Journal of Agricultural Engineering

Journal of Agricultural Engineering 2026; LVII:1706
doi:10.4081/jae.2025.1706

Locomotor activity of dairy cows in new and converted barns

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Abstract

Locomotor activity contributes to the fitness and physiological stability of dairy cows and is a key indicator of animal welfare. Modern barn design should therefore aim to promote cow movement. A central question is whether such activity-promoting environments require entirely new construction or whether existing barns can be effectively converted to meet current welfare standards. This observational study investigates the structural and technical factors influencing cow activity under practical farming conditions. Data were collected on 18 commercial dairy farms in Baden-Württemberg, Germany, of which six featured converted existing facilities and twelve newly constructed barns between 2018 and 2022. Cow activity was measured using ALT pedometers (Holz, Falkenhagen, Germany) over 56 measurement periods from 2020 to 2022. A total of 633 cows were monitored, yielding 24,202 daily activity records. Activity pulses were analyzed using a linear mixed-effects model accounting for repeated measures and hierarchical data structure. The results showed no significant differences in locomotor activity between cows housed in newly built versus converted barns. Similarly, no significant effect was observed for floor type (slatted vs flat). In contrast, pasture access, month of measurement, milking system, parity, and days in milk significantly influenced activity levels. Cows with pasture access displayed the highest activity, and seasonal effects pointed to environmental influences. Two farms exhibited markedly elevated activity: presumably one due to long distances to pasture, the other due to feed presentation via an external hayrack – highlighting the impact of specific management features. Contrary to earlier research, rubber flooring did not significantly affect activity. This may be explained by the widespread use of rubber flooring (on average 80% coverage) across nearly all farms, which reduced variability. Herd size and milk yield also showed no significant effect, likely due to the use of automated feeding systems reducing the need to walk for feed. While causal conclusions are limited by the non-randomized study design, the results suggest that well-executed barn conversions can offer locomotor opportunities equivalent to those of new buildings. This supports the view that modern conversions can be a resource-efficient and welfare-compatible solution for updating dairy housing. The findings provide a valuable evidence base for structural planning and policy development in sustainable dairy farming.

Key words: dairy cow welfare; barn construction; converted barns; locomotor activity.

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Introduction

Movement opportunities contribute significantly to the overall fitness and welfare of dairy cows (Shepley *et al*., 2020). Exercise improves homeostasis by increasing red blood cell counts and reducing plasma lactate (Blake *et al*., 1982; Davidson and Beede, 2003, 2009). It lowers NEFA levels, mitigating metabolic risks (Adewuyi *et al*., 2006), and prevents ketosis through ketone metabolism (Buer *et al*., 2016). Trained cows show improved cardiovascular function (Davidson and Beede, 2003; Blake *et al*., 1982). Efficient claw mechanism supports blood circulation and horn formation, while poor nutrient delivery to the vascularized epidermis impairs horn quality (Günther, 1991; Greenough, 2007; Mülling and Budras, 1998; Maierl and Mülling, 2004).

The locomotor patterns exhibited by dairy cows are characterized by individual consistency, reflecting both their physiological state and the strategies they employ to cope (Müller and Schrader, 2005; Wierig *et al*., 2019). While the overall activity of the herd is shaped by management routines, individual behavior varies depending on factors such as parity, lactation stage, and health status, particularly lameness (Brzozowska *et al*., 2014; Thorup *et al*., 2015; Ji *et al*., 2021; Kok *et al*., 2023). Hut *et al*. (2022) showed that behavioral time budgets for eating, lying, standing, walking, and rumination differ significantly by parity and lactation stage, with primiparous cows exhibiting reduced lying and increased standing and walking postpartum. Farm management also affected activity, as cows on conventional milking systems with pasture access spent more time walking and standing and less time lying than those on automatic milking systems without pasture. All cows displayed a consistent circadian rhythm, characterized by greater daytime activity and nighttime rest, with primiparous cows walking more during the day than multiparous cows. These patterns correspond with findings by Maselyne *et al*. (2017), who reported a steep decline in lying time until four weeks postpartum, followed by a gradual increase, reflected similarly in motion index and step frequency. While Müller and Schrader (2005) found little impact of ambient temperature and light on cow activity, other studies show seasonal effects, with reduced activity in winter, suggesting behavioral thermoregulation (Brzozowska *et al*., 2014) and increased standing during heat stress, especially in afternoons (Heinicke *et al*., 2017). According to Abeni and Galli (2016), a higher temperature-humidity index (THI) is associated with increased cow activity, suggesting that it could be used as an early indicator of heat stress.

Several factors are known that influence exercise of dairy cows. When given the choice between pasture and indoor housing, cows show a preference for pasture, particularly at night (Arnott *et al*., 2017; Legrand *et al*., 2009). Pasture access significantly increases the locomotor activity in dairy cows compared to loose housing (Bleuler, 1981; Krohn *et al*., 1992; Brade 2001; Crump *et al*., 2019; Benz *et al*., 2020; Shepley *et al*., 2020; Hut *et al*., 2022). Shepley *et al*. (2020) observed increased overall activity and behavioral variability during summer pasture access, with pasture visits positively correlating with indoor movement.

Rubber flooring has been designed to replicate the softness of pasture (Benz, 2002; Telezhenko and Bergsten, 2005), as deformable surfaces are better able to accommodate anatomical and biomechanical requirements (Keller *et al*., 2009; Schmid *et al*., 2009). In comparison with concrete slats, the utilization of rubber flooring has been demonstrated to enhance claw health and encourage natural behaviors (Benz, 2002). However, it has been observed that cattle tend to move more rapidly across rubber than concrete flooring surfaces, as evidenced by numerous studies (Telezhenko and Bergsten, 2005; Flower *et al*., 2007; Alsaaod *et al*., 2017). Furthermore, it has been demonstrated that rubber flooring surfaces are associated with elevated levels of activity in cattle (Platz *et al*., 2008; Jungbluth *et al*., 2003; Flower *et al*., 2007). Providing 1.85 m of rubber flooring in front of the feed bunk increased the time cows spent standing without eating on the rubber surface, and also led to a slight increase in total standing time elsewhere in the pen (Fregonesi *et al*., 2004).

Space availability influences cow activity, with increased space stimulating locomotor activity (Jensen, 1999; Telezhenko *et al*., 2012). High stocking density reduces activity due to restricted space and social stress (Estevez *et al*., 2007). Activity also depends on parity, lactation stage, health, and social integration (Müller and Schrader, 2005; Davidson and Beede, 2009; Hut *et al*., 2022; Hasenpusch, 2023). Contemporary dairy housing systems are progressively designed to incorporate the aforementioned factors, including access to pasture, deformable walking surfaces (*e.g*., rubber flooring), sufficient space allowance, and management practices that account for parity, lactation stage, and social dynamics. However, the extent to which such conditions can be replicated in converted barns, where structural constraints may limit design flexibility, remains uncertain. The central question that emerges from this study is whether barn conversions can offer dairy cows comparable locomotion opportunities to those found in purpose-built, modern housing systems.

This observational study compares the activity data of cows from six converted barns and twelve newly constructed barns. The farms exhibited a high level of structural and technical standards, as evidenced by the prevalence of rubber flooring in walking areas and the near-universal installation of elevated feedstalls with feeding place dividers. The objective of this analysis is to determine whether a barn conversion can provide cows with movement opportunities comparable to those available in a new barn construction.

Materials and Methods

Survey data collection was carried out in 18 dairy cow farms in Baden-Württemberg, in southern Germany. The herd size ranged between 38 and 240 cows, which is typical for family-run farms in south-west Germany. With an area of 35,751 square kilometers, Baden-Württemberg is the third largest German federal state, located in the southwest of Germany. There are approximately 5,000 dairy farms in Baden-Württemberg with a total of 300,000 dairy cows. The farms were spread across Baden-Württemberg in different geographical regions and climate zones (Figure 1).

At each farm, the barn was either newly built or converted between 2018 and 2022 as part of the EIP Agri Project "Bauen in der Rinderhaltung in Baden-Württemberg". The project aimed to reconcile the conflicting objectives of animal welfare and environmental protection by implementing combinations of structural and technical solutions to reduce ammonia emissions on practical farms, while also testing these solutions for functional safety.

The farmers at each farm were required to make structural-technical contributions in the fields of optimizing animal welfare, reducing ammonia emissions and sustainability. In the area of ammonia emission reduction, the main objective was to reduce the amount of soiled, *i.e*., emission-active, surfaces and to minimize the contact time between feces and urine on the remaining soiled surfaces and to clean them effectively. As a result, feeding places on 17 farms were designed as elevated feedstalls with dividers. The remaining farm with a slatted floor had feeding place dividers without platforms (farm C2). On 16 farms, emission-reducing rubber flooring was used at least in the feeding alley, as this was assumed to have the greatest effect on ammonia emission reduction and claw health (Benz *et al*., 2024). One farm used an automated system to distribute straw on the alleys (farm C4). Excluding this particular instance, in which walking surfaces were

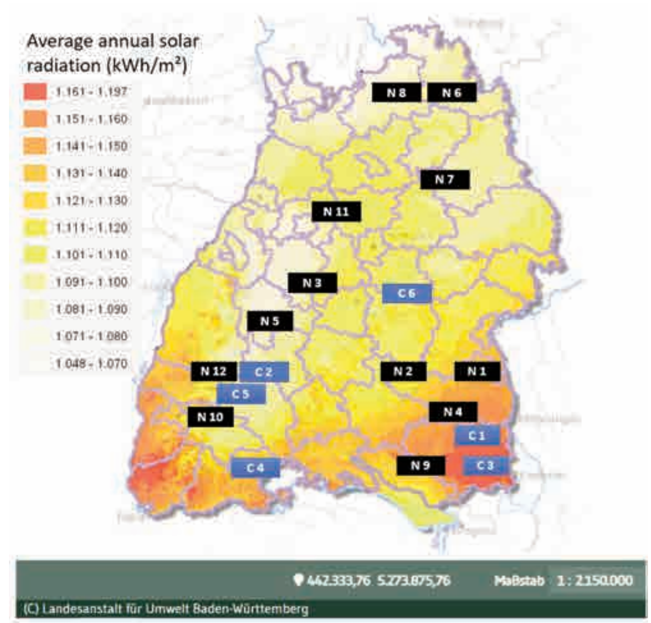


Figure 1. Distribution of sampled farms across the whole of Baden-Württemberg in different geographical regions and climate zone. Blue, farms with converted barns; black, farms with new barns.

somewhat deformable due to the straw bedding, the average proportion of rubber-covered walking area across the remaining 17 farms was 80%. Ten farms used an automatic milking system (AMS), with one farm switching from parlor milking to AMS within the study period (farm C2). Summer grazing was practiced on seven farms, with one farm providing grazing in the form of “exercise pasture” with feed provided in the barn (farm N6). Eight farms had attached exercise yards, and a further two had integrated exercise yards (farms N6 and N7). Barns were categorized into converted and newly built barns. The definition of a barn construction project as a conversion was determined by the utilization of more than 50% of the functional areas comprising lying, feeding and milking (including the waiting area, each calculated at 50%) of an existing barn (Table 1).

The categorization of Farm N12 as a new building was determined by the fact that only 39% of the functional areas were utilized in the existing building, with 38% of lying and 28% of feeding occurring in the old building. The primary determining factor in this case was the location of the waiting area, which was situated in the new building. Consequently, only 50% of the milking area was considered in the calculation.

The calculation of the walking area per cow was based exclusively on the area where cows could actually walk, i.e., excluding the areas of cubicles and feedstalls. One of the farms was a compost-bedded barn with elevated feedstalls. In this case, the lying area was included in the calculation of the total walking area, as it was not possible to clearly distinguish between functional zones. Tables 2 and 3 summarize the characteristics of the farms and illustrate the barn layouts.

As the floor plans of the 18 farms clearly show, most of the projects were built individually and are not directly comparable. The exception is the new six-row barns with an attached structured exercise yard, where the floor plans are similar (N1, N2, N3). In particular, the converted barns are very different in terms of the layout of the functional areas, but there are also similarities. For instance, a minimum width of 2.5 to 3 meters has been implemented in the feeding alleys, which are typically equipped with yielding rubber mats. In addition, in both, the new buildings and the conversion projects, the feed pens were designed as elevated feed stalls with feed pen dividers at least every second feed pen. The cubicles were all 1.2 to 1.25 meters wide, with facing cubicles at least 5 to 5.30 meters long and cubicles against a wall 2.7 to 3 meters long. A well-designed indoor climate control concept was consistently implemented throughout. Fans and/or roof or wall openings were installed in some places to assist with air exchange. The subsequent images offer a visual representation of the construction methods employed in the converted barns (Figure 2).

Measurement technology; data collection and evaluation

ALT pedometers (Holz, Falkenhagen, Germany) were used to measure activity. The pedometers were configured to record step activity in the form of activity pulses at a rate of 70 records per second. It should be noted that the ALT pedometers used in this study provided activity pulses and not activity time. The devices were attached to the left forefoot, positioned on the front of the fetlock

Table 1. Definition of a conversion project by utilization of > 50% of the functional areas of the existing building.

Farm	Lying (%)	Feeding (%)	Milking (%)	Average (%)
C1	100	100	100	100
C2	21	37	100	52
C3	66	46	100	71
C4	100	100	100	100
C5	49	100	100	83
C6	84	80	100	88
(N12)	38	28	50	39

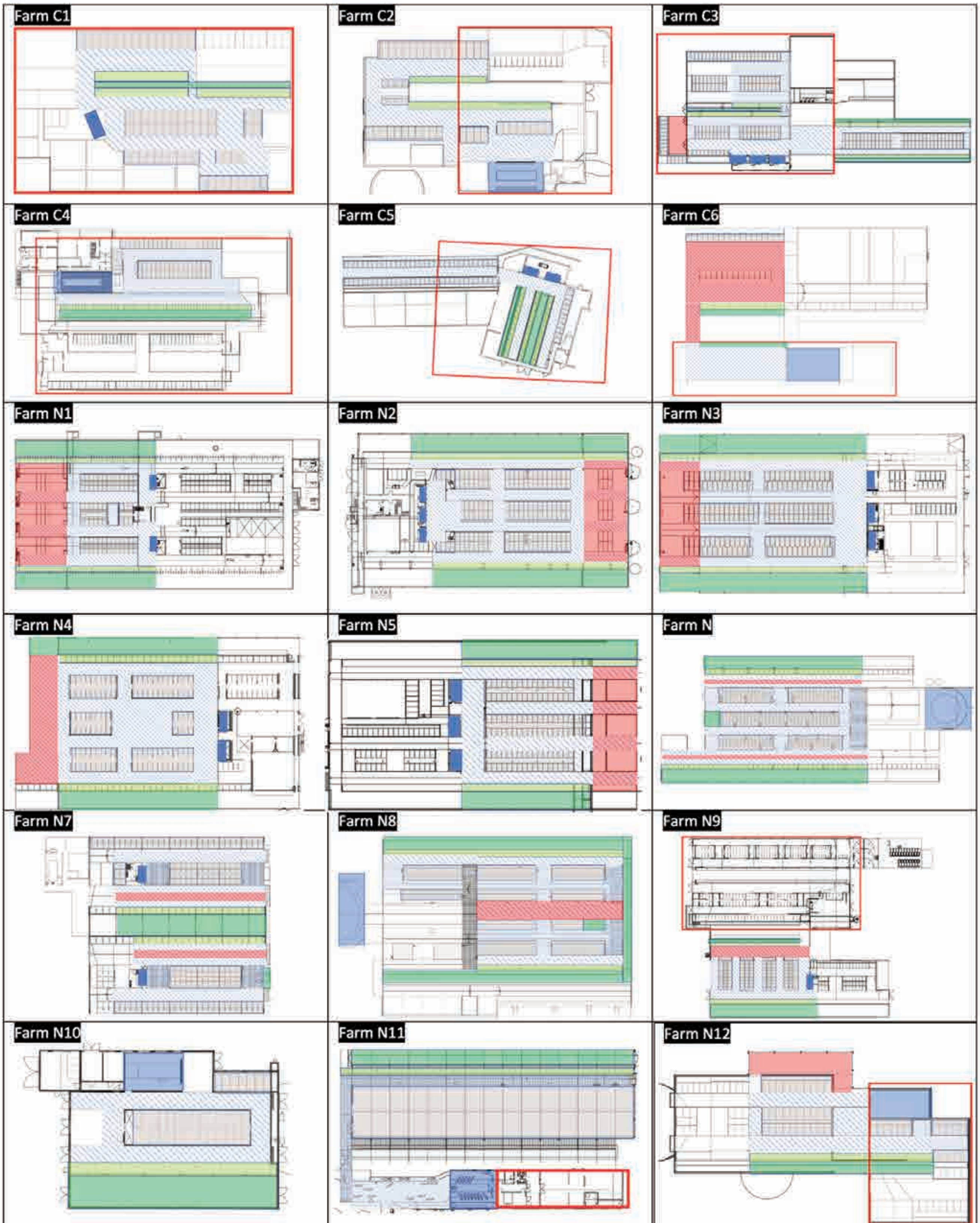
C, conversion; N, new building.

Table 2. Characteristics of the 18 participating farms with new and converted loose housing systems.

Farm (C, converted; N, new built)	Herd size	Milking system (AMS, automatic; P, parlor)	Lactating animals without special need	Breeds	Annual milk yield (kg)	Floor type (alleys) (S, slatted; P, paved)	Total walking area (m²)	Walking area on exercise yard (m²)	Pasture access	Space per cow (m²/cow)	Proportion of rubber-covered walking area (%)
C1	78	AMS	74	BV, SBT, FL[*]	7500	S[#]	215			2.9	100
C2	44	AMS	38	BV, VW[*]	6100	P[#]	247		x	6.5	100
C3	193	AMS	149	BV, SBT, RBT[*] FL[*]	6700	P[#]	879		x	5.9	51
C4	62	P	58	FL	4900	P[#]	539		x	9.3	
C5	72	AMS	72[§]	VW	7500	S	281	64	x	3.9	100
C6	198	P	112	FL[*]	9400	P[#]	997	265		8.9	40
N1	144	AMS	67	SBT, RBT, FL[*]	9500	P[#]	791	356		11.8	87
N2	163	AMS	136	SBT, FL[*]	11500	P[#]	898	180		6.6	93
N3	188	AMS	165	FL	11200	P[#]	974	204		5.9	55
N4	146	AMS	128	SBT, RBT	10300	P[#]	1203	250		9.4	100
N5	150	AMS	120	SBT, RBT, FL[*]	9900	P[#]	624	176		5.2	80
N6	230	P	186	FL[!]	8100	P[#]	1097	440[°]	x[§]	5.9	76
N7	148	AMS	96	FL	11000	P[#]	710	236[°]		7.4	86
N8	210	P	179	SBT, RBT, FL[*]	8700	P[#]	1125	328		6.3	58
N9	180	AMS	72	SBT, FL[*]	9700	S[#]	504	164		7.0	93
N10	42	P	35	BV, SBT[*]	8100	P[#]	165		x	4.7	100
N11	75	P	58	SBT	5400	P[#]	980		x	16.9	
N12	48	P	42	VW	7800	P[#]	298	113	x	7.1	64

[*]Also crossbred animals; [#]feeding alley predominantly with elevated feedstalls; [°]integrated; [§]exercise pasture with feed provided in the barn.

Table 3. Floor plans with color-coded functional areas.



C, conversion; N, new building; red frame, existing building; EY, exercise yard; iEY, integrated exercise yard (both in red); green feeding table; light green elevated feedstalls.

with the engraved triangle facing down to ensure correct orientation. Dairy cows were randomly selected in advance from a list of all cows at a specific farm. Cows that were lame or in poor health were excluded from the study. Between 15 and 20 animals were selected per period, but data were partly lost due to technical problems. This meant that a single measurement period resulted in data sets with a smaller number of animals than originally planned. For organizational reasons, the recording period length varied. This was simply due to the need for staff to be available and for the farmer to have time to help with the application and removal of the pedometers.

The pedometers recorded ankle temperature, stride activity and lying times (both lateral and sternal) at a fixed 60-min interval with sensitivity level 9 set according to the manufacturer's recommendations. This sensitivity level was chosen to ensure reliable step detection while minimizing false activity signals. It was considered optimal based on the floor conditions (e.g., proportion of rubber-covered walking area) and prior testing and provided an appropriate balance between detection accuracy and false signal reduction. Activity values were then summed up to daily values.

Data was transmitted wirelessly via a modem and stored in an SQL database for further processing. The system consisted of three components: a pedometer logger; a modem with a PC connection; and communications software that enabled automated data retrieval and analysis. A total of 56 periods across 18 farms were observed between 2020 and 2022 (Figure 3). Pedometer data on

Figure 2. Illustration of the six converted barns, including information about *e.g.*, walking surfaces, feeding pens, feeding systems.

daily activity measures were available from 18 farms with a total sample of 633 dairy cows. Some cows were measured in two periods resulting in 697 cow-by-period combinations. In each cow-by-period, data were repeatedly measured for up to 190 days. Data with unexpected high and low activity values smaller than 50% or larger than 200% of the mean activity per cow-by-period were deleted. Values larger than twice the mean normally indicated heat behavior. Values lower than expected occurred at the first day of measurement or are caused by technical problems. In the latter, this often resulted in missing values on all following days. Additionally, one cow was excluded because the day of calving was not documented. Finally, a total of 24,202 out of 25,032 datapoints were used.

Statistical model

Data were analyzed using the following model:

$$y_{ijklmnopq} = \mu + \alpha_i + \gamma_j + \delta_k + \theta_l + \vartheta_q + f_m + p_{mn} + c_{mno} + \beta_1 x_{1ijklmnopq} + \beta_2 x_{2ijklmnopq} + \beta_3 x_{3ijklmnopq} + \beta_4 x_{4ijklmnopq} + \beta_5 x_{5ijklmnopq} + \beta_6 x_{6ijklmnopq} + e_{ijklmnopq}$$

where $y_{ijklmnopq}$ is the observation of cow o in lactation q observed in period n of farm m with floor type i, construction project j, pasture k at day p of month l, μ is the intercept, α_i is the fixed effect of floor type γ_i, g_j is the fixed effect of construction project j, δ_k is the fixed effect of pasture k, θ_l is the fixed effect of month l, ϑ_q is the fixed effect of lactation q, f_m, p_{mn}, and c_{mno}, are the random effects of farm m, period n within farm m and cow o within period and farm, β_x (x = 1 to 6) are the slope parameters for herd size ($x_{1ijklmnopq}$), milk yield ($x_{2ijklmnopq}$), area per cow ($x_{3ijklmnopq}$), proportion of rubber-covered walking area ($x_{4ijklmnopq}$), day in milk ($x_{5ijklmnopq}$), and total area ($x_{6ijklmnopq}$), and $e_{ijklmnopq}$ is the error of $y_{ijklmnopq}$. The random effects p_{mn} and c_{mno} accounts for the hierarchical sampling and therefore for the repeated measures data structure of periods and cows, respectively. Error effects within a farm-by-period-by-cow combination were allowed to be temporary autocorrelated with a first order autoregressive variance-covariance structure. However, fitting both a constant covariance *via* c_{mno} and a first order autoregression resulted in close to zero variance of cow effects and a bounded covariance of 1. The latter means that the covariance just captures the cow main effects. We therefore dropped the autocorrelation and kept constant covariance. All covariates were farm-specific and thus equal for all observations from the farm. To fulfil pre-requisites of normal distributed and homogeneous variance of residuals, data were logarithmically transformed prior to analysis. If covariates were not significant, they were dropped in the final model. This was the case for the covariate herd size (p=0.4583), farm milk yield (p=0.4300), rubber proportion (p=0.2468), area per cow (p=0.4093), and total area (p=0.6851). Means were estimated in case of significant F tests. These means were back-transformed for presentation purposes and denoted as medians. Differences of adjusted means were back-transformed and denoted as ratios. Standard errors were back-transformed using the Delta method. Additionally, for the predictive variables floor type and construction project an equivalence test was performed. Means were considered as equivalent if their difference was less than 15% (0.14 on the logarithmic scale).

The analysis was performed using the PROC MIXED procedure in SAS. Variance component starting values as well as the first order autoregression model was fitted using ASReml 4.2 stand-alone due to memory problems in SAS.

Results

The results and figures presented below are based on model-adjusted means and illustrate the effects of various fixed factors on locomotor activity. The median activity of two of the analyzed farms differed significantly from the average across all farms (farm C4, p=0.0018; farm N8, p=0.0047). Overall, ten farms had activity levels below the median (85-99%), while eight had activity levels above the median (100-139%) (Figure 4). The characteristics of the construction project (new build or conversion) and the floor type (slatted or paved) had no significant impact on animal activity. Both showed equivalent activity levels, with differences of up to 15% being considered as negligible. On the other hand, the factors pasture, month, milking system and lactation number showed significant influences, as shown in Table 4.

Days in milk

There was a statistically significant negative effect of days in milk on activity (0.02% per day), indicating a slight decrease in activity with advancing lactation.

Floor type, milking system, grazing

The number of recorded activity impulses on paved floors was slightly higher than on slatted floors (2%); however, the difference was not statistically significant. Barns equipped with an automatic milking system (AMS) showed significantly higher activity levels (34%) compared to conventional milking parlors. Cows with pasture access exhibited significantly higher activity (85%) than those without access (Figure 5).

Months

From November to February, locomotor activity values were 12% below the 12-month mean, whereas the July to September values were 29% higher (Figure 6).

Lactation number

Animals with higher lactation numbers showed decreasing activity (Figure 7).

Discussion

This study is an observational study. It is not an experiment where factor levels were randomly applied to farms. Therefore, causal relationships cannot be inferred from the results of this

Table 4. Sources and p-values from analysis of variance table for the factors pasture, construction project, floor type, month, milking system, parity and days in milk on cow activity; p-values corresponding to significant F-tests are in bold.

Effect	p
Pasture (yes/no)	**<0.001**
Construction project (conversion/new build)	0.5061
Floor type (slatted/level)	0.2448
Month	**<0.001**
Milking system (milking parlor/AMS)	**0.0016**
Lactation number	**<0.001**
Days in milk	**0.0034**

study alone. It is fundamentally possible, for example, that the newly built and converted barns differ systematically with regard to a third variable that is not considered by our model. Furthermore, the study does not show that activity was increased due to building new or converted barns, as activity data prior to building barns were not available. Additionally, data were highly correlated due to the repeated data structure. Our attempt was therefore to include all possible variables known to influence cow activity into the analysis and to account for the repeated data structure by fitting an appropriate model. However, we cannot rule out that other factors may have influenced the results without being considered in the model. The results of the study appear to be valid due to good agreement with the results of already known experiments and the large amount of data (633 cows, 24,202 data points,

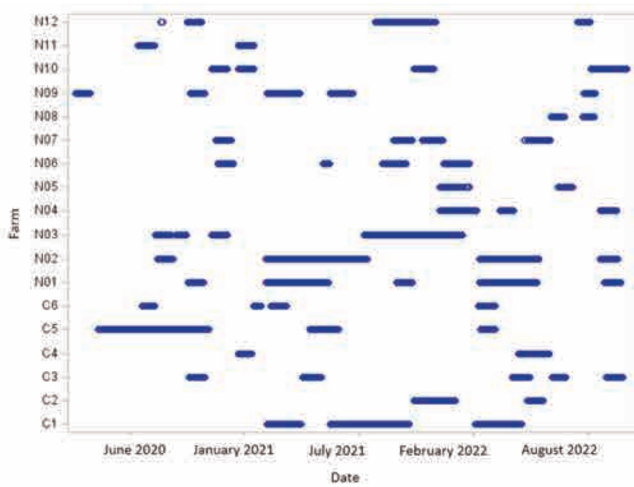


Figure 3. Measurement periods on the 18 farms.

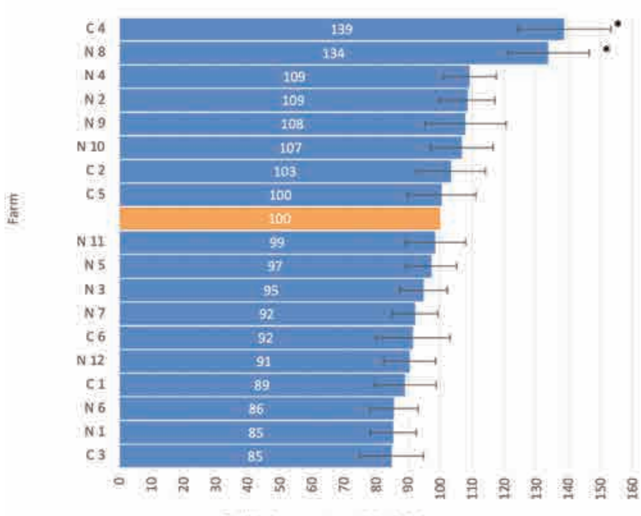


Figure 4. Relative activity of cows on the 18 farms in relation to median activity across farms. Ratios are based on back-transformed adjusted mean differences. Ratios significantly different from 1 (= 100%) are marked with an asterisk. Ratios are based on back-transformed adjusted mean differences.

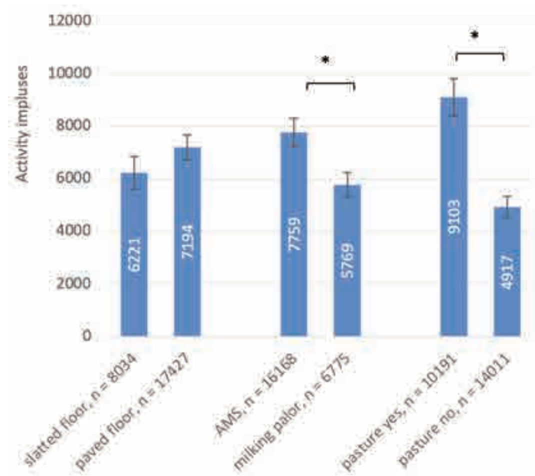


Figure 5. Activity pulses for the covariates floor type (slatted/paved), milking system (AMS/milking parlor) and pasture (yes/no), adjusted medians and standard errors, significant differences are marked with an asterisk. Means are based on back-transformed adjusted means.

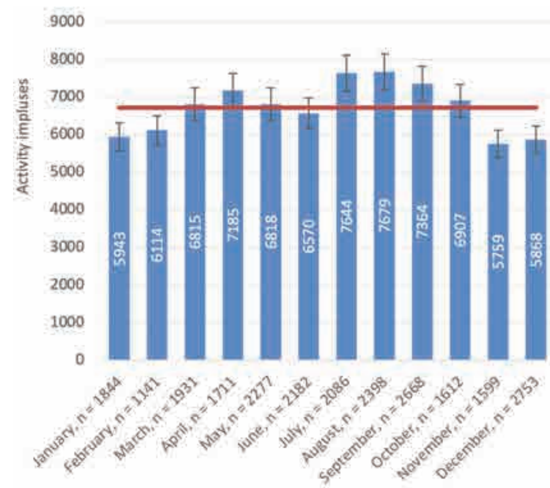


Figure 6. Activity in the twelve months of the year (adjusted medians with standard error). Means are based on back-transformed adjusted means. The red line indicates the mean value.

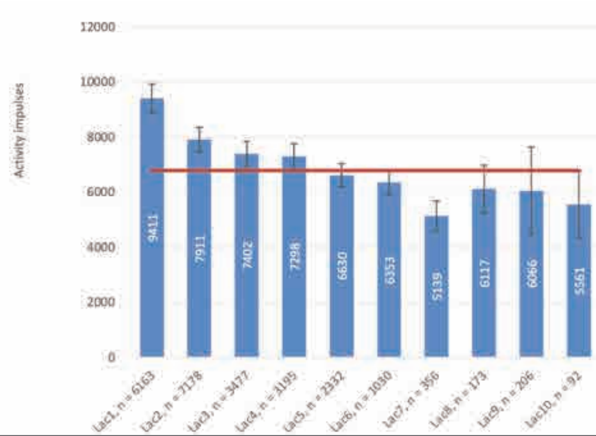


Figure 7. Activity of animals from the first to the tenth lactation (adjusted medians with standard error). Means are based on back-transformed adjusted means. The red line indicates the mean value. Lac1 to Lac10 stands for Lactation 1 to Lactation 10.

18 farms, three years of data). However, proof of causal relationships requires experimental verification and interpretation of current results needs to make carefully.

It is clear that physical activity as measured by our pedometers is generally beneficial to the health of cows (Lamb *et al*., 1979; Lamb *et al*., 1981; Blake *et al*., 1982; Günther, 1991; Gustafson, 1993; Mülling and Budras, 1998; Bleeke, 2003; Maierl and Mülling, 2004; Adewuyi *et al*., 2006; Keil *et al*., 2006; Davidson and Greenough, 2007; Buer *et al*., 2016). Although we were able to identify key influencing factors, our study was not designed to determine the optimal level of locomotor activity, which remains an open question in dairy science.

Two of the farms showed observed activity levels that deviated upwards by around 40%. The first is Farm C 4, an organic Demeter farm located in the very south of Baden-Württemberg. The animals graze on pasture all day from spring to autumn, except on hot days, where pasture was allowed only at night. Although median activity is adjusted for the pasture effect, the increased activity for that farm is plausible as cows from this farm also graze on more distant areas, which automatically involves longer journeys. The higher activity can therefore be explained by the intensive grazing and the distances to the pastures.

The second farm with higher activity, Farm N8, does not offer grazing, but incorporates a unique feature. In addition to the automated partial mixed feed ration, a hay rack was integrated adjacent to the exercise yard. According to the farm manager, the hay rack is frequented by the animals. Moreover, a higher proportion of roughage in the ration leads to more activity (Mastellone *et al*., 2022). As this barn was not operational until the spring of 2022, the housing system was novel to the animals, and thus, there was a short period of acclimation. It is also possible that collection bias has distorted Farm N8 results. Unlike on the other farms, it was not possible on Farm N8 to take repeated measurements in different seasons. Data collection occurred mostly on warm days. Since it is known that animal activity increases in hot weather (Heinicke *et al*., 2017; Ramón-Moragues *et al*., 2021), this could also explain the increased activity observed on Farm N8. While the study reflects real-world housing conditions, the influence of temperature on cow activity could not be assessed, as no on-farm temperature or humidity measurements were available.

An effect of herd size, total barn area, or walking area per cow on locomotor activity could not be confirmed in our study, as none of these factors showed a statistically significant influence. This contrasts with findings by Telezhenko *et al*. (2012), who reported that larger barns, typically associated with larger herds, promote greater activity, independent of individual space allowance. In line with their results, however, we also found that walking area per cow had no measurable impact on activity levels.

This study found no statistically significant effect of rubber flooring on cow locomotor activity. This finding is somewhat counterintuitive given that the design of walking surfaces is widely recognized as a key factor in influencing the locomotor activity of dairy cows (Shepley *et al*., 2020). Rubber flooring provides a comfortable, deformable surface that aligns with the physiological needs of cows (Keller *et al*., 2009; Schmid *et al*., 2009) and has been associated with increased activity levels in previous studies (Benz, 2002; Jungbluth *et al*., 2003; Bendel, 2005; Flower *et al*., 2007; Platz *et al*., 2008). However, the lack of a significant effect in our data is likely due to the high prevalence of rubber flooring across all of the study farms. On 16 out of 18 farms, rubber mats had been installed in the feeding alley at least – an area of the barn known to concentrate cow movement and activity (Shepley *et al*., 2020). These installations were originally intended to reduce ammonia emissions, as the feeding alley is considered to offer the greatest mitigation potential (Benz *et al*., 2024). The rubber mats used featured urine-draining properties that further improved floor hygiene and comfort. The yielding rubber flooring also supports slip resistance. Deformation of the mats when weight is transferred onto them can provide better traction and prevent initial slipping after first contact (Telezhenko and Bergsten, 2005). Nearly 80% of the total walking area across all farms was covered with rubber mats. This narrow variation in flooring conditions likely introduced a ceiling effect, making it difficult to detect statistically distinguishable differences in locomotor activity attributable to flooring type. It can thus be assumed that the high proportion of rubber flooring masked any possibility of observing a significant effect.

Furthermore, no significant influence of the average farm milk yield on animal activity on farm level was found. The average annual yield of the 18 farms was 8,600 kg, with moderate dispersion (coefficient of variation of 0.23). It is possible that finding no significant influence of milk yield is related to the feeding system. In eleven of the farms, an automatic milking system was used, in which the individual concentrated feed was delivered. In the others, an automatic feed pusher was used. If such systems were not in place, animals with higher milk yields -and therefore receiving more concentrate feed, as described by Mastellone *et al*. (2022)- would be expected to show increased activity. This is likely due to their greater nutritional demands and associated feeding behavior. According to Oberschätzl-Kopp *et al*. (2016), feed presentation frequency has a significant influence on activity, but that management factor was not tracked separately in this study. However, all participating farms had either an automated feeding system or an automatic feed pusher. It seems reasonable to suggest that the introduction of automated feeding systems has served to reduce the necessity for cows to move more frequently in order to obtain their feed. This has potentially contributed to a reduction in the anticipated discrepancies in activity levels across cows with disparate milk yields.

In alignment with the findings of Bleuler (1981), Brade (2001), Benz *et al*. (2020) and Crump (2019), this study demonstrated that the pasture factor had a statistically significant influence on the observed activity level. The activity level was observed to be approximately twice as high on farms with grazing compared to those without grazing.

The month when observations were taken was also influencing activity. The period between July and September was characterized by activity levels that exceeded the prevailing average by one-third. This phenomenon is hypothesized to be due to higher temperatures during these months, as shown by studies such as those by Heinicke *et al*. (2017), Ramón-Moragues *et al*. (2021), and Abeni and Galli (2016). Note that the given means were already adjusted for pasture.

The study also observed a significant relationship between parity and locomotor activity: the higher the parity, the lower the activity. This is consistent with Hut *et al*. (2022), who report markedly reduced lying time and increased standing and walking in primiparous cows. These differences are attributed to a combination of physiological demands and social dynamics, such as lower hierarchical status and more evasive behavior, which may limit access to resting areas and increase locomotor activity.

Characteristics of the building project

This study focused on investigating differences between newly built and converted barns. Of the 18 farms analyzed, 12 had built new barns, while six had opted for a barn conversion. No significant differences between new and conversion barns could be demonstrated. A possible limitation of the result could be the fact that four of the barn conversions analyzed also offered access to pasture, while this was only the case for three of the new buildings. However, as already explained, the variable “pasture” (as well as the month, milking system, and parity) was taken into account in the statistical model and the mean values were adjusted accordingly. The result can therefore be interpreted in the sense that a barn conversion can create conditions for the activity of cows comparable to those offered by a new building. An important equalizing aspect in this study is the high proportion of rubber flooring on all farms, as the design of the walking surface is considered to be a key element for activity (Benz, 2002; Bendel, 2005; Platz *et al*., 2008; Shepley *et al*., 2020).

Conclusions

This observational study, which included six barn conversions and twelve newly constructed barns, found a non-significant difference in locomotor activity levels after accounting for factors such as grazing opportunity, seasonality, milking system, parity and days in milk. These results suggest that well-executed barn conversions can provide movement opportunities that are comparable to those of new constructions. However, given the limited number of converted barns (n=6) relative to newly built barns (n=12) in our survey, it is recommended that conclusions be drawn with caution. Further research with experiments and/or larger samples is needed to confirm these findings and refine recommendations for optimal barn design.

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Supplemental Material:

Floor plans of the 18 farms are available at: https://nbn-resolving.org/urn:nbn:de:bsz:950-opus4-42508

Received: 24 January 2025; Accepted: 10 October 2025.

Contributions: all the authors made a substantive intellectual contribution, read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of interest: the authors declare no conflicts of interests and confirm accuracy.

Funding: the project was funded as part of the European Innovation Partnership "Agricultural Productivity and Sustainability" (EIP-AGRI). The funding measure was part of the Rural Development Plan for Baden-Württemberg 2014-2020 (MEPL III). The project was funded by the state of Baden-Württemberg and the European Agricultural Fund for Rural Development (EAFRD).

Availability of data and materials: the datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.