected on particular days of the week instead of consistent days of life for all calves. To accurately calculate feed conversion ratios, measurements on the same day of life must be used. Therefore, we used regressions to estimate both DMI of starter and BW for each housing unit by day of life. For pair-housed calves, BW measurements (collected on the same day within each pair) were averaged within each pair, and measurement dates for both BW and DMI were converted to the day of life based on the younger calf within each pair; the age of the younger calf was selected instead of averaging the age of the calves within each pair because step-down weaning was conducted based on the former.

Due to the notable differences in the temporal curves for daily starter DMI and BW, we fitted different regression models for each variable. For starter DMI, we performed regressions for each housing unit using generalized additive models, through the 
\texttt{gam()} function from the \texttt{mgcv} package of the R programming language (R version 4.1.0). We determined the number of basis functions (i.e., k parameter) based on the smallest Akaike information criterion (AIC) value. Due to issues with predictions using the normal distribution (i.e., biologically implausible negative values predicted by the equations), we chose to use the Tweedie distribution. For BW, we performed regressions for each housing unit using a nonlinear exponential model \[y \sim a \times \exp(b \times \text{days of life})\], through the \texttt{nls()} function of the \texttt{stats} base R package.

The regressions for each housing unit were used to determine predicted BW and cumulative DMI at specific milestones: the start of weaning (d 42 of life), end...
of weaning (d 53 of life), and 6 d after weaning (d 59 of life, as the minimum age at which calves moved to postweaning housing was on d 60). The predicted BW values were used to calculate ADG from birth to the start of weaning (d 1–42 of life), during weaning (d 43–53 of life), and postweaning (d 54–59 of life). The predicted cumulative DMI values were used to calculate feed conversion ratio (DMI of starter/ADG) over the same 3 time periods. We chose to run the treatment-comparison analysis on FCR rather than feed efficiency (FE; ADG/DMI of starter) as we were only accounting for starter intake, which has a low or unmeasurable consumption rate in the early preweaning period until milk rations are reduced (Khan et al., 2007a,b), and near-zero values in the denominator can adversely affect analysis or inferences; nonetheless we report FE values descriptively.

### Statistical Models and Treatment Comparisons
All analyses were conducted using SAS software (version 9.4, SAS Institute Inc.). Housing unit (individual or pair) was the experimental unit, and thus for pair-housed calves, all dependent variables were averaged within pairs before analysis. The assumptions of normality and equal variance were evaluated by visually examining plots of the residuals.

To evaluate the effects of individual versus pair housing on hutch microclimate (change in T after 1 h of restriction) and calves’ thermoregulatory responses (change in RT or OT after 1 h), linear mixed models (PROC MIXED) were used. Each model included the fixed effects of housing treatment, week of life (wk 4, 6, and 9), and their interaction, with a random effect of housing unit nested within treatment. The models for BW included the birth weight as a covariate. Based on the lowest AIC and Bayesian information criterion (BIC) values, a variance components covariance structure was selected.

The proportion of time individually versus pair-housed calves spent inside hutches was compared using generalized linear mixed models with a β distribution (PROC GLIMMIX) with fixed effects of housing treatment, week of life (wk 4, 6, and 9), and their interaction, with a random term for housing unit nested within treatment.

To evaluate the preference of pair-housed calves to be together, one-sample t-tests were used to compare the proportion of time they were observed in the same location against 50% (chance, no preference), separately for each week of life (wk 4, 6, or 9).

The starter intake and growth performance measures were evaluated separately for the preweaning (BW: d 42 of life; ADG, DMI, and FCR: d 1–42 of life), during weaning (BW: d 53 of life; ADG, DMI, and FCR: d 43–53 of life), and postweaning periods (BW: d 59 of life; ADG, DMI, and FCR: d 54–59 of life). Linear mixed models (PROC MIXED) were constructed for each measure with a fixed effect of housing treatment and a random term for housing unit nested within treatment. The models for BW included the birth weight as a covariate. Based on the lowest AIC and BIC values, a variance components covariance structure was selected.

### RESULTS

#### Hutch Restriction Responses

**Change in Internal Hutch Temperature.** There was a housing treatment main effect ($F_{1,30} = 6.6, P = 0.016$), with a greater increase in internal hutch
temperature during the 1 h of restriction when both pair-housed calves were inside a hutch (+2.34°C, SEM = 0.26°C) relative to the individually housed calves (+1.39°C; Figure 2A). There was no main effect of week of life or treatment × week of life interaction (F_{2,55} ≤ 1.8; P > 0.18).

**Ocular and Rectal Temperature.** For OT, the results suggested a housing treatment main effect (F_{1,30} = 3.1, P = 0.089), with a greater increase after the 1 h of restriction occurring in the individually housed calves compared with the pair-housed calves (+0.98 vs. +0.27°C, respectively, SEM = 0.28°C; Figure 2B); a larger sample size is needed to fully assess this outcome. There was no main effect of week of life or treatment × week of life interaction for the change in OT (F_{2,57} ≤ 0.7; P > 0.52). For change in RT, no main effect of housing treatment (F_{1,30} = 0.1) or week of life, nor treatment × week of life interaction was detected (F_{2,59} ≤ 0.6; P > 0.54; Figure 2C).

**Behavior**

**Hutch Use.** There was a housing treatment main effect (F_{1,25} = 8.9, P = 0.006), where individually housed calves spent a greater proportion of their time inside the hutch relative to the pair-housed calves (93.9% vs. 90.7% of time observed, respectively, SEM = 0.8%). There was no main effect of week of life or treatment × week of life interaction (F_{2,25} = 1.6; P > 0.23).

**Social Preference.** In all 3 wk observed, pairs had a preference to be together in the same hutch at the same time (89.7% vs. 88.6% vs. 79.4% of observations for wk 4, 6, and 9 of life, respectively, SEM = 1.3, 1.2, and 4.2% respectively; P < 0.0002).

**Feed Intake and Growth Performance**

**BW.** No effect of housing treatment on BW, when accounting for birth weight, was detected at d 42, 53, or 59 of life (F_{1,20} ≤ 2.3; P ≥ 0.14; Figure 3A).

**Dry Matter Intake.** No effect of housing treatment on DMI of starter was detected during the preweaning or weaning periods (F_{1,30} ≤ 1.8; P ≥ 0.19; Figure 3B). During the postweaning period, there was evidence to support our hypothesis that starter DMI was greater in pairs compared with the individually housed calves (F_{1,30} = 4.2, P = 0.050).

**Average Daily Gain.** No effect of housing treatment on ADG was detected during the preweaning, weaning, or postweaning periods (F_{1,30} ≤ 1.5; P ≥ 0.24; Figure 3C).

**Feed Conversion Ratio.** No effect of housing treatment on FCR was detected during the preweaning, weaning, or postweaning periods (F_{1,30} ≤ 0.8; P ≥ 0.39; Figure 3D). Descriptive comparisons of FE (ADG/starter DMI) between pair- versus individually housed calves during the different phases are as follows: preweaning = 3.50 versus 3.86, respectively (SEM = 0.55), weaning = 0.83 versus 0.86 (SEM = 0.04), and postweaning = 0.44 versus 0.47 (SEM = 0.03).

**DISCUSSION**

Our study is the first to explicitly examine the potential benefits of pair housing for alleviating cold stress in outdoor-housed dairy calves, particularly by standardizing the amount of time calves spent inside the hutches. We found some limited evidence in support of our hypothesis that pair housing, compared with individual housing, reduced the effects of cold stress by increasing the temperature inside the hutch when 2 calves were inside the hutch together relative to the single calf. Pair-housed calves spent the majority of the time together and spent more time outside the hutches than individually housed calves. No effect of housing was found on FCR, BW, or ADG during the 3 periods. After weaning, we found evidence suggesting support of our hypothesis that pair-housed calves would have greater starter DMI than those housed individually. Overall, pair housing calves can provide some measured benefits over individually housing calves to reduce cold stress during winter.

**Hutch Microclimate and Calf Thermoregulation**

On average, hutches were 1°C warmer after pairs of calves, rather than single calves, were restricted inside for 1 h. The lower critical temperature for calves up to 8 wk of life is around 8 to 10°C (Webster et al., 1978; Gebremedhin et al., 1981). Therefore, weather conditions in the present study exposed calves to cold stress across the entire experimental duration between December to March, with 100% and 96% of the daily average and maximum ambient temperature measurements, respectively, recorded as ≤10°C. For farmers raising calves in outdoor hutches in continental climates such as Wisconsin, an increase of 1°C inside the hutches could make an impactful difference in the thermal comfort and welfare of these calves in winter.

Our results are the first to demonstrate systematically how the body heat of 1 versus 2 calves influence the internal microclimate of the hutches during winter-time, in agreement with the results of another study our group conducted at the same facility in summer-time (Reuscher et al., 2024). In contrast, one previous study did not detect differences in temperature inside hutches shared by pairs of Jersey calves versus those of individually housed calves (Pemppek et al., 2016). How-
Figure 2. Dependent variable responses in the pair- and individually housed treatments after calves (n = 16 pairs vs. 16 individuals) were restricted inside the hutch for 1 h (with pair-housed calves together inside the same hutch). The dependent variables were (A) internal hutch temperature and calves’ (B) ocular temperature and (C) rectal temperature. Baseline values are shown for reference; treatment differences were analyzed based on the change from baseline after 1 h. Main effects of treatment were detected ($P < 0.05$) in hutch temperature between pair- and individually housed calves. Evidence suggesting a main effect of treatment was detected ($0.05 < P < 0.10$) in ocular temperature between pair- and individually housed calves. No main effects of week or treatment × week interactions were found for any variables. Error bars represent 95% CI.
Figure 3. Growth performance responses in the pair- and individually housed treatments (n = 16 pairs vs. 16 individuals), using predictions from regression models standardizing measurements by day of life. The dependent variables were (A) BW at d 42 and 53 of life (the start and end of weaning, respectively) and d 59 of life (before calves moved to postweaning group housing), accounting for birth weight, (B) DMI of starter during the preweaning, weaning, and postweaning periods (d 1 to 42, 43 to 53, and 54 to 59 of life, respectively), (C) ADG during those periods, and (D) feed conversion ratio (FCR) of starter (DMI of starter/ADG) during those periods. Lowercase letters indicate evidence suggesting (P = 0.050) treatment differences within a time period. Error bars represent 95% CI.
ever, this is likely due to differences in breed (Jerseys are smaller and can be expected to generate less heat) and methodology, as the authors did not standardize or report how much time calves spent in the hutches when recording the maximum and minimum temperatures from the data loggers.

Despite the differences in hutch microclimate between treatments, we did not detect a difference in the change in calf RT after 1 h of restriction inside the hutch. This could be because postrestriction values did not differ noticeably from baseline in either treatment. On average, the prerestriction measurements did not reflect hypothermia in calves, considered to be when RT drops below 37°C (Carstens, 1994). The lack of hypothermic states at baseline was likely because the calves spent, on average, over 90% of their total time inside the hutch, which was deeply bedded, and they were placed outside of the hutches only briefly before the 1 h restriction process occurred. Although we made this decision for the welfare of the calves, this likely limited our ability to detect changes in RT. Additionally, as this is the first study standardizing the amount of time calves spent inside the hutch to measure changes from baseline, it may be that, even if baseline values qualified as hypothermic, 1 h of restriction is not long enough to generate an effect on the RT of calves. Methodological adjustments are likely needed in future studies to capture changes in RT.

We also measured OT as a thermoregulatory response, as used in another winter study involving preweaning calves (Scoley et al., 2019) and in summer with buffaloes (Brcko et al., 2020). In contrast with our predictions, we found evidence to suggest that OT in individually housed calves increased by +0.7°C greater than for pair-housed calves during the 1 h of restriction. Instead of serving as a measure of thermoregulation, OT in this context could have captured a different source of stress, such as from handling or social isolation. Perhaps our results captured a stress-related increase in OT, similar to that documented to occur in adult dairy cattle during social isolation (Stewart et al., 2007; Mineu et al., 2023). For the individually housed calves in our study, the only social contact was hearing other calves or seeing them while outside the hutch; during restriction inside the hutch, they may have experienced social isolation stress. Similarly, during a summer study by our group at the same facility, OT decreased twice as much when pair-housed calves were restricted together compared with when they were separated (Reuscher et al., 2024). Calves raised in visual isolation from peers have been shown to be more fearful than socially housed calves in novelty testing scenarios (Jensen and Larsen, 2014) and more reactive to human handling (Duve et al., 2012). In contrast, pair-housed calves in our study were restricted together inside the hutch; the presence of their companion may have reduced the magnitude of the increase in OT during the 1 h due to social buffering, that is, the ability to cope with stress and resulting in the lowering of fear responses (De Paula Vieira et al., 2010; Overvest et al., 2018).

**Hutch Use**

On average, all calves spent over 90% of their time inside a hutch. However, the amount of time pair-housed calves were observed to be outside was 3.2 percentage points greater than the individually housed ones, equivalent to 46 min/d. Furthermore, in wk 9, individually housed calves were never recorded outside the hutch on d 3 of observation, whereas pair-housed calves spent 9% of the time outside. As they were fully weaned by that week, and starter and water were located inside the hutch, the calves had fewer reasons to go outside. The differences in time spent outside suggest that pair-housed calves may have been better able to cope with the cold stress than the individually housed ones. We speculate the pair-housed calves may have spent more time outside to express play behaviors. We could not accurately record play behavior due to the 15-min time sampling interval used in this study. A previous study reported that socially housed calves engaged in more locomotor play behavior than individually housed ones did, although greater space allowance also plays a role (Jensen et al., 1998), and play behavior is sometimes interpreted as an indicator of positive welfare in calves. As the hutches have too little space to allow for locomotor play, the only place this could be expressed would be in the outdoor enclosure. Future research using continuous behavior observation could elucidate how calves spent their time outdoors, including engaging in play.

A previous study using similar adjacent hutches for pair-housed calves reported that calves spent approximately 55% of their time inside a hutch during a Canadian winter, regardless of whether they were pair- or individually housed (Wormsbecher et al., 2017). However, in the summer portion of their trial, pair-housed calves spent 53% of the time inside a hutch, whereas individually housed ones spent only 33% of the time inside. The researchers attribute this seasonal difference to a potential tradeoff in individually housed calves between seeking visual social contact versus thermal comfort in winter. The difference in the percentage of time spent outdoors in winter in the earlier study compared with ours may be due to methodological differences. The previous study only recorded behavior during the day (and not overnight, when the lowest temperatures
occurred and calves would be expected to increase time inside the hutch) and observed calves for 20 min per h during 6 nonconsecutive hours from 0730 and 1800 h on 1 d/wk for the 6-wk trial, whereas we recorded in 15-min intervals during 72 consecutive hours in 3 separate weeks of life.

In our study, regardless of location (outside or in either hutch), calves within a pair had a preference to be together most of the time, consistently around 80% to 90% of the time observed among pairs. This proportion is at least as high as in other North American studies in the summer, fall, and winter seasons, which reported that 80% of the time, pairs chose to be in the same hutch together (Pempek et al., 2013; Wormsbecher et al., 2017; Reuscher et al., 2024). Calves have been demonstrated to be motivated to access and maintain physical contact with another calf (Holm et al., 2002; Ede et al., 2022) and spend time in proximity to preferred social companions in group housing (Færevik et al., 2007; Lindner et al., 2022).

In addition to a potential overall motivation for social proximity, the high proportion of time pair-housed calves chose to spend in the same hutch was also consistent with our original hypothesis that calves may choose to huddle together for warmth in winter conditions. Bovine veterinary practitioners have long noted that hypothermic calves can be identified through their behavior of seeking proximity to a source of heat such as a farmer or other animal (Anderson and Bates, 1984). Research studies have also documented dairy calves huddling for warmth in noninsulated barns, and the huddling increased as the ambient temperature decreased (Bøe and Havrevoll, 1993). Another study reported that group-housed calves raised in a cold environment (Finland) averaged about 72% of their time near another calf (Hänninen et al., 2003). Our finding that 2 calves in the same hutch warms the microclimate more than a single calf adds support to the theory that calves huddle for warmth in cold weather to benefit thermoregulation.

Although calves preferred to share the same space the majority of the time, there are likely downsides to providing only a single hutch for multiple calves, especially as Holsteins grow; in contrast, providing 2 connected hutches per pair results in at least the same per-calf area as in individual housing. In addition to the size of the housing unit playing a significant role in locomotor behavioral expression (Tapki et al., 2006; Færevik et al., 2008), adequate bedded space allowance of at least 3.3 m² per calf is important to maintain sufficient volume for air exchange and to maintain bedding dryness (Nordlund and Halbach, 2019). However, this space recommendation is based on studies in pens within calf barns, and typical outdoor hutches provide less space, when excluding the outdoor enclosure, which may not be usable resting space depending on the conditions. A key management practice during winter is to provide calves with deep, dry bedding for nesting as insulation to maintain heat around the calf (Nordlund, 2008). An additional concern about housing 2 calves with a single hutch is that the bedding would become soiled twice as fast and need more farm labor to maintain. However, if provided with 2 hutches, the calves can, in theory, distribute their usage.

Initially, we hypothesized that calves would prefer to be together and potentially spend more time in 1 of the 2 hutches, but hutch preference may change over time as the bedding became soiled. We reported temporal patterns of hutch use only descriptively. During wk 4 of life, on average, pair-housed calves did appear to use one hutch more initially, but then used both hutches equally by d 3 of observation. However, during wk 6 and 9, the calves appeared to continue to use the same hutch more often between d 1 and 3. Nonetheless, the variation among pairs of calves in use of their 2 hutches was 2- to 3-fold greater on d 3 in each week; this suggested a lack of temporal consistency in potential hutch preference, perhaps due to environmental factors (e.g., wind, sun). These patterns potentially underscore the importance of providing pair-housed calves with the option to move between hutches. However, we were limited in our ability to address this question, as the protocol on the research farm was for farm staff to add new straw twice weekly as well as when deemed necessary by visual assessment. This protocol resulted in fresh bedding being added to some of the hutches during the observation periods. The effect of this management protocol can be clearly seen in the descriptive bedding DM data for individual calf hutches: in all 3 wks, the bedding was drier at the end of the 3-d observation period than on the first day. Future studies could more directly address how the bedding DM plays a role in calf preferences and how this affects farm labor.

**Starter Intake and Growth**

During the preweaning and weaning periods, we did not detect any differences in DMI of starter, ADG, BW (accounting for birthweight), or FCR between housing treatments. However, during the postweaning period, we observed evidence suggesting greater DMI in pair-housed relative to individually housed calves; no differences in the other measures were detected during this period. Previously, several studies reported greater DMI of starter, BW, or ADG for pair- or group-housed calves compared with individually housed calves in the preweaning (Babu et al., 2004; Hepola et al., 2006; De Paula Vieira et al., 2010) or weaning periods (Costa et
Our results are consistent with some other studies that did not detect differences between pair- and individually housed calves during the preweaning phase (Pempek et al., 2016; Liu et al., 2020) but did report either tendencies (Liu et al., 2020) or significantly greater (Pempek et al., 2016) DMI for pair-housed calves during the postweaning phase compared with the individually housed calves. Both of those authors attributed the greater postweaning DMI shown by pair-housed calves to social facilitation (De Paula Vieira et al., 2010; Jensen et al., 2015; Miller-Cushon and DeVries, 2016). A calf may be more likely to approach the starter when the other calf in the pair is already feeding. In our study, pair-housed calves could see their companions eating, whereas the individually housed ones could see other calves only when they were already outside the hutch. The reason these differences were detected only after weaning is unclear. However, on a numerical basis, we observed individually housed calves outside the hutch less in wk 9 than in previous weeks, and on d 3 of observation that week, they were never recorded outside. Thus, their opportunity to see other calves eating may have become even more limited after weaning. In addition, another study reported formerly pair-housed calves ate grain sooner, and in greater quantities, than individually housed calves after the move to postweaning group housing (De Paula Vieira et al., 2010).

The lack of treatment differences in preweaning growth performance in the current study is perhaps because these measures are cumulative and reflect the combination of several housing and management factors. Calves were fed per farm protocol, receiving a milk allowance of ∼10% of their BW in the first 5 ± 1 d of life. This practice may have affected our growth results, as it has been recommended to increase milk allowance to 15% of BW in winter to accommodate the metabolic strain (Anderson and Bates, 1984). Another such factor may be that all calves wore jackets until 21 ± 1 d of life. In a previous study, individually housed calves who had their jackets removed at 20 d of age had lower ADG for the week following jacket removal compared with calves who never received jackets (Scoley et al., 2019). The energy intake from previously jacketed calves was not sufficient to compensate and maintain heat production and growth (Scoley et al., 2019). In the current study, removing the jackets after calves wore them continuously for the first 3 wk of life may have confounded our ability to detect the effects on growth performance resulting from pair-housed calves having a conspecific with which to share a hutch and maintain body heat. Nonetheless, following farm protocol and for welfare reasons, we provided jackets in the early weeks of life when the calves were most vulnerable to severe cold stress in outdoor housing. It was necessary to remove the jackets to allow calves the potential to share body heat directly in the pair-housed treatments. In addition, we bedded the hutches deeply with straw, which provides insulation (Nordlund, 2008). It is possible that this management factor to reduce heat loss further limited our ability to detect treatment differences. Future studies in different climates or with different management practices could further explore the potential for pair housing to provide growth benefits in winter conditions.

Only 2 other studies comparing individually housed calves to pair- or group-housed ones have reported measures of how efficient the calves were at converting energy intake to growth performance, and they also found no treatment differences (Hepola et al., 2006; Zhang et al., 2021). The latter study, similar to ours, focused on concentrate feeding efficiency (ADG/daily concentrate intake) of pair- versus individually housed calves; the numerical difference between their treatments of 0.34 (Zhang et al., 2021) was nearly identical to the 0.36 difference in our study. A limitation of our study’s ability to fully capture FE is that we did not include energy from milk. Nonetheless, an earlier study incorporating the total DMI from milk, hay, and starter (Hepola et al., 2006) likewise did not detect differences in efficiency between individual and group housing. Because few studies to date have evaluated these outcomes, future studies incorporating total energy intake could add to our understanding of the effects of social housing on growth efficiency.

In the literature, the method of determining how efficient an animal is at converting the nutrition they consume into a measure of production (growth or lactation) is variable. Two factors vary: first, whether the input (feed) or the output (growth or lactation) should be used in the numerator or denominator, and second, the terminology used. The output has been used in the numerator when reporting feed conversion efficiency (kg gain/kg DMI in heifer calves; Scoley et al., 2019), concentrate feeding efficiency (ADG/daily concentrate intake in male dairy calves; Zhang et al., 2021), or FE (calculated as gain/feed in heifer calves; Hepola et al., 2006; Khan et al., 2007a,b; Litherland et al., 2014; and milk output/feed input in lactating cows; NASEM, 2021). However, others have reported FE with the output in the denominator (feed/gain in heifer calves; Coleman et al., 1996; and in growing heifers; Hoffman et al., 2007), as with feed conversion ratio (feed/gain in beef cattle; Cottle and Pitchford, 2014). Because methods for reporting efficiency are variable.
and sometimes contradictory across studies, we encourage other researchers to report (at least descriptively) both feed conversion ratio (DMI of starter/ADG) and FE (the inverse), to facilitate comparison of magnitudes across studies.

CONCLUSIONS

We found some limited evidence to support our hypothesis that pair housing, compared with individual housing, reduced the effects of cold stress in outdoor-housed dairy calves. When calves were restricted inside a hutch in pairs rather than individually, the temperature inside the hutch increased more. Perhaps due to both general motivation for social contact and the benefits of sharing body heat, pair-housed calves spent a substantial majority of their time together. They also spent more time outdoors than individually housed calves, perhaps reflecting better ability to cope with cold stress. Although no treatment differences were detected in many growth performance outcomes, we observed evidence suggesting support for our prediction of greater starter intakes for pair-housed calves during the postweaning period, potentially due to social facilitation. Pair housing calves during the winter can provide benefits to calf welfare by providing social contact and some alleviation of cold stress.

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