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SCIENTIFIC OPINION

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Welfare of dairy cows

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Abstract

This Scientific Opinion addresses a European Commission's mandate on the welfare of dairy cows as part of the Farm to Fork strategy. It includes three assessments carried out based on literature reviews and complemented by expert opinion. Assessment 1 describes the most prevalent housing systems for dairy cows in Europe: tie-stalls, cubicle housing, open-bedded systems and systems with access to an outdoor area. Per each system, the scientific opinion describes the distribution in the EU and assesses the main strengths, weaknesses and hazards potentially reducing the welfare of dairy cows. Assessment 2 addresses five welfare consequences as requested in the mandate: locomotory disorders (including lameness), mastitis, restriction of movement and resting problems, inability to perform comfort behaviour and metabolic disorders. Per each welfare consequence, a set of animal-based measures is suggested, a detailed analysis of the prevalence in different housing systems is provided, and subsequently, a comparison of the housing systems is given. Common and specific system-related hazards as well as management-related hazards and respective preventive measures are investigated. Assessment 3 includes an analysis of farm characteristics (e.g. milk yield, herd size) that could be used to classify the level of on-farm welfare. From the available scientific literature, it was not possible to derive relevant associations between available farm data and cow welfare. Therefore, an approach based on expert knowledge elicitation (EKE) was developed. The EKE resulted in the identification of five farm characteristics (more than one cow per cubicle at maximum stocking density, limited space for cows, inappropriate cubicle size, high on-farm mortality and farms with less than 2 months access to pasture). If one or more of these farm characteristics are present, it is recommended to conduct an assessment of cow welfare on the farm in question using animal-based measures for specified welfare consequences.

Keywords: dairy cows, husbandry systems, lameness, mastitis, welfare

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Summary

Background and European Commission's request

The European Commission requested the European Food Safety Authority (EFSA) to provide a scientific opinion on the welfare of dairy cows, reflecting the most recent scientific knowledge on the topic. This mandate was received in the context of the comprehensive evaluation of the animal welfare legislation undertaken by the European Commission in the framework of its Farm to Fork strategy, including Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes.

The first Term of Reference (ToR) requested a description of the most prevalent housing systems for dairy cows and practices of keeping them in the EU.

The second ToR requested a description of five welfare consequences specific to dairy cows: locomotory disorders (including lameness), mastitis, restriction of movement, inability to perform comfort behaviour and metabolic disorders. For these welfare consequences, the European Commission requested to define the most feasible animal-based measures (ABMs), to identify hazards potentially leading to them and finally to provide recommendations to prevent or correct them.

The third ToR requested to identify specific relevant hazards, i.e. farm characteristics, leading to the above-mentioned welfare consequences and which can be used to classify the level of risk for animal welfare based on data that are currently collected, or that can easily be collected at farm level (e.g. milk production, herd size, housing system).

Structure of the scientific opinion

In this scientific opinion, three assessments were performed according to each ToR: Assessment 1 on the housing systems; Assessment 2 on the welfare consequences, hazards, preventive and corrective measures; and Assessment 3 on the hazards (from here onward called 'farm characteristics') to identify farms at risk of poor welfare.

The opinion contains conclusions and recommendations for each of the three assessments. The level of certainty associated with the conclusion is reported in all conclusions, except for those that are purely descriptive (e.g. description of welfare consequences).

Assessment 1 – housing systems

Assessment 1 of this opinion describes the following housing systems: 1. tie-stalls, 2. cubicle (free-stall) housing, 3. open-bedded systems (bedded systems with straw yards, compost or dry manure) and 4. systems with access to outdoor areas (systems with access to outdoor loafing area and systems with access to pasture). For each system, the distribution in the EU is reported as well as an overview of the main strengths, weaknesses and hazards for welfare of dairy cows. A comparison of the different housing systems was included in the second assessment (see Assessment 2).

The most prevalent housing systems in the EU are cubicle housing systems, followed by open-bedded systems and tie-stalls. The proportion of farms offering access to pasture has declined in several EU MSs in the last decades, with an increasing number of farms converting to zero-grazing systems. The number of grazing days per year varies markedly between and within countries. The impact on animal welfare of each housing system is highly variable and affected by the quality of the physical environment and management on a specific farm. However, there is substantive evidence that cows permanently tied in stalls have impaired welfare due to behavioural restriction compared to loose-housing systems (where cows are not tied).

The main hazards for reduced cow welfare in tie-stalls are the duration of tethering, the adequacy of tethering design, the dimensions of the stall and the characteristics of the lying surface. If the tether design is inadequate (too short neck chain or poorly positioned neck rails), the stalls are too short or narrow, or the lying surfaces are not or only little deformable, the resting behaviour of cows is particularly inhibited, and the risk of integument alterations increases.

The main hazards for reduced cow welfare in cubicle housing systems are a non-deformable lying surface including shallow bedding, inappropriate dimension and design of the cubicles including positioning of cubicle fittings, rough or slippery flooring in the alleys, low total space allowance and overstocking at the cubicle.

The main hazards for reduced cow welfare in open-bedded systems are poor hygiene of the lying areas and a low space allowance per cow. Maintaining adequate cow cleanliness in straw yards requires higher quality of management and a larger amount of bedding compared to cubicles.

The main hazards for reduced cow welfare in systems with access to loafing area are poor hygienic conditions and lack of shelter in extreme climatic conditions.

The main animal welfare hazards in managing cows at pasture are: insufficient shelter from adverse climatic conditions, insufficient access to water, insufficient or discontinuous nutrient supply, inadequate parasite control, poorly maintained walking tracks or roads and rushing cattle while walking.

Assessment 2 – welfare consequences

Assessment 2 addresses the five welfare consequences requested in the mandate in terms of animal-based measures (ABMs), prevalence in different housing systems and hazards identified. Resting problems were additionally discussed in the context of the welfare consequence restriction of movement.

Locomotory disorders

Lameness is one of the major welfare issues in dairy cows and is often associated with pain and reduced ability to perform natural behaviour. Gait and foot lesion scoring are feasible ABMs to identify and score lameness. There is no clear evidence that one housing system is consistently better in terms of lameness reduction. Foot and leg disorders are multifactorial, resulting from interactions between the farm environment, management, nutrition and animal characteristics including genetic background, age and lactation stage.

Regarding system comparison, temporary access to pasture is associated with a lower prevalence of integument damage compared to zero-grazing systems. Cubicles with shallow beds or mats (i.e. bedding less than 30 cm on concrete surfaces or less than 5 cm of compressed material on mats (compressed as a result of the animal lying on it)) are associated with an increased risk of claw disorders and a higher prevalence of lameness compared to a pasture-based systems.

Preventing lameness includes regular gait scoring followed by early treatment of lame cows. Dimensions and design of the lying area(s) and cubicle furniture should match the size of cows ensuring that comfort is optimised, freedom of lying behaviour (natural postural changes) is allowed and risk of injury is minimised. Dairy cows should be provided with dry, soft and deformable lying surfaces (see above). The walking and standing surface should be clean, dry, non-slip and avoiding sharp edges. Tracks for pasture access should be suitable for long-distance walking (e.g. even surfaced, free from stones and debris).

Mastitis

Mastitis is a disease characterised by inflammation of the mammary gland commonly caused by an intramammary infection (IMI), mainly bacterial. The condition can be divided into clinical mastitis (i.e. associated with clinical signs) and subclinical mastitis, despite there is no clear-cut respective definition of the two types. Clinical mastitis affects dairy cow welfare due to, e.g. the painfulness of the condition and associated changes in behaviour. The welfare relevance of subclinical mastitis is unknown. Suitable ABMs for the occurrence of mastitis are the incidence rate of clinical disease and routine (monthly or daily in case of automatic milking systems) measurement of individual cow somatic cell counts.

Regarding system comparison, mastitis is a multifactorial disease, the hazards of which are diverse and no housing system (including pasture access) has been consistently identified as superior to others with regards to the incidence or prevalence of mastitis.

Type of bedding is the only housing-related hazard associated with mastitis prevalence. Cows housed in sand-bedded cubicles have lower somatic cell counts than those housed in cubicles with organic bedding materials.

Assessment of key mastitis hazards, which are mostly cow and management related, should be undertaken regularly and a farm-specific plan for the control, including treatment and prevention of mastitis, should be formulated based on disease patterns and risks present on-farm. Udder health should be routinely monitored on farm using both the incidence rate of clinical mastitis and individual cow somatic cell counts in order to timely take appropriate management decisions.

Restriction of movement and resting problems

Restriction of movement refers to the inability of the animal to move freely or walk comfortably due to e.g. restrictive space allowance or inadequate floor properties resulting in pain, discomfort or frustration.

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Closely related to restriction of movement are resting problems due to inadequate design and properties of the lying area resulting in the cow's inability to lie or rest comfortably, or to perform unimpaired lying down or rising up movements.

ABMs for restriction of movement and resting problems are gait, hygiene and lesion scoring, as well as deviations from normal lying down and rising up movements and agonistic interactions.

Regarding system comparison, restriction of movement in dairy farming is related to the housing system itself, to the design and features of particular housing systems, to the stocking densities and to the extent of outdoor access. Tethering imposes severe restriction of movement. Compared to loose-housing systems, it particularly restricts lying down and rising up movements, lying postures, oestrus, calving and social behaviour. In terms of level of restriction, the different housing systems are ranked as follows: year-round tethering, which is particularly restrictive, followed by cubicle housing and open-bedded systems and finally pasture, which is the least restrictive. Both tie-stalls and cubicles are associated with more resting problems and restriction of the lying down and rising up movement compared to open-bedded systems (straw, compost or dry manure bedded-packs), in particular when the size of stalls and cubicles are inappropriate for the size of the cows.

Dairy cows should not be permanently housed in tie-stalls because of the continuous and severe restriction of movement and social behaviour, and the risk of thwarting of lying down and rising up movements as well as prevention of comfortable resting postures. While from a welfare perspective housing in tie-stalls should in general not be practised, in a transition period housing in tie-stalls with regular access to a loafing area, or access to summer pasture, could be used to reduce the impact on restriction of movement, resting and social behaviour.

In cubicle housing systems, at least one cubicle per cow should be provided. Dry, soft and deformable lying surfaces, preferably deep bedding (either in cubicles or a deep bedded pack), should be provided because they are associated with longer lying time and ease of lying down and rising up movements. For deep-bedded cubicles, when bedding material is placed and retained on concrete surfaces, a minimum depth of 30 cm should be provided. When bedding is placed on the top of mats or mattresses, a minimum depth of 5 cm of compressed material (compressed as a result of the animal lying on it) should be provided. For instance, this corresponds to ~3 kg of straw per day to be provided per cubicle space. Studies on other materials should be carried out.

Access to well-managed pasture (i.e. well-drained, provision of shade) should be provided because it offers opportunity to walk freely, ease of changing posture and a comfortable lying area.

A total indoor area – including lying area – of at least 9 m^2/cow should be provided.

Minimum width and length of cubicles as well as other features that should be provided for cubicles are recommended (see specific recommendations for details).

Inability to perform comfort behaviour

Comfort behaviour of dairy cows includes self-grooming by use of tongue, hooves, horns or tail, or objects (e.g. cow brushes or pen fixtures). The function of self-grooming is to maintain the integument, but allo-grooming (e.g. licking a conspecific) also has functions in relation to social behaviour. ABMs for the inability to perform comfort behaviour include observations of self-grooming, allo-grooming and brush use.

Regarding system comparison, cubicle housing systems are associated with better hygiene and cow cleanliness compared to tie-stalls and open-bedded systems.

Tethering thwarts the ability to perform self-grooming. Tethering should not be practised except for limited time periods for events such as veterinary treatments or milking, because it severely restricts the ability to perform comfort behaviour. In cubicles, flooring should not be slippery to allow postures associated with self-grooming to be adopted. Brushes should be available in all loose-housing systems, but further research on the appropriate number per cow and location of brushes is needed.

Metabolic disorders

The metabolic disorders investigated, i.e. ketosis, subacute ruminal acidosis, displaced abomasum and hypocalcaemia (milk fever) commonly occur during the peripartum period or in early lactation. Although aetiologies differ, a variety of feeding and farm management practices are associated with an increased risk of these metabolic disorders. Subclinical forms of ketosis, ruminal acidosis and hypocalcaemia are more prevalent than the clinical forms of the disease. No single ABM is suitable for all metabolic disorders. Suitable ABMs for the occurrence of metabolic disorders are the incidence rate of clinical cases and for subclinical ketosis individual cow beta-hydroxybutyrate (in blood) or ketones levels (in milk or urine). Body condition scoring in the dry period is a useful proxy ABM for metabolic disease since over-conditioned cows are at increased risk of reduced dry matter intakes and metabolic disorders.

Regarding system comparison, there is no clear evidence that any one housing system is consistently superior to another in terms of the incidence or prevalence of metabolic disorders, which are rather linked to diet composition and feeding management.

However, housing systems predispose to metabolic diseases if they affect the appropriate feeding of cows or predispose to disorders that affect feeding (e.g. lameness). Preventive strategies based on key risks arising from feeding and management practices should be in place to minimise the occurrence of metabolic disease.

Assessment 3 – Farm characteristics to identify farms at risk of poor welfare

Assessment 3 includes an analysis of farm characteristics (e.g. milk yield, herd size) that could be used to classify the level of on-farm welfare. An approach based on expert knowledge elicitation (EKE) was developed. Five farm characteristics resulted from the EKE: if one or more of these farm characteristics are present, it is recommended to conduct an assessment of cow welfare on the farm in question.

In order of importance attributed by the experts, these characteristics were: (1) farms with more than one cow per cubicle at maximum stocking rate, (2) farms with a limited total space (including outdoor loafing areas) for housed cows ($< 7\,m^2$/cow), (3) farms on which cubicle dimensions are inappropriate for the size of the cows, (4) farms with high annual on-farm mortality (i.e. more than 8% including emergency slaughter) rates and (5) farms on which cows have less than 2 months per year with access to pasture.

For farms with each of the characteristics identified above, welfare consequences can be assessed using specific farm-level assessments (based on animal-based measures). These are reported in detail in the opinion and in the conclusions.

It is recommended that the risk-based scheme developed from the EKE is piloted to validate its usefulness in practice prior to implementation.

Table of contents

efsa JOURNAL

1. Introduction

1.1. Background and terms of reference as provided by the requestor

In the framework of its Farm to Fork strategy, the Commission will start a comprehensive evaluation of the animal welfare legislation. This will include the following acts:

1) Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes[1];
2) Council Directive 1999/74/EC of 19 July 1999 laying down minimum standards for the protection of laying hens[2];
3) Council Directive 2008/119/EC of 18 December 2008 laying down minimum standards for the protection of calves[3] (Codified version);
4) Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs[4] (Codified version);
5) Council Directive 2007/43/EC of 28 June 2007 laying down minimum rules for the protection of chickens kept for meat production[5];
6) Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97[6];
7) Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing.[7]

These acts are based on scientific opinions that are outdated. In the context of possible drafting of legislative proposals, the Commission needs new opinions that reflect the most recent scientific knowledge. Since the EFSA has already accepted mandates on the protection of animals at the time of killing, no opinion is requested on this topic. Against this background, the Commission would like to request the EFSA to review the available scientific publications and possibly other sources to provide a sound scientific basis for future legislative proposals.

This request is about the protection of dairy cows. The latest scientific opinion which was used for the current legislation was published in 1997. Since then the EFSA adopted opinions on the welfare of dairy cows in 2009,[8] 2012,[9] and 2015.[10]

The Commission therefore considers opportune to request EFSA to give an independent view on the protection of dairy cows.

This request refers to cows which have had a calf and are kept for milk production and to pregnant heifers in the last third of gestation. These include dual purpose breeds used for milk production.

For this request, the EFSA will:

1) Describe, based on existing literature and reports, the most prevalent housing systems and practices of keeping them in the EU, including tie-stalls, cubicle housing and systems with free lying area, combined or not with certain outdoor access with grazing.
2) Describe the following **welfare consequences** for the housing systems and practices specified above:
   - inability to perform comfort behaviour,
   - restriction of movement,
   - locomotor disorders,

[1] OJ L 221, 8.8.1998, p. 23.
[2] OJ L 203, 3.8.1999, p. 53.
[3] OJ L 10, 15.1.2009, p. 7.
[4] OJ L 47, 18.2.2009, p. 5.
[5] OJ L 182, 12.7.2007, p. 19.
[6] OJ L 3, 5.1.2005, p. 1.
[7] OJ L 303, 18.11.2009, p. 1.
[8] Scientific report on the effects of farming systems on dairy cow welfare and disease. https://efsa.onlinelibrary.wiley.com/doi/10.2903/j.efsa.2009.1143r
[9] Scientific Opinion on the use of animal-based measures to assess welfare of dairy cows. https://doi.org/10.2903/j.efsa.2012.2554
[10] Scientific Opinion on the assessment of dairy cow welfare in small-scale farming systems. https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903/j.efsa.2015.4137

- metabolic disorders,
- mastitis.

3) Define the most feasible **animal-based measures** to assess the welfare consequences above;
4) Identify the most relevant **hazards,** leading to the welfare consequences above mentioned
5) Provide recommendations to prevent or correct the welfare consequences above mentioned (resource and management-based measures). The recommendations should be based on key risk factors that may increase the likelihood of welfare consequences to occur.
6) Identify the specific relevant hazards, leading to the welfare consequences above-mentioned and which can be used to classify the level of risk for animal welfare based on data currently collected (e.g. milk production, herd size, housing system etc.).

1.2. Interpretation of the terms of reference

The terms of reference (ToR) received by EFSA were discussed and interpreted by the EFSA panel on Animal Health and Welfare and by the EFSA Working Group (WG) on the welfare of dairy cows. Definitions were discussed and agreed, and the methodology to address each part of the request defined.

The WG adopted the definition of a dairy cow provided in the mandate text; 'a cow which have had a calf and are kept for milk production and to pregnant heifers in the last third of gestation. These include dual purpose breeds used for milk production'. Accordingly, younger, or male cattle were not considered in the SO. In addition, only welfare on farm aspects was discussed; welfare aspects related to the welfare during transport, slaughter or on-farm killing were considered out of scope.

Assessment 1 (Chapter 4) of this opinion covers ToR1 of the mandate ('Describe, based on existing literature and reports, the most prevalent housing systems and practices of keeping them in the EU, including tie-stalls, cubicle housing and systems with free lying area, combined or not with certain outdoor access with grazing') and describes the above-mentioned housing systems. Per each system, the opinion reports the distribution in the EU and gives an overview of main strengths, weaknesses and hazards reducing the welfare of dairy cows. Assessment 1 does not include a comparison of housing systems, which is instead addressed later in the opinion (see Assessment 2).

It was agreed that the most prevalent housing systems in the European Union (EU) were already included in the mandate text, and hence, no new system was added to the list of those to be assessed. However, the type of system was refined in some cases: systems with free lying area were named 'open-bedded systems' and further specified into 'straw yards' and 'compost and manure-bedded systems'; access to outdoor areas was differentiated into 'access to outdoor loafing' area and 'access to pasture'. This was because it was considered that the characteristics of these systems had different elements potentially impacting welfare that deserved to be specified and discussed. Furthermore, the wording 'housing systems' was used instead of 'husbandry systems' because the focus on the opinion was on the housing infrastructure rather than dairy management practices.

Assessment 2 (Chapter 5) covers ToR 2 ('Describe the following welfare consequences for the housing systems and practices specified above: inability to perform comfort behaviour, restriction of movement, locomotor disorders, metabolic disorders, mastitis'), ToR3 ('Define the most feasible animal-based measures to assess the welfare consequences above'), ToR4 ('Identify the most relevant hazards, leading to the welfare consequences above mentioned') and ToR5 ('Provide recommendations to prevent or correct the welfare consequences above mentioned').

For the five listed welfare consequences, it was agreed to adopt the definitions identified in the EFSA methodological guidance for the development of animal welfare mandates in the context of the Farm to Fork Strategy (see Section 3.1.1.3, EFSA AHAW Panel, 2022).

It was noted that the welfare consequence 'resting problems' was also very relevant to be considered when evaluating welfare aspects of each housing system, but it was not specifically mentioned in the mandate. Resting problems were additionally discussed in the context of the welfare consequence restriction of movement.

In this document, 'lameness' and 'locomotor disorders' are considered synonyms and are used interchangeably, and the term 'foot and leg disorders' is meant to also include problems that do not necessary cause a change in gait or normal locomotion pattern.

Per each welfare consequence, a set of animal-based measures is suggested and an analysis of the prevalence in different housing systems is provided. A detailed comparison of welfare consequences among housing systems is provided in this section, and details about the hazards impacting on different welfare consequences are reported.

Hazards for each welfare consequence were further classified into 'common hazards' (considered hazards potentially present in all husbandry systems; for instance wet surfaces, which can occur regardless of housing system, as a hazard for lameness), and into 'specific hazards' (e.g. neck rail position as a hazard for lameness in tie-stalls).

Management-related hazards are summarised at the end of each section. To keep the focus on housing, it was agreed that management measures will not be reported in the recommendations.

Assessment 3 (Chapter 6) of this opinion covers ToR6 ('Identify the specific relevant hazards, leading to the welfare consequences above-mentioned and which can be used to classify the level of risk for animal welfare based on data currently collected (e.g. milk production, herd size, housing system etc.).').

The main objective was to identify potential herd-level variables that could be easily used in wide-scale monitoring of farms to predict poor dairy welfare on farm.

While it was considered by the working group that such close indicators of on-farm welfare (and that were not animal-based measures) were unlikely to exist, it was agreed to assess the scientific literature to evaluate which relationships have been reported so far. Given that the EFSA Guidance for developing Farm to Fork mandates (EFSA AHAW Panel, 2022) did not include a methodology to address this type of requests, a dedicated method was developed to address this part of the mandate.

This aims at identifying herd-level characteristics that could provide an indication of welfare risk and integrated in a welfare monitoring system. More details on the methodology used to address each point of the mandate are described in the next section.

2. Data and methodologies

2.1. Data sources

Peer-reviewed scientific articles were the main source of data used in the assessment. Data from grey literature and from Member States such as official European statistics (Eurostat), official national statistics, statistical reports from national institutions (e.g. VIT Germany) and statistical reports from international/European institutions were also used to address ToR 1. See Appendix A for the list of statistical offices and databases of the EU-MS countries.

2.2. Methodologies

2.2.1. Literature searches

2.2.1.1. Identification and description of housing systems (ToR 1)

To present figures on the importance of dairy cow husbandry in the EU-MS countries (e.g. number of cows, milk yield), official data from EU Member States were used. For the description of the most prevalent housing systems for dairy cows including main hazards for poor cow welfare, advantages and disadvantages, an extensive literature search was run on 'Web of Science'. Out of 112 search results, 14 articles were identified as relevant. Details of the search and inclusion criteria are reported in Appendix B, Table B.1.

2.2.1.2. Identification of welfare consequences, hazards and animal-based measures (ToR 2, ToR 3 and ToR 4)

In this document, the overall approach to scientific assessment to welfare was that described in the EFSA guidance risk assessment for animal welfare (EFSA AHAW Panel, 2012) and the more recent EFSA AHAW Panel (2022). According to this theoretical framework, the welfare assessment consists of two components, i.e. the risk assessment, with identification of the negative welfare consequences (adverse effects) that occur to an animal in response to a hazard, and the benefit assessment, with identification of positive welfare consequences. In the current document, EFSA addressed the European Commission mandate by focusing on the adverse effects only, and in the context of this opinion, the adverse effects are called 'welfare consequences'.

Extensive literature searches were performed for each of the welfare consequences listed in the mandate. From the retrieved papers, information on the welfare consequence prevalence in different housing systems was derived, as well information on the associated hazards and animal-based measures.

Search string details, inclusion criteria and results of each search are reported in Appendix B (Table B.2 for locomotory disorders, Table B.3 for mastitis, Table B.4 for restriction of movement and resting problems, Table B.5 for inability to perform comfort behaviour, Table B.6 for metabolic disorders).

Following the literature review, data were extracted from relevant publications and presented in a tabular format to allow comparisons and observations of trends across studies.

2.2.2. Uncertainty assessment

The overall methodology to assess uncertainty in this SO followed the approach described in Sections 3.2.1 and 3.2.2 of EFSA (EFSA AHAW Panel, 2022). The main sources of uncertainty relate to study external and internal validity. External validity is very limited because of high variability between production systems and management practices in different areas of the European Union. This means that results from one particular study will not be generalisable to other farms, areas or countries. Internal validity may be limited because some studies are small, cross-sectional, have not fully controlled for potential confounders, and the measures used are rarely standardised. In this case, there is a low degree of certainty that any causal relationships proposed are true effects. More research using robust study design to establish causal relationships would be invaluable to provide unequivocal evidence of the impact of farming system on dairy cow welfare.

A judgement on the certainty of each conclusion was carried out, except for those conclusions that are purely descriptive (e.g. description of welfare consequences). The certainty ranges were derived from three predefined certainty ranges from EFSA (2019) (Table 1). A group discussion took place during which experts had the chance to explain the rationale behind their judgement, and a consensus on which category better reflects the overall certainty was reached.

When a certainty range is added at the end of a paragraph in the conclusions, it is considered that it applies to all sentences within that paragraph.

Table 1: Certainty ranges defined in EFSA (2019) and used to classify the certainty of conclusion statements

Certainty range	50–100%	66–100%	90–100%
Expression of certainty	More likely than not	From likely to almost certain	From very likely to almost certain

3. Assessment 1: most common housing systems for dairy cows in the EU

3.1. Housing systems in dairy farming

Over the last decades, various housing systems have been developed for dairy farming, and these may be combined with different lengths of grazing period, which vary between country and region. Throughout Europe, accommodating dairy cows indoors, at least during winter, is widely practised. Pure pasture-based systems (without winter housing), as in New Zealand, are only present to a small extent within Europe (Reijs et al., 2013), e.g. in the Portuguese Azores (de Almeida et al., 2021) and on a small proportion of dairy farms in Ireland. In several MSs or regions, such as Ireland and Galicia (Spain), as well as in the case of transhumant systems in the Alpine regions (Tarantola et al., 2016; Zuliani et al., 2018), pasture-based production during the summer is combined with indoor-housing during winter.

Despite the ongoing agricultural transition to more intensive and larger scale farming systems, small-scale farms are the majority in various EU MS (e.g. Poland, Romania, Lithuania, Bulgaria) as represented by the traditional farm type in the Alpine region (Zuliani et al., 2018). Particularly in these small-scale farms, tie-stall systems, where the cows are permanently tethered during the winter months, remain common (e.g. Winnicki and Jugowar, 2011; Popescu et al., 2013; Tarantola et al., 2016; Väärikkälä et al., 2019; Blanco-Penedo et al., 2020; Lora et al., 2020). However, various types of loose housing are now also relatively common, particularly in medium-sized and larger farms (e.g. Animal Welfare Centre, 2014; Pöllinger et al., 2018; Statistisches Bundesamt, 2021b).

An essential criterion for differentiating between dairy cow housing systems, apart from tethered animals (tie-stalls) versus loose housing, is the design of the lying area. This can be in the form of single free stalls (cubicles) in which lying areas are separated for individual animals or a free, open area that is used for movement as well as for lying and resting. Systems with cubicles can be designed with shallow or deep bedding, which can differ in the effect on animal welfare. Systems with an open lying area usually contain bedding material (full-slatted systems are not common in the dairy cow sector); essentially, a distinction can be made between straw yards (deep-litter systems) and more recently developed manure- or compost-bedded packed barns (Blanco-Penedo et al., 2020). Particular types of loose housing with an unstructured lying area are the so-called garden barns, which combine an artificial floor that separates manure and urine with rows of trees and shrubs (Galama et al., 2020). This novel housing type, which is currently rare, is not described further in this report.

Both tie-stall and loose housing barns can be designed as insulated or not insulated (naturally ventilated) systems (Lambertz et al., 2014). Both types of housing may be supplemented by an outdoor loafing area, which offers additional space for exercise and exposure to outdoor weather conditions. Housing systems may also be combined with access to pasture which can vary in use and intensity – from less intensive exercise ('jogging') pastures to more intensive grazing pastures.

An overview of the husbandry systems including aspects described above is provided in Figure 1. Detailed information on the main characteristics of each housing system including the key strengths, weaknesses and hazards of each system in terms of animal welfare are given in Sections 4.2, 4.3, 4.4 and 4.5 below.

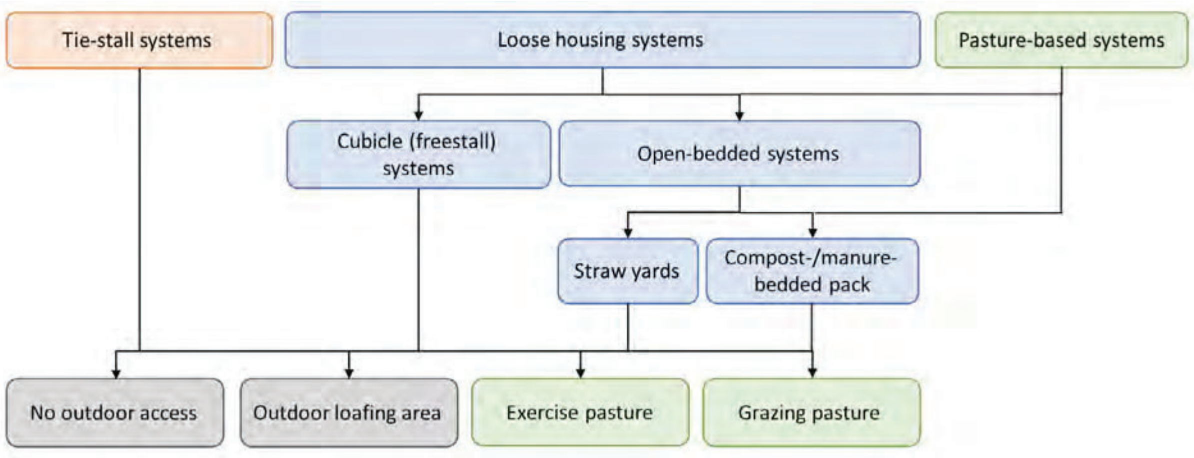

Figure 1: Overview of prevalent housing systems for dairy cows in the EU Member States

A description of dairy cow housing systems in selected EU member states is given in Appendix C including the main milk-producing countries (in terms of total milk quantity) as well as other countries representing a range of different climatic regions.

3.2. Tie-stall systems

3.2.1. Description

In tie-stall systems, animals are tethered while in the barn; however, a distinction can be made between (a) permanent tethering (all year round) and (b) tethering during the winter period combined with a varying degree of access to pasture during the summer (review in Beaver et al., 2021). In the case of grazing during summer, cows will be tethered for part of the day and/or at milking times. Some farms also provide access to an outdoor loafing area in winter for cows otherwise kept in tie-stall systems.

In organic farming in the EU, tie-stall housing of cows is only permitted in exceptional cases: according to Regulation (EU) 2018/848, small-scale farms with a maximum number of 50 animals (excluding young stock) can be approved to allow their cows access to pasture during the grazing period, and during the rest of year to give cows access to an outdoor area for exercise twice per week (Duval et al., 2020).

Depending on the herd size, housing typically consists of one or more rows of tie-stalls (Maasikmets et al., 2015; Tarantola et al., 2016) each with an alley to remove the manure. The alley is also used as a walkway by the cows if, e.g. access to pasture or an outdoor loafing area is provided. The individual stalls can differ in terms of dimensions (length, width and height), lying surface (with or without rubber mat), bedding material and depth of it (such as straw, saw dust or sand) and in terms of type of tethering (e.g. neck chain or neck rails) (review in Beaver et al., 2021).

One characteristic feature of tie-stalls is that different cow activities, e.g. feeding/drinking, lying/resting, comfort behaviour, social and elimination behaviours and milking have to take place in the stall. Milking in the stall is conducted using a pipe milking system or, in smaller farms, a bucket milking system.

In conventional dairy farming, apart from the general requirements in Council Directive 98/58/EC, there are no specific legal EU regulations/restrictions on tethering, except in individual countries, such as Sweden, where access to pasture must be provided during the summer (Loberg et al., 2004), and where construction of new buildings to tether cows has been prohibited since 2007 (Lundmark Hedman et al., 2018). In Denmark, only tie-stall systems built before 2010 may currently be used.[11] A Danish ban on tethering will come into force in 2027 and until then grazing is mandatory in summer in tethered herds (review in Beaver et al., 2021). In Austria,[12] permanent tethering is not permitted, but with exemptions in terms of lack of space for loafing areas or safety concerns.

3.2.2. Distribution

Worldwide, tie-stall systems have been the predominant type of housing for dairy cows for decades (EFSA AHAW Panel, 2009a,b). In 2008, the proportion of cows tethered at least temporarily during winter in Europe was estimated to be between 20% in the lowlands and 80% in higher, marginal regions (Veissier et al., 2008). Also, more recent literature describes tethering as common practice and widespread throughout the EU, especially on smaller scale farms (Popescu et al., 2013; Nipers et al., 2016; Tarantola et al., 2016; Blanco-Penedo et al., 2020; Lora et al., 2020). However, in various countries, the use of tie-stall systems is declining compared to loose-housing systems (review in Barkema et al., 2015) and data are available, e.g. for Germany (Statistisches Bundesamt, 2021b), Austria (Pöllinger et al., 2018), The Netherlands, Sweden, Denmark, Finland (Barkema et al., 2015) and Estonia (Maasikmets et al., 2015). An overview of data from national statistics or broader epidemiological research is provided in Table 2.

Table 2: Distribution of tie-stall systems reported for individual EU-MS countries

Country (Region)	Level	n farms	% farms	n cows	% cows	Reference
AT	Sample	1,851	–	–	37.0	Pöllinger et al. (2018)
DK	National		18.0	18,600	3.3	Statistics Denmark (2021a,b)
FI	National	–	70.0	–	–	Animal Welfare Centre (2014)
FR	National	–	10.6	–	5.5	Idele (2021)[(a)]
DE	National	21,530	32.1	479,300	11.5	Statistisches Bundesamt (2021b)
IT (Alps)	Regional	–	> 98.0	–	–	(ISTAT 2005 in Corazzin et al., 2010)
NL	National	–	8.0	–	4.0[(b)]	(review in Barkema et al., 2015)
PL (Wielkapolska)	Regional	–	–	371,500	87.1	(Winnicki and Jugowar, 2011)
RO	National	–	75.0–90.0[(c)]	–	–	(Popescu et al., 2013)
SE	National	–	42.6	–	21.6	(Sverige, 2021)

(a): Figures refer to the year 2015.
(b): Official national statistics from 2012 (CBS, 2012).
(c): Estimates by the authors.

3.2.3. Strengths, weaknesses and hazards that contribute to reduced welfare in tie stall systems

Strengths of tie-stall systems in terms of cow welfare have been reported such as a possible reduction in prevalence of certain claw disorders (review in Beaver et al., 2021) and reduction in agonistic interactions within the herd (Popescu et al., 2014).

[11] BEKENDTGØRELSE nr 1743 af 30/11/2020 (Gældende) Bekendtgørelse om dyrevelfærdsmæssige mindstekrav til hold af kvæg (Free translation: Ministerial order no 1743 of 30/11/2020 (In force) Ministerial order on animal welfare minimum requirements for housing of cattle).

[12] BKA, 2004. Bundesgesetz, witzerm ein Tierschutzgesetz erlassen sowie das Bundes-Verfassungsgesetz, die Gewerbeordnung 1994 und das Bundesministeriengesetz 1986 geän witzeerden. Bundesgesetzblatt Nr. BGBI. Nr 118/2004 (with most recent modifications 28-07-2022). In German. https://www.ris.bka.gv.at/eli/bgbl/I/2004/118 (accessed 04-12-2022).

Regarding weaknesses, various scientific studies conclude that keeping dairy cows in tie-stall systems can impair animal welfare. Mitigation of hazards within this housing system may, however, limit certain physical or behavioural problems (review in Beaver et al., 2021).

Important welfare implications of tethering compared to loose housing arise from the restricted freedom of movement (Veissier et al., 2008), which can be associated with an increased prevalence of locomotory disorders (Bielfeldt et al., 2005; Mattiello et al., 2005; Kara et al., 2011; Bouffard et al., 2017), as well as an inability to lie or rest comfortably (Haley et al., 2000; Ostojić Andrić et al., 2011; Popescu et al., 2014), an inability to perform comfort and social behaviour (review in Beaver et al., 2021) and an inability to perform oestrus behaviour. In addition, tethering restricts typical calving behaviour as well as early maternal behaviour.

Negative effects of tethering vary, however, depending on whether the cows are tethered all year round or given access to outdoor areas or pasture. Compared to year-round tethering, temporary access to pasture or an outdoor loafing area was found to be associated with a lower prevalence of integument damage (Corazzin et al., 2010; Popescu et al., 2013; Bernhard et al., 2020), improved claw conformation (Loberg et al., 2004; Corazzin et al., 2010) and reduced prevalence of lameness (Regula et al., 2004; Mattiello et al., 2005; Corazzin et al., 2010; Popescu et al., 2013). The inability to perform oestrus behaviour is associated with a lower prevalence of skin lesions and wounds in the tail head and pelvis region (Felton et al., 2012).

Stall dimensions, characteristics of the lying surface and adequacy of tethering were found to be important factors for impaired welfare of cows in tie-stalls (CIGR, 2014). Cows' lying behaviour is particularly inhibited and the risk of integument alterations increased, if cubicles are too short or narrow, if lying surfaces are not well cushioned or if tethering is inadequate (too short neck chain or poorly positioned neck rails) (Bouffard et al., 2017; Bernhard et al., 2020). However, short stalls and short neck chains, although not recommended, can have a beneficial effect on the cleanliness of the cows (Bouffard et al., 2017).

In tie-stall systems social behaviour within the herd is particularly limited; cows only have direct contact with their immediate neighbours except at times when they have access to outdoor loafing areas or pasture. Cattle are highly social animals and form a social herd structure based on dominance and lasting preferential bonds (Bouissou et al., 2001). Restricted social behaviour in tethered herds might negatively affect the animal welfare. Tethered cows with 1 hour of daily access to a yard performed a similar level of social interactions during this 1 hour as loose-housed cows did during a day (Krohn, 1994), suggesting a rebound effect and thus that social behaviour had been thwarted during tethering. Conversely, restricted social behaviour in tie-stall systems can be advantageous for lower ranking cows since fewer agonistic interactions are possible (Popescu et al., 2014) and the competition for feed and lying places is restricted (von Keyserlingk and Weary, 2010).

Principal strengths and weaknesses, as well as hazards that contribute to reduced welfare in tie-stall systems are summarised in Table 3 (see also chapter 5 for a detailed comparison between this and other housing systems).

Table 3: Strengths, weaknesses and hazards that contribute to reduced welfare in tie-stall systems

Strengths	Reduced prevalence of certain claw disorders e.g. digital dermatitis and white-line disease (review in Beaver et al., 2021)
	Reduced agonistic interactions within the herd (Popescu et al., 2014)
Weaknesses	Increased risk of integument damage (Ostojić Andrić et al., 2011; Bouffard et al., 2017; Bernhard et al., 2020)
	Increased risk of certain claw disorders e.g. heel erosion and lameness (Bielfeldt et al., 2005; Kara et al., 2011; Ostojić Andrić et al., 2011; Bouffard et al., 2017)
	Inhibited lying behaviour (Ostojić Andrić et al., 2011; Popescu et al., 2014; Bouffard et al., 2017)
	Inhibited social behaviour (review in Beaver et al., 2021)
	Restriction of movement (Veissier et al., 2008)
	Inhibition of oestrus behaviour (Felton et al., 2012)

Hazards of reduced welfare	Period of time tethered (i.e. permanent (year-round) as opposed to periodic tethering of cows) (Regula et al., 2004; Popescu et al., 2013; Bernhard et al., 2020)
	Inappropriate stall dimensions (Bouffard et al., 2017)
	Inappropriate lying surface (Bernhard et al., 2020)
	Inappropriate characteristics of tethering (e.g. length of neck chain) (Bouffard et al., 2017)

3.3. Cubicle (free-stall) housing systems

3.3.1. Description

Cubicle systems are based on the provision of free stalls (cubicles), which define where cows are supposed to lie. Passageways between rows of cubicles and the feed alley provide space for movement, loafing and feeding of cows. Faeces and urine are deposited on the floor of the alleys. In order to drain the floor surface, manual or automatic manure scrapers, manure robots, washing systems or slatted floors are used. Regardless of the cleaning system, the material most commonly used for flooring is concrete. In order to improve its softness and comfort for the cows while lying, solid as well as slatted concrete cubicle floors can be covered with synthetic mattresses.

Cubicle housing systems can differ in terms of cubicle design and manure management system (solid versus liquid), which may be associated with different floor types (solid versus slatted floors). Cubicles are generally raised above floor level and typically have a concrete base with or without synthetic mats, which may be accompanied by bedding material, the layer of which can vary from rather thin to thick. A wide range of bedding materials are used; the most common are straw, sawdust, sand and recycled manure solids.

Regardless of whether the cubicles are designed as shallow or deep-bedded, they are equipped with partitions (cubicle fittings) to the sides and to the front (e.g. neck rail, front rail, brisket board), which serve to guide the cow into the correct lying position and facilitate lying down and rising up movements (reviewed by Bewley et al., 2017). Partitions serve to control the position of cows without unduly restricting their movement (CIGR, 2014). The brisket board aids the cow positioning herself in the cubicle while resting or standing; the neck rail encourages cows to move backward on rising and prevents them from standing too far forward; the head rail prevents cows going too far ahead in the cubicle (CIGR, 2014).

3.3.2. Distribution

Loose housing with cubicles is the predominant dairy cow housing system in various EU-MSs (see Section 4.2.2), especially on farms with larger herds (review in Barkema et al., 2015). In the countries that are high milk-producing, especially in the west and north of the EU, such as Germany, The Netherlands and Denmark, cubicle systems are used in the majority of dairy farms. In eastern EU-MSs, such as Poland (Winnicki and Jugowar, 2011), Romania (Popescu et al., 2013) and Latvia (Nipers et al., 2016), the adoption rates are likely to be lower, although increasing in number. However, official data are only available for some countries (Table 4).

Table 4: Frequency of cubicle systems reported for individual EU-MSs

Country (Region)	Level	n Farms	n farms with cubicles	% farms with cubicles	n cows	% cows	Reference
AT	Sample	1,851	–	–	–	59.0	Pöllinger et al. (2018)
DK	National	–		–		60.7[(a)]	Statistics Denmark (2022b)
FR	National	–	–	32.9	–	42.3	idele (2021)[(b)]
DE	National	–	36,950	55.1	3,461,900	83.1	Statistisches Bundesamt (2021b)
DE (North)	Sample	253	211	83.4	–	–	PraeRi (2020)
DE (East)	Sample	252	198	78.6	–	–	PraeRi (2020)

Country (Region)	Level	n Farms	n farms with cubicles	% farms with cubicles	n cows	% cows	Reference
DE (South)	Sample	260	175	67.3	–	–	PraeRi (2020)
NL	National	–	–	–	–	95.0	CBS (2012)
PL (Wielkopolska)	Regional	–	–	–	–	12.9	Winnicki and Jugowar (2011)

(a): Refers to all cows in Denmark; 84% of cows in Denmark are dairy cows.
(b): Figures refer to the year 2015.

3.3.3. Strengths, weaknesses and hazards that contribute to reduced welfare in cubicle housing systems

Strengths of cubicle systems over straw yards in terms of cow welfare have been reported as improved cow cleanliness (Fregonesi and Leaver, 2001; Molina et al., 2020) and a reduced risk of impaired udder health (Peeler et al., 2000; Fregonesi and Leaver, 2001; Leso et al., 2019).

Regarding weaknesses, cubicles provide a more restricted lying area than straw yards and compost-bedded packs due to the partitions and other elements of the cubicles such as head and neck rails thus potentially reducing the ability to move. Cubicles generally require a relatively large amount of bedding material to maintain hygienic conditions and a comfortable lying surface. In systems with shallow beds or mats, bedding needs are reduced but these systems offer reduced lying comfort. Dairy cows lie down for longer in deep-bedded cubicles than in cubicles with mattresses with minimal bedding (e.g. Tucker et al., 2003; Calamari et al., 2009). The dryness of bedding is important for comfort around lying; cows demonstrated a clear preference for dry rather than wet bedding when provided with both options (Fregonesi et al., 2007) and showed longer lying durations the less moist beddings were (Reich et al., 2010). Furthermore, fewer hock injuries occur in cows housed in cubicles with a deep bedding of straw, sawdust or sand than in cubicles with mattresses with minimal bedding (e.g. Weary and Taszkun, 2000; Wechsler et al., 2000). Cubicles with shallow beds or mats have been reported to be associated with an increased risk of claw disorders and a higher prevalence of lameness, both when comparing year-round housing in cubicles to a pasture-based system (Olmos et al., 2009a) and to deep-bedded cubicles (Cook et al., 2004; Fulwider et al., 2007) or straw yards (Frankena et al., 2009).

Regarding hazards, the lying surface including inappropriate bedding, dimensions of the cubicles, positioning of cubicle fittings and type of flooring (Bernardi et al., 2009; Brenninkmeyer et al., 2013; Cook et al., 2004; Fregonesi et al., 2009; Fulwider et al., 2007; Lardy et al., 2021) is one of the main hazards associated with cubicle housing systems with regard to cow welfare.

Increased integument alterations found in cubicle systems in various studies have been attributed to abrasive lying surfaces and to contact/collisions with cubicle fittings (review in Kester et al., 2014). The positioning of cubicle fittings, however, can have inconsistent effects on different aspects of cow welfare; Bernardi et al. (2009) examined the effects of different neck rail positions on the cleanliness of cows and found cows were dirtier and had more soiled udders when neck rails were less restrictively positioned, because cows were more likely to defecate on the lying surface (Bernardi et al., 2009; Fregonesi et al., 2009). Conversely, more restrictive positioning can have negative effects in terms of integument damage (Brenninkmeyer et al., 2013), lying behaviour (Fregonesi et al., 2009) and claw health associated with higher prevalence of lameness (Bernardi et al., 2009). Importantly, all aspects of cubicle design should be specifically considered in relation to cow size (dimensions and weight) in order to lower the risks of skin lesions, lameness and soiling (Lardy et al., 2021).

Another hazard is the type of floor in the alleys and at the feed manger. An inappropriate floor surface, or insufficient cleaning of the floor, can cause impaired claw health in cubicle systems (Dippel et al., 2009a; Somers et al., 2003, 2005a; Telezhenko et al., 2009). Roughened concrete surfaces can lead to excessive claw wear and claw disease. Conversely, smooth and slippery floor surfaces can restrict the natural behaviour of cows (Telezhenko and Bergsten, 2005). Covering the floor with rubber mats can improve claw health, reduce prevalence of lameness (Eicher et al., 2013), improve locomotion and better support cow comfort (by allowing self-grooming) and oestrus behaviour (Platz et al., 2008).

A summary of strengths, weaknesses and hazards for reduced welfare in cubicle systems is given in Table 5 (see also chapter 5 for a detailed comparison between this and other housing systems). For context, it should be noted that many of the quoted studies were undertaken over 10 years ago and since this time improvements in cubicle design and management have been made. It is therefore uncertain the extent to which these risks currently apply.

Table 5: Strengths, weaknesses and hazards for reduced welfare in cubicle systems

Strengths	Clean animals (Fregonesi and Leaver, 2001; de Boyer des Roches et al., 2014; Molina et al., 2020)
	Improved udder health (Peeler et al., 2000; Fregonesi and Leaver, 2001; Leso et al., 2019)
Weaknesses	Difficulties in lying and lying down/rising up behaviour (Cook et al., 2004; Fregonesi et al., 2009; Olmos et al., 2009a; de Boyer des Roches et al., 2014)
	Increased risk of claw disorders and lameness (Cook et al., 2004; Bernardi et al., 2009; Frankena et al., 2009; Burgstaller et al., 2016)
	Increased risk of integument alterations (Brenninkmeyer et al., 2013; Fulwider et al., 2007; de Boyer des Roches et al., 2014; Lardy et al., 2021)
Hazards of reduced welfare	Inadequate lying surface (Dippel et al., 2009a; Somers et al., 2003, 2005a; Telezhenko et al., 2009; Telezhenko and Bergsten, 2005)
	Inadequate cubicle dimensions and positioning of cubicle fittings
	Inadequate floor surface and cleaning management

3.3.4. Cubicle design and dimensions

Cubicles should allow dairy cows to lie and rest comfortably, and to lie down and rise up without physical contact (collision or friction) against partitions. Recommendations for cubicle dimensions aim to optimise cows' comfort and hygiene (i.e. minimise soiling of the bedding), minimise the risk of injury and facilitate natural behaviours. Recommendations are therefore a compromise between comfort and hygiene.

Recommendations for cubicle dimensions differ according to cow size, which varies between breeds. Important cow attributes are height at the withers, diagonal body length and width at shoulders (Figure 2).

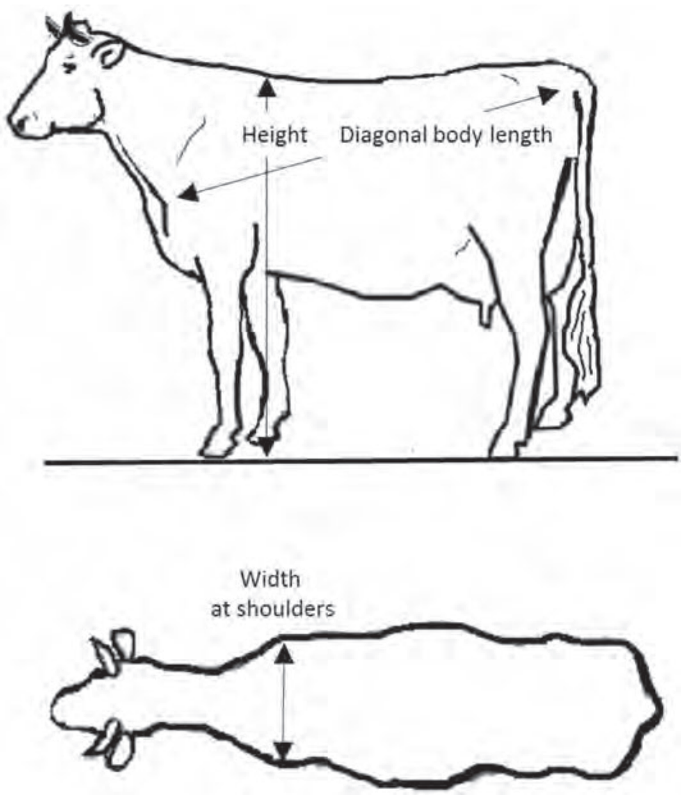

Figure 2: Measurement of cows' body dimensions (© CIGR)

Definitions of criteria for measuring cubicle dimensions are listed below and illustrated in Figure 3.

- Cubicle width: distance between the cubicle partitions.
- Cubicle resting length: horizontal distance from the curb where the cow can lie: space available for the cow to lie.
- Overall cubicle length: The overall cubicle length should provide for body space (lying, standing), headspace and lunging space.
- Neck rail height: vertical neck rail distance from the floor.
- Neck rail distance: horizontal neck rail distance from the curb.
- Brisket board height: vertical brisket board distance from the floor.

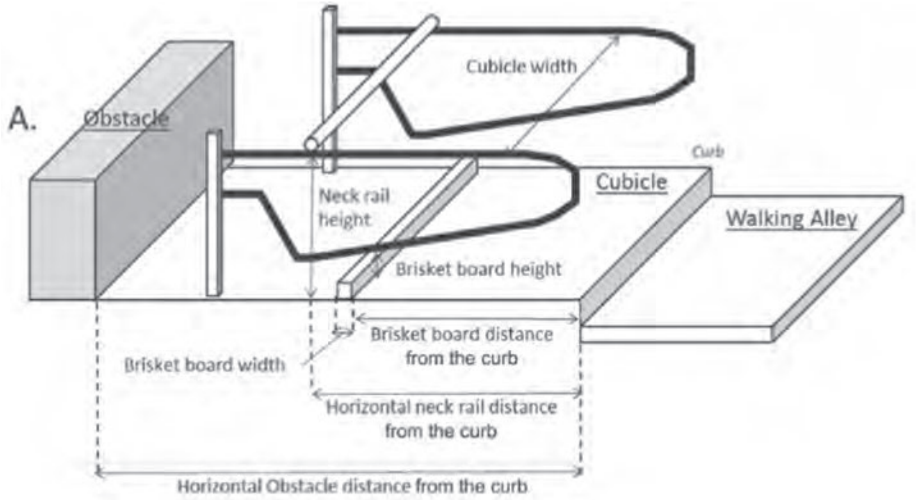

Figure 3: Schematic representation of important cubicle design criteria (© 2023 Elsevier inc.)

Scientific literature and technical recommendations for cubicle dimensions were assembled from countries where information was available.[13] The information was extracted from several recent sources; scientific papers (Lardy et al., 2021; CIGR, 2014) international technical recommendations, and technical recommendations from several countries: AHDB (UK),[14] TEAGASC (IRL), IDELE (FR), Danish recommendations[15] and legislation (DK)[16]; Wisconsin D[17] (US),[18] Ontario (CAN) and Austria.

Having considered the different recommendations for cubicle design, the working group identified specific elements of design to be of particular importance (Table 6). These are considered minimum recommendations; no upper limit is mentioned in the reviewed sources.

13 https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Docs/Dairy%20housing%20cubicles.pdf
14 https://www.teagasc.ie/media/website/rural-economy/farm-management/cubicle_bed_2020.04.07.pdf
15 Indretning af stalde til kvæg: danske anbefalinger: tværfaglig rapport (Free translation: Design of housing for cattle: interdiciplinary report). 2018. SEGES, Denmark.
16 BEKENDTGØRELSE nr 1743 af 30/11/2020 (Gældende) Bekendtgørelse om dyrevelfærdsmæssige mindstekrav til hold af kvæg (Free translation: Ministerial order no 1743 of 30/11/2020 (In force) Ministerial order on animal welfare minimum requirements for housing of cattle).
17 https://nydairyadmin.cce.cornell.edu/uploads/doc_317.pdfhttps://nydairyadmin.cce.cornell.edu/uploads/doc_317.pdf
18 https://www.ontario.ca/page/dairy-housing-free-stall-base-material-and-bedding-options

Table 6: Recommendations for selected cubicle design criteria including examples for differently sized cows

Design criteria	Recommendations	Examples for differently sized animals	
		Holstein × Montbeliard cross (height at withers 1.44 m, diagonal length 1.6 m; Lardy et al., 2021)	**Holstein (height at withers 1.52 m, diagonal length 1.86 m) (Green M, pers comm.)**
Cubicle width (CW)	0.83 × cow height	1.2 m	1.26 m
Cubicle resting length (CRL)	1.1 × cow diagonal length	1.76 m	2.05 m
Cubicle length (CL): head-to-head, space sharing	1.8 × cow height	2.59 m	2.74 m
Cubicle length (CL): non-space sharing cubicles (e.g. against a wall)	2.0 × cow height	2.88 m	3.04 m
Neck rail height (NRH)	0.80–0.90 × cow diagonal length	1.28–1.44 m	1.49–1.67 m
Neck rail distance: horizontal neck rail distance from the kerb (NRD)	1.2 × cow height	1.73 m	1.82 m
Brisket board height (BBH)	10 cm	10 cm	10 cm

The examples of dimensions given in the above table are suggested for improving cow cleanliness and decreasing injuries and lameness. Other studies explored the impact on rising and lying behaviours (Dirksen et al., 2020) and demonstrated that increased dimensions (increased lung space ratio) decreased the proportion of atypical head movements; however, detailed recommendations about such increased dimensions are not reported.

From the above-mentioned literature, other important recommendations related to the design of cubicles include:

- Curb with 15–20 cm height, no sharp edges.
- Slope between 2% and 5%.
- Brisket board either round or without sharp edges.
- Partitions with space to allow different lying/leg positions and prevention of injuries of hip and rib.

3.4. Open-bedded systems

3.4.1. Introduction

Open-bedded systems are defined here as an open area without partitions for animals to rest and exercise. This housing type is sometimes also referred to as free-walk systems (e.g. Blanco-Penedo et al., 2020; Galama et al., 2020), but the term 'open-bedded systems' will be used in this opinion.

The design of open-bedded systems vary widely (e.g. Blanco-Penedo et al., 2020). As with cubicle systems, the functional areas for lying/resting and moving can be separated from the feeding area in the open-bedded system (two-area barn); in such cases, the animals are accommodated in two areas, a solid floor feeding area and an open-bedded area. However, there are also designs that only offer one uniform open-bedded area (single-area barn).

A main distinction between open-bedded systems is the bedding material used for the lying area. The traditional system is a straw yard but alternative systems are compost-bedded packs (Leso et al., 2020) and in drier regions manure-bedded packs (Klaas et al., 2010). Innovative special open-bedded systems, such as the so-called cow gardens with artificial floors that separate manure and urine (Galama et al., 2020), are typically used for experimental purposes and are therefore not described in this opinion.

3.4.2. Distribution

Compared to tie-stall and cubicle systems, open-bedded systems are less common in the EU-MS. Open-bedded systems may, however, be found in combination with cubicle housing systems, with dry or recently calved cows being kept in open-bedded systems and other lactating cows in cubicle systems. Data or estimates regarding the frequency of open-bedded systems are only available for individual EU-MS, and in some cases, no distinction is made between conventional straw yard and (compost-) bedded pack systems.

Data from national statistics or from broader epidemiological studies reveal percentages of farms with open-bedded systems in the dairy cow sector ranging from 0.0 to 56.5% (Table 7). These systems are more common in organic dairy farming in some countries.

Table 7: Frequency of open-bedded systems (straw yards and compost-bedded pack barns) in countries of EU-MS countries

Country	Level	n farms	% farms	n cows	% cows	Reference
AT	Sample[(a)]	–	–	–	4.0	Pöllinger et al. (2018)
DK	National	–	–	182,000	32.2[(b)]	Statistics Denmark (2021b)
FR	National	–	56.5	–	52.2	idele (2021)[(c)]
DE	National	7,130	10.6	160,300	3.8	Statistisches Bundesamt (2021b)
NL	National	–	–	–	0.0	CBS (2012)

(a): n = 1,851.
(b): Refers to all cows in Denmark; 84% of cows in Denmark are dairy.
(c): Cows figures refer to the year 2015.

Compost-bedded pack barns were first installed in the US as an alternative to conventional straw yards (Janni et al., 2007; Lobeck et al., 2011; Black et al., 2013; Leso et al., 2020). Because of perceived positive effects on cow welfare, the system received increasing attention, and was also adopted in European countries a few years later. The first compost-bedded pack barn was built in 2009, in the Netherlands (Galama P., 2014). Use of compost-bedded packs has since been reported in other EU MSs, e.g. Denmark (Svennesen et al., 2014), Spain (Astiz et al., 2014; Fuertes et al., 2021), Italy (Leso et al., 2013), Germany (top agrar, 2019) and Austria (Ofner-Schröck et al., 2015; Burgstaller et al., 2016; Pöllinger et al., 2018). It is also reported that in other EU MSs (i.e. Sweden, Slovenia, Bulgaria, Slovak Republic, Finland) compost-bedded packs are in use (Leso et al., 2020). Overall, however, the adoption of compost-bedded packs in the EU-MSs is believed to be very low compared to other housing systems and also compared to straw yards.

In the limited available sources, only estimates of the total number of farms (the Netherlands and Italy) or data based on an epidemiological survey (Austria) are reported (Table 8).

Table 8: Distribution of compost-bedded pack barns in EU-MSs

Country (Region)	Level	n farms	% cows	Reference
AT	Sample[(a)]	–	1.0	Pöllinger et al. (2018)
IT	National[(b)]	50	–	Leso et al. (2013)
NL	National[(b)]	40	–	Galama P., (2014)

(a): n = 1,851.
(b): Estimation of the total number of farms with compost bedded-pack barn within the country.

3.4.3. Straw yards

3.4.3.1. Description

Straw yards (also referred to as deep-litter systems) are the ‘conventional’ open-bedded system. The lying area is regularly (usually daily) littered with straw, which causes the bed to deepen over time. The frequency of removing the bedding is dependent upon the stocking density and litter management and may be several times a year.

With regard to the space allowance, a lying area of at least 6 m^2 per dairy cow has been recommended in order to ensure undisturbed lying for all animals (Bachinger et al., 2015; Pelzer, 2012; Eilers, 2018). For horned dairy cows, larger areas ranging between 8 m^2 and more than 10 m^2 per cow has been recommended (Bachinger et al., 2015; Eilers, 2018; LAVES Tierschutzdienst, 2007; Schneider, 2011). However, there is very limited scientific evidence supporting these recommendations.

3.4.3.2. Strengths, weaknesses and hazards that contribute to reduced welfare in straw yards

Strengths of straw yards include offering potential for improved claw health and locomotion, and less integument damage compared to cubicle systems (Brinkmann et al., 2011; de Boyer des Roches et al., 2014; Frankena et al., 2009; Haskell et al., 2006; Rutherford et al., 2009; Somers et al., 2003). With regard to aspects of natural behaviour, an investigation of cows' time budgets by Fregonesi and Leaver (2001) reported that cows in straw yard systems spent more time lying and ruminating, and increased synchronisation of lying behaviour to a higher degree than cows in cubicle systems, which may be attributed to increased comfort around resting.

Weaknesses of straw yards include the potential to have a deleterious impact on cow welfare, because maintaining adequate cow cleanliness can be difficult. Cows in straw yards have been found to be dirtier than those in cubicle systems (Fregonesi and Leaver, 2001), which was associated with increased somatic cell counts (SCC) and a higher incidence of clinical mastitis (Barnouin et al., 2005; Fregonesi and Leaver, 2002, Fregonesi and Leaver, 2001; Peeler et al., 2000). More soiling and impaired udder health was identified in straw yards with lower space allowances in the lying area as compared to larger space allowance (4.5 m^2 vs. 9 m^2 per cow; Fregonesi and Leaver, 2002).

Thus, hazards within straw yards contributing to reduced welfare include dirty bedding and limited lying area.

Principal strengths, weaknesses and hazards that contribute to reduced welfare in straw yard systems are summarised in Table 9 (see also chapter 5 for a detailed comparison between this and other housing systems).

Table 9: Strengths, weaknesses and hazards that contribute to poor welfare in straw yard systems

Strengths	Natural lying and lying down behaviours (Phillips and Schofield, 1994; Fregonesi and Leaver, 2001)
	Improved claw health and locomotion (Livesey et al., 1998; Somers et al., 2003; Haskell et al., 2006; Frankena et al., 2009; Rutherford et al., 2009)
	Improved leg and joint health (Haskell et al., 2006)
Weaknesses	Increased risk of dirty animals (Fregonesi and Leaver, 2001)
	Increased risk of impaired udder health (Barnouin et al., 2004, 2005; Fregonesi and Leaver, 2001; Peeler et al., 2000)
Hazards of reduced welfare	Poor hygiene of the lying areas (Fregonesi and Leaver, 2002; Barnouin et al., 2005)
	Inadequate space allowance (Fregonesi and Leaver, 2002)

3.4.4. Compost- and manure-bedded pack barns

3.4.4.1. Description

Similar to straw yard systems, in compost-bedded barns, the entire lying area consists of an open-bedded pack for resting and activity. However, in compost-bedded pack barns, unlike conventional straw yards, the bedding should be tilled daily to promote water evaporation and enhance aerobic microbial activity to start the composting process (Leso et al., 2020).

Although compost-bedded pack systems in different regions and countries worldwide share similar characteristics (i.e. an open-bedded lying area which is frequently cultivated), notable differences can be found between systems developed in different climates (Leso et al., 2020). In particular, systems prevalent in the US and gaining increasing interest in the EU can be distinguished from those in drier regions: compost-bedded-pack systems common in Israel are based on the concept of providing cows with large spaces. Due to the dry climates and low stocking density, little or no additional organic material beside cow manure is needed to keep the lying surface dry (Klaas et al., 2010).

In contrast, compost-bedded pack barns in North America and the EU are typically bedded with wood shavings, sawdust or other organic material that are compostable (other than straw). The system requires tilling to incorporate the manure, urine and air into the pack and allow it to dry. For the composting process to work, the internal temperature and moisture content of the pack must be maintained at specified levels (Eckelkamp et al., 2016a).

To allow for sufficient aeration and absorption of manure and urine by the bedding and the composting process to work (Black et al., 2013), compost- and manure bedded pack systems require a larger area per cow than what is typically available in cubicle and straw yard systems. Examples of space allowances from the scientific literature are 7 and 9 m^2/cow in Minnesota (Barberg et al., 2007; Lobeck et al., 2011), 9–11 m^2/ cow in Spain (Fernández et al., 2020) and 25 m^2/cow in Italy (Biasato et al., 2019). Recommended animal densities in the bedded area range from 7.4 m^2 (Janni et al., 2007) to more than 15.0 m^2 per cow (Barberg et al., 2007; Lobeck et al., 2011; Galama P., 2014; Biasato et al., 2019; Fernández et al., 2020). Recommended stocking densities depend on several factors, including climate, bedding, pack management and cow characteristics (Leso et al., 2020).

3.4.4.2. Strengths, weaknesses and hazards that contribute to reduced welfare in compost-bedded pack systems

Strengths of compost-bedded pack systems are described here. Studies have indicated that, compared to other housing systems, compost-bedded pack systems have the potential to improve aspects of cow welfare (review in Leso et al., 2020). The main reported advantages – particularly compared to cubicle systems – include improved comfort while lying, enhanced claw health, a lower prevalence of lameness and enhanced leg and joint health (Table 10).

Compared to cubicle systems with various lying surfaces, a lower prevalence of hock lesions (Fulwider et al., 2007; Klaas et al., 2010; Lobeck et al., 2011) and lameness (Lobeck et al., 2011; Borchers, 2018) or moderate lameness (Blanco-Penedo et al., 2020) was found in compost-bedded pack systems in some studies. In contrast, Burgstaller et al. (2016) found no difference in the prevalence of lameness between these two housing systems, although some types of lesions were more common in cubicle systems. In terms of integument damage, the prevalence appears to vary significantly depending on the bedding material used in the bedded packs (Shane et al., 2010), but a lower prevalence of moderate and severe integument alterations (Fernández et al., 2020) and fewer hairless patches, leg lesions and swellings of lower hind legs (Blanco-Penedo et al., 2020) have been reported for compost-bedded pack systems compared to cubicles.

Weaknesses of compost-bedded pack systems are described here. Research has indicated that cows are dirtier in compost-bedded packs than in cubicle housing systems (Blanco-Penedo et al., 2020; Fernández et al., 2020), although other studies indicate that adequate cow cleanliness and udder health can be achieved (Fulwider et al., 2008; Ofner-Schröck et al., 2015). According to the review by Leso et al. (2020), adequate pack management and control of moisture are essential to maintain cow cleanliness and to reduce the risk of mastitis. Leso et al. (2020) also recommend that large amounts of bedding are used to keep the pack dry and cows clean, especially in cold and humid weather conditions.

Hazards within compost-bedded pack systems which can reduce welfare include type of bedding material and inadequate quantity of bedding material and poor pack management including failure to control of moisture and heat.

In terms of cow behaviour, a study conducted in the US reported that cows in compost-bedded pack systems tended to adopt natural lying positions (Endres and Barberg, 2007). Compared to cows in cubicle systems, cows in compost-bedded pack barns were found to have longer overall daily lying times (Eckelkamp et al., 2014; Borchers, 2018) with more frequent lying bouts and accordingly shorter lying phases (Eckelkamp et al., 2014). Overall lying times, however, were shortened with increasing temperature–humidity index (Endres and Barberg, 2007). In one study, the duration of the lying movement was shorter on compost compared to cubicles (Ouweltjes and Smolders, 2014), while in another study, the lying down and rising up movements were of similar durations on compost and in cubicles.

Principal strengths, weaknesses and hazards that contribute to poor welfare in compost-bedded pack systems are summarised in Table 10 (see also chapter 5 for a detailed comparison between this and other housing systems).

Table 10: Strengths, weaknesses and hazards that contribute to reduced welfare in compost-bedded pack systems

Strengths	Allow natural lying and lying down/rising up behaviours (Borchers, 2018; Eckelkamp et al., 2014; Endres and Barberg, 2007; Ouweltjes and Smolders, 2014)
	Improved claw health and locomotion (Lobeck et al., 2011; Ofner-Schröck et al., 2015; Burgstaller et al., 2016; Borchers, 2018)
	Improved leg and joint health (Fulwider et al., 2007; Klaas et al., 2010; Lobeck et al., 2011)
Weaknesses	Increased risk of dirty animals (review in Leso et al., 2020)
	Increased risk of impaired udder health (Leso et al., 2019)
Hazards of reduced welfare	Heat production in the pack due to the composting process (review in Leso et al., 2020)
	Increased moisture in the lying surface (review in Leso et al., 2020)

3.5. Access to outdoor areas (loafing areas and pasture)

In both tie-stall and loose housing, cows can be provided with additional outdoor loafing area which is typically adjacent to the housing and provides the opportunity for exercise and access to fresh air, sunlight and other weather elements. Access to pasture provides even greater access to these resources, although at the same time, the risk of exposure to adverse weather conditions may increase. Characteristics are described in the following chapters.

3.5.1. Access to outdoor loafing area

An outdoor loafing area (paddock, outdoor yard) can be defined as an open or partly roofed area that is not part of the main structure of the building but is adjacent to it or a short distance away. It is designed to give cows more space to perform behaviours normally restricted by housing. These areas can be equipped with different facilities, such as cow brushes or additional feeding or lying areas (Haskell et al., 2013; Smid et al., 2020). The space provided per cow tends to vary greatly between farms (Dippel et al., 2009b; Schneider, 2010; Lutz et al., 2019; Thompson et al., 2020).

3.5.1.1. Distribution

No data on the distribution of housing systems with outdoor loafing area were accessible in the official statistics. However, data from epidemiological studies in broader or stratified samples were available from individual countries and are listed in Table 11.

Table 11: Distribution of farms in which cows have access to an outdoor loafing area and/or pasture reported in epidemiological studies for individual EU-MSs

Country (Region)	Sample size	% Farms	Access to	Reference
AT	1,851	50.0[(a)]	Outdoor loafing area	Pöllinger et al. (2018)
DE (North)	253	5.9 (85.4)[(b)]	Outdoor loafing area and/or pasture	PraeRi (2020)
DE (East)	252	17.5 (71.4)[(b)]		
DE (South)	260	8.8 (48.8)[(b)]		
NL	174	9.2	Outdoor loafing area	de Vries et al. (2015)

(a): Only outdoor areas < 10 m^2 per cows were counted as outdoor loafing area.
(b): Farms providing only access to outdoor loafing area (in brackets farms providing outdoor loafing area and/or pasture).

3.5.1.2. Strengths, weaknesses and hazards that contribute to reduced welfare in systems with access to outdoor loafing areas

The main strengths of the outdoor loafing area are seen in the access to the outdoor climate providing cows with the opportunity to move outside if it is hot or humid inside the housing and in the relatively low-cost expansion of exercise and loafing space for the cows, which may positively affect animal health and behaviour. Especially for lower ranking cows, the additional area may be a place of retreat and avoidance of agonistic interactions with conspecifics (Haskell et al., 2013). Cows will prioritise lying behaviour when an area of pasture is used as a loafing area (Langford et al., 2021).

However, cow welfare effects of an outdoor loafing area have, so far, only been investigated or considered in a limited number of studies.

In the few studies on associations with claw and integument health, the results are inconclusive: in cows kept in tie-stall systems with temporary access to an outdoor loafing area, Keil et al. (2006) found less integument damage in cows spending more time per day in the outdoor area, but more damage with more frequent access. On farms with loose housing systems, Dippel et al. (2009b) found higher odds for lameness on farms with outdoor loafing area, which the authors attribute to the confounding effects of other farm characteristics. Poorly designed or ill-kept outdoor areas can increase the risk of some hoof diseases (e.g. foot rot, heel erosion) compared with animals always indoors (Bielfeldt et al., 2005; O'Driscoll et al., 2008, 2009).

Results from studies on cow behaviour, focusing on social behaviour in herds with horned dairy cows, however, point in the same direction: with increased outdoor loafing space allowance per cow, fewer agonistic interactions (Schneider, 2010; Lutz et al., 2019) and lower prevalence of horn-related integument damage were found (Schneider, 2010; Knierim et al., 2020).

Principal strengths, weaknesses and hazards that contribute to poor welfare in outdoor loafing areas are summarised in Table 12 (see also chapter 5 for a detailed comparison between this and other housing systems).

Table 12: Strengths, weaknesses and hazards that contribute to reduced welfare in outdoor loafing areas

Strengths	Improved conditions for cows to thermoregulate and exercise (Galán et al., 2018)
	Reduction in agonistic interactions with conspecifics (Schneider, 2010, Haskell et al., 2013, Lutz et al., 2019)
	Reduction in integument damage (Keil et al., 2006, Schneider, 2010, Knierim et al., 2020)
Weaknesses	Increase in certain hoof diseases (Bielfeldt et al., 2005; O'Driscoll et al., 2008, 2009)
	Heat stress if free access to the indoor area is not provided (Galán et al., 2018)
Hazards of reduced welfare	Aspects of the design and management, such as quality of the floor, hygiene management and space allowance (Bielfeldt et al., 2005; O'Driscoll et al., 2008, 2009, Lutz et al., 2019; Schneider, 2010, Knierim et al., 2020)

3.5.2. Access to pasture

With regard to access to pasture, different intensities (in terms of hours per day, days per year and area offered) can be distinguished in dairy cow husbandry. Essentially, a distinction can be made between the following grazing systems:

- exercise-paddock, providing the cows restricted access to rather small pastures, mainly over the vegetation period during spring/summer
- pasture-grazing and housing, where pasture contributes significantly to the dietary ration of the cows, mainly over the vegetation period during spring/summer
- pasture-grazing only, where the cows are kept outdoors exclusively (Azores, Portugal) or for the large majority of the year, with or without access to an out-wintering or stand-off pad (enclosed area of pasture covered in bedding, e.g. wood bark; used in New Zealand and in Ireland), (O'Driscoll et al., 2008; Al-Marashdeh et al., 2019).

3.5.2.1. Distribution

Due to climatic conditions and/or limited availability of pasture, year-round access to pasture is not achievable in most EU countries (Reijs et al., 2013). Exceptions are the Portuguese Azores Islands, with a mild climate all year round (de Almeida et al., 2021), and Ireland, though with a lower proportion of farms. Common in Ireland, however, are pasture-based systems with grazing periods over a large part of the year and shorter periods of winter indoor housing (Crossley et al., 2021). Summer pasture is also a feature of vertical transhumant systems found in the Alpine region including areas of Austria, Slovenia and Italy, aiming to exploit pastures located at higher altitudes during the warmest months of the year. During the winter season, different housing systems are used (Corazzin et al., 2010; Tarantola et al., 2016; Zuliani et al., 2018).

In most regions and countries of the EU-MSs, different grazing intensities (exercise or grazing pasture) are practised during the summer grazing period. The number of grazing hours each day and grazing days per year can vary markedly between countries and between farms within country (Reijs et al., 2013; Becker et al., 2018; Hennessy et al., 2020).

Since around the 1990s, the proportion of farms offering access to pasture has been declining in several EU countries, and an increasing number of farms has been converting to all-year-housing systems (Reijs et al., 2013). The percentages of farms offering pasture or the percentage of grazing dairy cows vary widely between countries and regions (Barkema et al., 2015; van den Pol-van Dasselaar et al., 2020).

An overview of data from individual EU-MSs is presented in Table 13. Official statistics are only available from individual countries (e.g. Germany, Denmark). In a recent review article by van den Pol-van Dasselaar et al. (2020), educated estimates from the working group 'Grazing' (European Grassland Federation) were compiled (data related to the years 2018–2019). However, it is important to note that definitions used for 'grazing' in terms of daily grazing times and grazing days per year varied between sources; therefore, these data should be considered as approximates. In addition, the proportion of farms offering pasture for grazing was not provided separately for the different studies.

Table 13: Distribution of farms offering pasture/grazing to dairy cows reported for individual EU-MSs based on national statistical data, epidemiological studies or educated estimates of the working group 'Grazing'; unless otherwise stated in footnotes, no standard definition of grazing time per day or per year was given

Country (Region)	Level	% Farms	% Cows	Reference
AT	Sample (n = 1,851)	–	71.0	Pöllinger et al. (2018)[(a)]
BE	National	–	30.0-90.0[(b)]	van den Pol-van Dasselaar et al. (2020)
CZ	National	–	5.0	van den Pol-van Dasselaar et al. (2020)
DK	National	–	24.7	Statistics Denmark (2021b)[(c)]
EST	National	–	10.0	van den Pol-van Dasselaar et al. (2020)
EST	National	61		Reimus et al. (2020)
FI	National	–	80.0	van den Pol-van Dasselaar et al. (2020)
FR	National	–	90.0	van den Pol-van Dasselaar et al. (2020)
DE	National	43.0	30.8	Statistisches Bundesamt (2021b)
GR	national	–	10.0	van den Pol-van Dasselaar et al. (2020)
HU	National	–	3.0 – 5.0	van den Pol-van Dasselaar et al. (2020)
IRL	National	–	95.0–100.0	van den Pol-van Dasselaar et al. (2020)
IT	National	–	10.0–30.0	van den Pol-van Dasselaar et al. (2020)
LT	National	–	75.0	van den Pol-van Dasselaar et al. (2020)
NL	National	80.0	(65.0–85.0)[(d)]	van der Peet et al. (2018)
PL	National	–	30.0[(e)]	van den Pol-van Dasselaar et al. (2020)
PT	National	–	60.0	van den Pol-van Dasselaar et al. (2020)
SI	National	–	20.0–40.0	van den Pol-van Dasselaar et al. (2020)
ES (Northwest)[(f)]	National	–	20.0–30.0	van den Pol-van Dasselaar et al. (2020)
SE	National	100.0	100.0[(g)]	van den Pol-van Dasselaar et al. (2020)

(a): 1–24 h/day on average 115 days per year.
(b): Marked differences between the regions Flanders and Wallonia.
(c): Refers to all cows in Denmark; 84% of cows in Denmark are dairy cows.
(d): Educated estimate reported in (2020).
(e): Winnicki and Jugowar (2011) reported a share of 10% for Wielkopolska Region.
(f): Lower proportions of grazing cows are estimated for the south of Spain (Molina et al., 2020).
(g): The national law requires pasture access during summer for all dairy cows.

3.5.2.2. Strengths, weaknesses and hazards that contribute to reduced welfare in systems that include access to pasture

Strengths of pasture access compared to zero-grazing are reported in several studies that have shown positive effects on various aspects of cow welfare, including health and opportunities to perform natural behaviour (Table 14). For most welfare outcomes, the more hours of grazing per day and the more days per year, the stronger the effect (review in Arnott et al., 2017). Within-farm comparisons between summer grazing and winter indoor housing periods have shown positive effects of grazing on various aspects of cow welfare (Burow et al., 2013a). Previous experience of access to outdoor pasture may increase the time cows spend at pasture, except in inclement weather (Shepley et al., 2017).

Impaired udder health in terms of increased somatic cell counts and incidence of clinical mastitis (Goldberg et al., 1992; Washburn et al., 2002; Firth et al., 2019), locomotor disorders including integument alterations, claw disorders and lameness (Haskell et al., 2006; Hernandez-Mendo et al., 2007; Olmos et al., 2009a; Burow et al., 2013a,b; de Vries et al., 2015; Wagner et al., 2017; Armbrecht et al., 2018; Sjöström et al., 2018) and reproductive disorders (Olmos et al., 2009b; Palmer et al., 2012) have been reported to be reduced with longer grazing periods, compared with zero-grazing or in a comparison of summer pasture to winter indoor housing. In some circumstances, the improved udder health may be related to the fact that cows on pasture are exposed to a lower challenge from environmental pathogens and are less soiled compared to housed cows (Ellis et al., 2007; Nielsen et al., 2011). With regard to mortality, which could be considered an iceberg indicator for cow welfare, lower rates were found with increasing number of hours on pasture or compared to zero-grazing (Washburn et al., 2002; White et al., 2002; Burow et al., 2011; Alvåsen et al., 2014).

Compared to tie-stalls or cubicle housing systems, pasture offers improved opportunities for cows to exhibit natural behaviours. Herd behaviour was found to be more synchronised (Krohn, 1994; Crump et al., 2019), and agonistic interactions between conspecifics occurred less often on pasture compared to during indoor housing (O'Connell et al., 1989).

On pasture, cows walk longer distances than when housed, which more closely aligns with their natural locomotion behaviour and walking to and from the milking parlour at least twice daily has been associated with improved hoof and joint health and possibly facilitates the recovery from claw injuries (Krohn, 1994; Hernandez-Mendo et al., 2007). However, walking on stony or uneven track surfaces can result in lameness (e.g. Chesterton et al., 1989).

Experimental studies in Switzerland and the UK reported that dairy cows spend more absolute time feeding on pasture, with shorter rumination times (Roca-Fernández et al., 2013; Dohme-Meier et al., 2014) and lower dry matter intakes (Dohme-Meier et al., 2014). In half-day grazing compared to zero-grazing, however, no differences were found in the relative times of feeding (Shepley et al., 2017; Smid et al., 2018).

In terms of lying behaviour, in most studies, pasture access has been associated with reduced daily lying times, possibly due to the time required for grazing (see Section 4.3.5). However, also longer total lying durations, longer lying bout duration and an increased number of lying bouts have been reported, which could be explained by improved comfort while resting and less competition for lying places (Crump et al., 2019; O'Connell et al., 1989; Olmos et al., 2009a; Singh et al., 1993). Several studies have also shown that cows reduce daily lying duration when lying surfaces are wet (Tucker et al., 2007; Schütz et al., 2010; Chen et al., 2017), which may occur at pasture.

Dairy cows can suffer from heat stress at pasture (Polsky and von Keyserlingk, 2017). Hot conditions lead to competition for shade and at the drinkers (Schutz et al., 2010, McDonald et al., 2020), and may thus affect social behaviours.

Systems that include access to pasture have potential weaknesses in terms of certain disease complexes, including parasitic infestation (e.g. *Ostertagia ostertagi* (Charlier et al., 2005; Forbes et al., 2008), *Fasciola hepatica* (Bennema et al., 2011), thermal stress due to cold or hot climatic conditions (review in Moons et al., 2014) and aspects of animal nutrition due to an insufficient or discontinuous energy supply and variable feed quality. These nutritional issues can lead to lower productivity, increase the risk of suboptimal body condition (Burow et al., 2013a; Crossley et al., 2021) and metabolic disorders (review in Mee, 2012). High-yielding dairy cows on pasture might not be able to meet their nutritional requirements exclusively from grazing (Hernandez-Mendo et al., 2007). Grazing presents several hazards that can lead to a high prevalence of lameness, especially in animals walking large distances (e.g. to be milked) on poorly maintained concrete roads or walking tracks. Also rushing cattle while walking increases the risk of lameness (Chesterton et al., 1989; Clarkson et al., 1996; Barker et al., 2009: Burow et al., 2014). Bran et al. (2018) showed that for every 1 km/h increase in the average speed of movement of the herd to or from milking, lameness incidence increased by 5%.

Principal strengths, weaknesses and hazards that contribute to reduced welfare in systems that include access to pasture are summarised in Table 14 (see also chapter 5 for a detailed comparison between this and other housing systems).

Table 14: Strengths, weaknesses and hazards that contribute to reduced welfare in systems that include access to pasture

Strengths	Reduced locomotor disorders e.g. dermatitis and heel horn erosion (Haskell et al., 2006; Hernandez-Mendo et al., 2007; Rutherford et al., 2009; Olmos et al., 2009a; Burow et al., 2013a,b; de Vries et al., 2015; Wagner et al., 2017; Armbrecht et al., 2018; Sjöström et al., 2018; Crossley et al., 2021)
	Improved udder health (Goldberg et al., 1992; Washburn et al., 2002; Firth et al., 2019)
	Lower risk of reproductive disorders (Olmos et al., 2009b; Palmer et al., 2012)
	More natural behaviours (O'Connell et al., 1989; Singh et al., 1993; Krohn, 1994; Olmos et al., 2009a; Crump et al., 2019)
	Lower risk of dirty legs and udders (Ellis et al., 2007; Nielsen et al., 2011)
Weaknesses	Increased risk of thermal stress (review in Moons et al., 2014)
	Increased risk of parasitosis (Charlier et al., 2005; Forbes et al., 2008; Bennema et al., 2011)
	Increased risk of low body condition and metabolic disorders (Hernandez-Mendo et al., 2007; Olmos et al., 2009b; Burow et al., 2013a; Crossley et al., 2021)
	Increased risk of locomotory and claw disorders e.g. sole ulcers (Chesterton et al., 1989; Clarkson et al., 1996; Barker et al., 2009; Burow et al., 2014; Bran et al., 2018; Navarro et al., 2013)
Hazards of reduced welfare	Insufficient shelter from adverse climatic conditions (review in Moons et al., 2014)
	Insufficient/discontinuous energy supply (review in Mee, 2012)
	Inadequate parasite control (review in Arnott et al., 2017)
	Poorly maintained walking tracks/roads, and rushing cattle while walking (Chesterton et al., 1989; Clarkson et al., 1996; Barker et al., 2009; Burow et al., 2014)

4. Assessment 2: most relevant welfare consequences for dairy cows

4.1. Locomotory disorders (including lameness)

This section focusses on foot and leg disorders that do cause a change in gait or to normal patterns of locomotion (locomotory disorders) but also on disorders that do not necessarily cause such changes.

4.1.1. Description of locomotory disorders (foot and leg disorders)

Foot and leg disorders can be divided into claw disorders such as sole ulcer or white line disease and disorders of the limbs (muscles, joints and skin). They are one of the major welfare issues in dairy cows as these disorders are commonly associated with pain (e.g. Brenninkmeyer et al., 2013; Somers and O'Grady, 2015; Burgstaller et al., 2016; Westin et al., 2016a; Führer et al., 2019). Additionally, they are often associated with restriction of the animals' ability to perform natural behaviours, such as locomotion and feeding. Foot and leg disorders can be associated with decreasing body condition and an increased risk of concurrent disease (review in Alvergnas et al., 2019; Charlton and Rutter, 2017; Huxley, 2013; Kester et al., 2014; Nuss and Weidmann, 2013; Oehm et al., 2019; Olechnowicz and Jaskowski, 2011; Penev et al., 2012).

Additionally, poor claw conformation (e.g. due to claw overgrowth or excessive claw wear) may affect gait and lead to lameness.

Lameness is an abnormal gait mostly resulting from injury or disease with pain being the most common cause of altered gait. Tissue damage and associated inflammation lead to the stimulation of nociceptors and release of e.g. pain mediators (Whay and Shearer, 2017). Depending on the type of lesions, the development of hyperalgesia has been described in lame dairy cattle, especially in animals with chronic lameness disorders. Hyperalgesia has been shown to last for 28 days after detection of the lesion (Whay et al., 1998) making lameness a long-lasting welfare issue even after treatment of a lesion. Severe forms of lameness which are characterised by inability or strong reluctance to bear weight on one or more limbs are often associated with weight loss, emaciation and weakness, which in addition to the highly painful state e.g. impair the animal's ability to reach or compete for resources such as feed and water.

Foot and leg disorders are usually multifactorial in aetiology, resulting from interactions between the farm environment, management, nutrition and animal characteristics including genetics, age and stage of lactation (review in Alvergnas et al., 2019; Arnott et al., 2017; Logue and Mayne, 2014; Oehm et al., 2019; Penev et al., 2012),

4.1.1.1. Claw disorders

Claw disorders can occur on individual or on several claws at the same time; however, the rear lateral claws are more frequently affected than the rear medial or the front claws (Dendani-Chadi et al., 2020). Causes of claw disorders can be divided into infectious and non-infectious. Both infectious and non-infectious claw disorders are influenced by management and housing, e.g. bedding types and floor characteristics and cleanliness.

In the ICAR claw health atlas (Egger-Danner et al., 2020), the 'working group on functional traits' harmonised descriptions of claw disorders in dairy cows.

Non-infectious claw disorders

Claw horn disruption lesions (CHDL) are a set of non-infectious foot lesions that include double soles, horn fissures, sole haemorrhages, sole ulcers and white line disease (review in Alvergnas et al., 2019). The exact aetiopathogenesis of CHDL remains unclear although a variety of hazards have been reported including aspects of the cow's environment and farm management practices (see later sections).

Infectious claw disorders

Infectious claw disorders are associated with various microorganisms. Digital and interdigital dermatitis as well as heel horn erosion are multi-bacterial in origin and associated with infection by *Treponema* spp. in addition to other anaerobic and aerobic bacteria. However, the precise aetiology remains to be determined (review in Alvergnas et al., 2019; Evans et al., 2016; Wilson-Welder et al., 2015). Interdigital phlegmon (Interdigital Necrobacillosis), in contrast, is mainly caused by *Fusobacterium necrophorum* following a puncturing trauma of the interdigital skin, although other bacteria may also be involved (review in Alvergnas et al., 2019; Wilson-Welder et al., 2015).

4.1.1.2. Limb disorders

Musculoskeletal disorders (arthritis)

Infectious or septic arthritis is a sporadic problem in adult animals and usually develops following penetrating wounds, extension from local infections, peri-articular cellulitis or from circulation of pathogens originating from infectious diseases located elsewhere, such as liver abscesses, endocarditis, lung abscesses, pneumonia, septic mastitis or chronic hoof infections (Desrochers and Francoz, 2014; Peek and Divers, 2017). *Trueperella pyogenes* is the most common organism isolated from septic joints (Peek and Divers, 2008). Arthritis and tendonitis caused by *Mycoplasma bovis* appear to be a unique condition in adult dairy cows as it develops as a primary condition, usually associated with high herd prevalence of incurable mastitis and pneumonia (Pfützner and Sachse, 1996a,b; Henderson and Ball, 1999; Penterman et al., 2022).

Uncomplicated and non-infectious trauma of some joints (usually carpus or tarsus) results in swelling and pain leading to a reluctance to flex the limbs or even to lie down. If the housing circumstances do not permit extension of the carpus when recumbent, further trauma to other extremities may result (Peek and Divers, 2008).

Degenerative arthritis is not common in cattle (Peek and Divers, 2008).

Probably the most common sites for septic arthritis in adult dairy cows are the interphalangeal joints (Heppelmann et al., 2009). These occur as extension of infections following hoof (e.g. sole ulcer) or interdigital skin (e.g. foot rot) lesions. These arthritis and concurrent osteomyelitis cause severe long-lasting pain. Cows will show very low body condition and reduced milk yield, normally leading to early culling. Those that are kept on the farm will eventually develop ankyloses of the affected joints but will be chronically lame (Desrochers et al., 1995).

Skin alterations (hock and knee lesions)

Integument alterations on the limbs (such as hock (tarsus) or knee (carpus) lesions) are the most common integument alterations across housing systems and include multiple clinical presentations ranging from mild hair loss to cellulitis, swelling and ulceration. The alterations can progress to more serious conditions involving subcutaneous tissue, bones or joints. Although a progression from mild to severe alterations is often suspected (review in Nuss and Weidmann, 2013), it is still uncertain and individual studies provide evidence for partly differing aetiologies. For instance, in a study by Potterton et al. (2011), there was only one common hazard (cubicle bedding material) for different severities of hock lesion. The authors concluded that ulceration was not the result of a progressive development of hair loss and that the underlying aetiology differed between different severities.

Non-infectious hair loss over the tarsal or carpal joints occurs due to repeated pressure or friction on abrasive surfaces when, for instance, lying or feeding. This mild damage indicates deficiencies in the quality of the housing but does not necessarily lead to lameness. However, if the skin in areas of hairless patches is penetrated, pathogens can enter. Infected and purulent lesions or lesions associated with swelling can be painful and cause lameness. A systemic spread of the infection via the blood or lymph systems can result in further diseases such as bacterial endocarditis. Swellings also predispose to the development of arthritis (review in Kester et al., 2014).

Damage to the hock joint is one of the most common pathological changes of the limbs of cattle and can primarily be attributed to inadequate dimensions of cubicles or hard or abrasive lying surfaces. The risk of lesions becoming infected is strongly dependent on the hygiene of the lying area. Due to the softer and more deformable nature of the surface, the prevalence of leg joint lesions was found to be low in dairy cows kept in straw yard or pasture-based systems compared to cubicle and tie-stall systems (review in Kester et al., 2014; Nuss and Weidmann, 2013).

Severe hock alterations have been reported to be associated with lameness (Brenninkmeyer et al., 2013; Burow et al., 2013b). However, the causal relationship between hock alterations and lameness remains unclear, since lame cows were also found to have longer lying times, which could in turn increase the risk of hock lesions (review in Kester et al., 2014; Nuss and Weidmann, 2013).

4.1.1.3. Claw conformation

Poor claw conformation traits have been found to be associated with lameness (Corazzin et al., 2010) including foot angle, dorsal wall length, heel depth and diagonal distance (Boelling and Pollott, 1998). Claw overgrowth due to too little locomotion and abrasion can lead to very long or corkscrew claws (Egger-Danner et al., 2020). Excessive claw wear in contrast can lead to thin soles, which again have been found to increase the risk of subsolar bruising, exposure of the corium at the white line or sole ulcers (van Amstel et al., 2004).

4.1.2. Animal-based measures for locomotory disorders

Claw or joint disease or trauma can be identified by an inspection of the animals´ limbs or claws and lameness can be detected using a gait assessment. However, considerable heterogeneity is present between studies in the definition and assessment of both claw disorders and lameness.

4.1.2.1. Animal-based measures for lameness

Lameness is described as an inability to express a normal and functional gait pattern in one or more limbs usually as a consequence of pain, caused for example by claw diseases, excessive claw wear, claw overgrowth, arthritis or other musculoskeletal disorders. A range of scoring systems (Table 15) to identify lame cattle have been established based on different characteristics of locomotion and body posture that rely on observations by humans (e.g. Sprecher et al., 1997; Welfare Quality®, 2009). Moreover, scoring systems can be derived from new technologies (such as computer-assisted kinematic techniques, pressure mats, weighing platforms, algometers and accelerometers) which register changes in the gait of cows (review in Olechnowicz and Jaskowski, 2011, Chambers et al., 1994; Chapinal et al., 2010; Pastell et al., 2010; Schulz et al. 2011; Alsaaod et al., 2012; Van Hertem et al., 2013).

Table 15: Measures used to assess lameness in cattle

Measure for	Scale/ method	Categories	Reference
Gait assessment	5-point scale	Smooth and fluid movement Imperfect locomotion, but ability to move freely not diminished Capable of locomotion but ability to move freely is compromised Ability to move freely is obviously diminished Ability to move is severely restricted	Flower and Weary (2006), Sprecher et al. (1997), Winckler and Willen (2001)
Gait assessment	4-point scale	Sound locomotion Steps uneven or shortened Identifiable problem in one or more limbs Severely impaired mobility	AHDB (2021), Barker et al. (2010)
Gait assessment	3-point scale	Not lame Moderately lame Severely lame	Brinkmann and Stevens (2016), Welfare Quality® (2009)
Assessment in tie-stalls	Four criteria to identify lameness from behind: weight shifting, sparing a foot while standing, unequal weight bearing when stepping from side to side, standing on the edge of the kerb		Leach et al. (2008) in Leach et al. (2009), Palacio et al. (2017)

Since it is not certain that all claw disorders or lesions result in pain or lameness, gait scoring is considered the most appropriate ABM for lameness as an evaluation of cow welfare (Table 16). Gait scoring provides a practical, feasible method to assess dairy cow lameness on-farm.

Table 16: Gait assessment as an ABM for lameness in terms of feasibility, sensitivity and specificity

ABM	Description of the ABM
Gait assessment	**Definition:** 3-point scale (Brinkmann and Stevens, 2016; Welfare Quality®, 2009) **Feasibility:** High – a practical way to assess lameness during on-farm inspection **Sensitivity and Specificity:** High sensitivity and high specificity

4.1.2.2. Animal-based measures for claw disorders

Claw condition (conformation), lesions and diseases are recorded and diagnosed during inspection, functional claw trimming and/or treatments by trained farmers, researchers, professional claw trimmers or veterinarians. In scientific studies, different recording methods have been used, from basic scoring systems that include lesion severity to methods that describe specific foot traits (e.g. wall length and horn hardness) or diseases (e.g. digital dermatitis). Key animal-based measures for the practical on-farm assessment of claw diseases are presented in Table 17.

Table 17: Assessment of ABMs for claw conditions or claw diseases in terms of feasibility, sensitivity and specificity

ABM	Description of the ABM
Digital dermatitis	**Definition:** Bacterial foot lesion that alters gait or posture of the animal. M-stages scoring system classifies the severity of the lesions (Egger-Danner et al., 2020 - ICAR Claw Health Atlas). Higher score means more severe lesions. **Feasibility:** High – less feasible than gait scoring but more feasible than scoring of all lesion types **Sensitivity and Specificity:** High sensitivity and high specificity (relates solely to identification of digital dermatitis)
Lesions of the claws	**Definition:** Scoring system for different types of claw lesions (Egger-Danner et al., 2020 – ICAR Claw Health Atlas). Higher score means more severe lesions.

ABM	Description of the ABM
	Feasibility: Low – possible if captured from routine foot trimming records otherwise not easily conducted during on-farm inspections **Sensitivity and Specificity:** High sensitivity but specificity dependent on the lesion type (not all lesions result in clinical lameness which reduces specificity) Prevalence by lesion type and severity would enhance interpretability

4.1.2.3. Animal-based measures for integument alterations of the limb

Multiple scoring systems for integument alterations of the limbs are in use with scores reflecting severity in terms of animal welfare. Inspections are made either from a distance (e.g. Welfare Quality®, 2009) or supplemented by palpation of the limb (e.g. Brenninkmeyer et al., 2013). Key animal-based measures for the practical on-farm assessment of integument alterations of the limb are presented in Table 18. These ABMs should be seen as complementary to the ABMs listed in Tables 16 and 17 for an overall assessment of lameness problems.

Table 18: Assessment of ABMs for claw conditions or claw diseases in terms of feasibility, sensitivity and specificity

ABM	Description of the ABM
Hock alterations	**Definition:** 3-point scale from Welfare Quality protocol addressing different types of alterations. Higher score means more severe lesions. **Feasibility:** High – practical assessment method **Sensitivity and Specificity:** Practical scoring system with high sensitivity and specificity
Knee alterations	**Definition:** 3-point scale from Welfare Quality protocol addressing different types of alterations. Higher score means more severe lesions. **Feasibility:** High – practical assessment method **Sensitivity and Specificity:** Practical scoring system with high sensitivity and specificity

4.1.3. Locomotory disorders in different housing systems

4.1.3.1. Prevalence of lameness

The prevalence of lameness reported from studies of different housing systems varied markedly, both within and between housing systems. For example, Katzenberger et al. (2020) found an average of 7.9% lame cows in tie-stall systems, whereas Oehm et al. (2020), Popescu et al. (2014) and Bouffard et al. (2017) found a substantially higher prevalence of over 20% lame cows using the same scoring system (see Appendix D, Table D.1 for an overview of the literature).

An evaluation of different studies in cubicle systems also revealed a diverse picture (Appendix D, Table D.2). Sjöström et al. (2018) found the average prevalence of lame cows (moderately and severely lame cows lumped together) ranging from 7% in Sweden to 26% in Germany and France. Using the same scoring system (3-point scoring according to Welfare Quality®, 2009), Gieseke et al. (2020) reported that on average 16% of cows in cubicle systems in Germany were severely lame. The highest prevalence was reported by von Keyserlingk et al. (2012); on average, 55% of cows assessed in each herd in the North-East of the USA were lame (score $\geq$ 3 in a 5-point system) and 8% were scored severely lame (score $\geq$ 4). The lowest proportions of lame cows among the studies included in this work (6%) were reported from Algerian small-scale farms (Dendani-Chadi et al., 2020).

In straw yard systems, the proportion of lame cows (including severely lame ones) ranged from 6% in Spain (Sjöström et al., 2018) to 27% in the UK (Barker et al., 2010) (see Appendix D, Table D.3, for an overview of the literature). This range is approximately comparable to that of studies in compost-bedded pack systems (total lameness prevalence from 4% in the US (score $\geq$ 3; Lobeck et al., 2011) to 25% in Austria (score $\geq$ 3; Ofner-Schröck et al., 2015), see Appendix D, Table D.4). For pasture-based systems (data recording in summer), a prevalence of 10% and 12% lame cows have been reported by Crossley et al. (2021) and Somers and O'Grady (2015) (Appendix D, Table D.5).

4.1.3.2. Prevalence of claw disorders

With regard to claw disorders, the herd prevalence depends on which traits or which disorders were evaluated. The prevalence of infectious claw disorders (e.g. digital dermatitis, interdigital necrobacillosis) is generally reported to be lower (0.0–3.1%) than non-infectious claw disorders (15.9–46.6%) in all housing systems with the exception of heel horn erosion (26.9–59.9%) (e.g. Häggman and Juga, 2015 for tie-stall systems and Burgstaller et al., 2016 for cubicle and compost-bedded pack systems). Specifically for heel horn erosion, a prevalence of up to 59.9% in cubicle systems and 26.9% in compost-bedded pack systems has been reported (Burgstaller et al., 2016). With regard to claw overgrowth, a herd prevalence above 15% has been reported in all housing systems. See Appendix D, Tables 6–8 for an overview of the literature.

There appears to be limited data related to herd prevalence of claw disorders in pasture-based systems (Appendix D, Table D.9). However, similar studies that only evaluated populations of lame cows within pasture-based systems suggest that white line disease and sole haemorrhage are the most common lesions associated with lameness.

4.1.3.3. Prevalence of hock, knee and stifle integument alterations

A high prevalence of both mild and severe hock alterations is reported from studies in tie-stall systems (e.g. 62.2% of mild hock alterations in Bernhard et al. (2020) and 58.3% of severe hock alteration in Bouffard et al. (2017), see Appendix D, Table D.10). With regard to knee alterations, prevalence differed between studies. Bouffard et al. (2017) found on average 43.8% cows with severe knee alterations in a sample of Canadian dairy herds, whereas Bernard et al. (Bernhard et al., 2020) found a mean prevalence of 13.8% in Swiss herds. Stifle alterations were only recorded separately by Bernhard et al. (2020) and occurred less often compared to hock and knee alterations. In cubicle systems, the prevalence of both mild and severe hock (or tarsus) and knee (or carpus) alterations differed markedly between different studies (see Appendix D, Table D.11). Overall, the prevalence was high (> 50% in Cook et al., 2016 and Ekman et al., 2018; > 20% in Burow et al., 2013b and Potterton et al., 2011).

In comparison to studies on cubicle or tie-stall systems, studies in open-bedded systems (exclusively in compost-bedded pack systems) found a prevalence of integument alterations at a lower level (0–8.8%; Fernández et al., 2020, Lobeck et al., 2011, Biasato et al., 2019, Ofner-Schröck et al., 2015, see Appendix D, Table D.12 for more details). No data on integument alteration prevalence in straw yard systems or pasture-based systems were reported in the reviewed studies.

4.1.4. Comparison of housing systems with regard to occurrence of locomotory disorders

Results presented in Section 4.1.3 illustrate substantial variability in the prevalence of lameness and lesions within each housing system, which means that any assessment made between systems requires caution. A summary of studies that have evaluated the prevalence of lameness, claw disorders and integument damage between housing systems is presented in Tables 19, 20 and 21, respectively.

Table 19: Comparison of housing systems regarding lameness prevalence and/or mean lameness scores

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
Algeria	% lame	↑	↓			Dendani-Chadi et al. (2020)
AT, IT	% lame	↑	↓			Katzenberger et al. (2020)
PL	% lame	ns	ns			Olechnowicz et al. (2010)
Türkiye	Mean score	↑	↓			Kara et al. (2011)
SRB	% lame	↑		↓		Ostojić Andrić et al. (2011)
ES	% lame	ns	↑	(↓)[(a)]		Pérez-Cabal and Alenda (2014)
ES	% lame		↑	↓		Sjöström et al. (2018)
FR, DE, SE	% lame		ns	ns		Sjöström et al. (2018)
UK	% lame		↑[(b)]	↓		Griffiths et al. (2018)

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
UK	% lame		ns	ns		Barker et al. (2010)
AT	% lame		ns		ns	Burgstaller et al. (2016)
ES	% severely lame		↓[c]		↑[c]	Fernández et al. (2020)
USA	% lame		↑[d]		↓[d]	Lobeck et al. (2011)
USA	Mean score		ns		ns	Eckelkamp et al. (2016b)

↓ = significantly less lameness ($p < 0.05$), (↓) = a tendency for less lameness ($p < 0.1$), ↑ = significantly more lameness ($p < 0.05$); ns = not significant or tendency. The housing systems compared are indicated by these arrows and empty cells mean that the corresponding housing system was not included in the comparison.
(a): Only in primiparous cows, no significant effect found in multiparous cows.
(b): Cubicles with mats or shallow bedding.
(c): Not significant regarding % moderately lame cows.
(d): Not significant regarding % severely lame cows.

Table 20: Comparison of housing systems regarding prevalence of claw disorders

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
AT, IT	Claw diseases	ns	ns			Katzenberger et al. (2020)
	Overgrown claws	↑	↓			
PL	Claw diseases	ns	ns			Olechnowicz et al. (2010)
FI	Infectious claw diseases		↓	↑		Häggman and Juga (2015)
	Non-infectious claw diseases		↑[a]	↓		
AT	Heel horn erosion		↑		↓	Burgstaller et al. (2016)
	White line disease		↑		↓	
	Concave dorsal wall		↑		↓	
	Interdigital hyperplasia		↑		↓	
	Double sole		ns		ns	
	Sole haemorrhage		ns		ns	
	Sole ulcer		ns		ns	
	Horn fissure		ns		ns	
ES	Inflamed coronet		↓		↑	Fernández et al. (2020)

↓ = significantly fewer disorders ($p < 0.05$), ↑ = significantly more disorders ($p < 0.05$); ns = not significant. The housing systems compared are indicated by these arrows and empty cells mean that the corresponding housing system was not included in the comparison.
(a): Slatted floor.

Table 21: Comparison of housing systems regarding prevalence of integument alterations on the limbs

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
AT, IT	% hock alterations	↑	↓			Katzenberger et al. (2020)
	% knee alterations	↑	↓			
UK	% hock mild		↑	↓		Potterton et al. (2011)
	% hock lesion		↑	↓		
	% hock swelling		↑	↓		
FR	score for absence of any type of injuries		↓	↑		De Boyer des Roches et al. (2014)

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
ES	% carpus mild		ns		ns	Fernández et al. (2020)
	% carpus severe		ns		ns	
	% tarsus mild		↑		↓	
	% tarsus severe		ns		ns	
USA	mean hock score		ns[(a)]		ns	Eckelkamp et al. (2016b)
USA	% hock alterations		↑		↓	Lobeck et al. (2011)

↓ = significantly fewer alterations ($p < 0.05$), ↑ = significantly more alterations ($p < 0.05$); ns = not significant. The housing systems compared are indicated by these arrows and empty cells mean that the corresponding housing system was not included in the comparison.
(a): Sand-bedded cubicles.

Several studies that have compared different housing systems with regard to foot and leg disorders have reported advantages in terms of lameness (Table 19) and integument alterations (Table 21) in cubicle systems compared to tie-stall systems, and in open-bedded systems (both straw yards and compost-bedded pack) compared to cubicle systems. In some studies, however, no significant differences were found between housing systems, which indicates that it is not necessarily the housing system alone that is decisive, but also the respective design and management.

With regard to claw disorders, an overall improvement is generally reported from tie-stalls to cubicles and from cubicles to open-bedded systems (Table 20). However, a differentiation must be made between different aetiologies. A study by Häggman and Juga (2015) identified fewer non-infectious claw diseases in straw yards than in cubicle systems, but the reverse was true for infectious claw diseases.

In summary, results presented in Tables 19–21 suggest substantial within-system variability in the prevalence of foot and leg disorders. It appears unlikely that any one system will always lead to a lower prevalence of lameness than another; the comparison is likely to depend on the specific context (e.g. quality and management) of the systems involved. Furthermore, the observational and cross-sectional nature of many studies means that causality (in terms of each system 'causing' lameness) should be attributed with care. Furthermore, many studies do not distinguish between different severity levels of lameness or leg lesions, thus making conclusions on the actual welfare state of the animals difficult.

4.1.5. Effects of outdoor access on locomotory disorders

A summary of studies that have evaluated the effect of access to pasture (or outdoor loafing) on the prevalence of lameness, claw disorders and integument damage between housing systems are presented in Appendix D, Tables D.13, D.14 and D.15, respectively.

In the studies included in this SO, zero-grazing was compared with summer grazing, winter housing periods with summer grazing periods or different grazing durations per day with regard to foot and leg disorders. Individual studies have also included a potential effect of access to an outdoor loafing area. Again, since most studies are observational by design, causality should be attributed with caution.

Lameness and integument alterations are usually less frequent in grazed herds in comparison to zero-grazing herds whether in tie-stall systems (Popescu et al., 2013: zero-grazing vs. outdoor access (pasture, paddock or both)) or in cubicles systems (de Vries et al., 2015: zero-grazing vs. summer grazing; Chapnal et al., 2013 and Barrientos et al., 2013: zero-grazing vs. dry cows grazing). Longer grazing periods are also associated with lower lameness and less integument alterations (Burow et al., 2013b; Wagner et al., 2017; Armbrecht et al., 2019; Dendani-Chadi et al., 2020). For example, in Armbrecht et al. (2019), the percentages of lame cows and cows with integument alterations were lower in herds grazing more than 10 h/day in comparison to 6–10 h/day or < 6 h/day of grazing (access to pasture at ≥ 120 days/year, data collected at the end of the pasture season). However, some studies reported no effect of outdoor access on lameness and integument alteration prevalences: e.g. Gieseke et al. (2020) found similar prevalences during winter in zero-grazing herds in comparison to herds grazing in summer for < 6 h/day. Within grazing herds, some studies found a higher prevalence of integument alterations during winter housing in comparison to summer grazing with no difference in lameness prevalence (Burow et al., 2013a; Crossley et al., 2021). See Appendix D, Table D.13 and Table D.15 for a literature overview.

With regard to claw diseases, the effect of pasture grazing or access to an outdoor loafing area was less clear (See Appendix D, Table D.14).

In summary, the impact of outdoor access on foot and leg disorders is variable and likely to be affected by the specific context of each study. There is limited evidence that outdoor access is associated with reduced lameness or reduced prevalence of claw disorders; this area requires further elucidation. Evidence for an association between outdoor access and a reduction in integument alterations is more compelling, although not absolute. Since most studies on outdoor access are observational or consider a limited set of managemental conditions, the extent to which outdoor access would be of general benefit for foot and leg disorders remains unclear.

4.1.6. Common hazards and preventive measures

With regard to the effects of different lying surfaces, research generally suggests that deep bedding and soft, deformable surfaces offer advantages over surfaces that provide no cushioning for the cow, ensuring comfortable locomotion and healthier limbs. Mats or mattresses installed on the stall base are more deformable than plain concrete but can – depending on the design – also be more abrasive and associated with increased prevalence of hock alterations, which has been reported in cubicle (Potterton et al., 2011) and tie-stall systems (Bernhard et al., 2020).

In loose housing systems, floor type can affect prevalence of lameness and claw disorders which may be attributable to standing on hard and/or wet surface, exposure of claws to liquid manure and walking on either very rough or slippery surfaces (review in Endres, 2017). Soft flooring (e.g. application of rubber on walking alleys) may help to reduce the wear on claws contributing to a reduction in certain claw disorders (e.g. heel horn erosion) and lameness (Haufe et al., 2012; Chapinal et al., 2013; Eicher et al., 2013). However, prevalence of sole haemorrhage was increased in herds on rubber floor compared to herd on mastic asphalt, which is highly slip-resistant (Haufe et al., 2012). Slippery or slatted compared to solid floor surfaces were identified as hazards for increased lameness (Sarjokari et al., 2013) and increased prevalence of infectious and non-infectious claw disorders (Kujala et al., 2010; Haufe et al., 2012; Häggman and Juga, 2015; Burgstaller et al., 2016). Strongly roughened solid floors or higher proportions of mastic asphalt floors, however, can lead to excessive claw abrasion and thus promote claw diseases, such as thin soles, and associated lameness (Führer et al., 2019).

Regular floor scraping reduces the exposure of claws to faeces and wet conditions, can be beneficial for claw health (e.g. digital dermatitis: de Jong et al., 2021) and improve locomotion (Chapinal et al., 2013; Somers et al., 2005a,b). However, automatic manure scraper systems were also found to be a potential hazard for hock alterations (Barrientos et al., 2013), traumatic claw damage (review in Penev et al., 2012) and lameness (Barker et al., 2010).

Effects of inappropriate tie-stall or cubicle dimensions and obstructed lunge space on the occurrence of hock alterations, claw disorders and lameness have been shown in previous studies that were not included in the literature search for this report (e.g. Busato et al., 2000; Somers et al., 2005a; Haskell et al., 2006; Keil et al., 2006; Dippel et al., 2009a,b; de Boyer des Roches et al., 2019). For example, the 'Newton Rigg' style of cubicle in which the cubicle divider has a post fitted to the rear edge of the lying area was associated with increased lameness and shorter lying times (Leonard et al., 1994). These impacts on leg disorders are considered to be related to inhibited lying behaviour, i.e. difficulty in lying down and rising up, collisions with the cubicle fittings and longer times standing (Cook et al., 2004; Fregonesi et al., 2009; Dippel et al., 2009a; Olmos et al., 2009a; Ostojić Andrić et al., 2011; Popescu et al., 2014; Bouffard et al., 2017). As mentioned above, adaptation to the cubicle dimensions (e.g. longer lying area, unrestricted neck rails) improves cow comfort around resting, enhances claw and limb health and reduces lameness, but can be at the expense of cow cleanliness and udder health (Bernardi et al., 2009; Fregonesi et al., 2009).

Having considered common hazards for foot and leg disorders, the following sections present hazards for these disorders individually for different housing systems.

4.1.7. Specific hazards per housing system and preventive measures

Various epidemiological or experimental studies have investigated potential housing, management, herd or animal hazards for lameness, claw disorders and/or integument alterations on the limbs of dairy cows. The majority of these studies were conducted exclusively in tie-stall systems or exclusively in cubicle systems; specific studies on hazards at pasture are limited and in straw yards or open-bedded systems no such studies were identified.

In the following tables, only the identified housing-related hazards are summarised, as these hazards are considered to be easier to regulate compared to the majority of the management-related hazards (e.g. feeding regime, claw trimming or foot bathing strategy) or animal-related hazards (e.g. breed, parity, lactation stage).

The presentation of results below is divided by housing system (tie-stall, cubicle system) and within cubicle systems further stratified by different foot and leg disorders (lameness, claw disorders, integument alterations).

4.1.7.1. Specific hazards for foot and leg disorders in tie-stall systems

For tie-stall systems, the identified housing-related hazards for lameness, claw disorders and integument alterations are summarised in Table 22 and are mostly associated with stall dimensions, stall design and lying surface.

Table 22: Housing-related hazards affecting lameness, integument alterations and claw disorders in tie-stall systems

Housing-related hazards affecting lameness		Effect	Reference
Stall dimensions	Recommended stall width	↓	Bouffard et al. (2017)
	Medium and short (vs. long stalls)	↑	Oehm et al. (2020)
Stall design	Recommended horizontal tie rail position Lower tie rail than recommended	↓ ↑	Bouffard et al. (2017)
Housing-related hazards affecting claw disorders			
Lying surface	Concrete (vs. mats)	↑	Häggman and Juga (2015)
	Concrete (vs. mats or bedding material)	↑	Kujala et al. (2010)
Housing-related hazards affecting integument alterations			
Lying surface	Bedding depth ≤ 2 cm (vs. > 2 cm) mats (vs. concrete)	↑ ↑	Bernhard et al. (2020)
Stall design	Free lunge space (> 73 cm) rear curb height ≥ 13 cm vs. > 25 cm absence of rear rail	↓ ↑ ↑	Bernhard et al. (2020)
	Chain shorter than recommended tie rail position as recommended	↑ ↓	Bouffard et al. (2017)

↑ = significant increase of prevalence of lameness ($p < 0.05$), ↓ = significant decrease of prevalence.

4.1.7.2. Specific hazards for foot and leg disorders in cubicle systems

For cubicle systems, housing-related hazards for lameness, claw disorders and integument alterations of the limb are summarised in Tables 23, 24 and 25.

Table 23: Housing-related hazards affecting lameness in **cubicle systems**

Housing-related hazards affecting lameness		Effect	Reference
Lying surface	Mats/mattresses (vs. deep-bedded (sand))	↑	Andreasen and Forkman (2012)
	Shallow (vs. deep-bedded)	↑	Chapinal et al. (2013)
	Concrete (vs. soft mats or deep-bedded)	↑	de Vries et al. (2015)
	Mats/mattress (vs. deep-bedded)	↑	Husfeldt and Endres (2012), Cook et al. (2016), Armbrecht et al. (2019)
	Abrasive (vs. soft surfaces)	↑	Barker et al. (2010)
	Shallow bedding, mat, mattress (vs. deep-bedded)	↑	Griffiths et al. (2018)
	Mat/mattress (vs. deep-bedded)	ns	Cook et al. (2016)
	Sand (vs. no bedding, mats, straw, sawdust, wood shavings)	↓	Westin et al. (2016b)
Floor type	Rubber on alley to milking	↓	Chapinal et al. (2013)
	Slipperiness Slatted vs. slatted + solid	↑ ↑	Sarjokari et al. (2013)

Housing-related hazards affecting lameness		Effect	Reference
	Grooved (vs. solid concrete[a])	↑	Pérez-Cabal and Alenda (2014)
	Groove spaces < 2 cm vs. no or > 2 cm	↑	Griffiths et al. (2018)
	Concrete (vs. rubber[b])	↑	Eicher et al. (2013)
	Fully floored (vs. partially floored mastic asphalt[c])	↑	Führer et al. (2019)
Cubicle dimension	Higher neck rails	↓	Gieseke et al. (2020)
	Obstructed lunge space	↑	Westin et al. (2016b)
	Cubicle width > = 0.83 × cow height; Neck rail height = 0.80 to 0.90 × cow diagonal length Unobstructed head zone > = 0.53 × cow height	↓ ↓ ↓	de Boyer des Roches et al. (2019)
Further housing hazards	Wider feeding alley	↓	Sarjokari et al. (2013), Westin et al. (2016b)
	Higher cow: cubicle ratio	↓	Gieseke et al. (2020)

↑ = significant increase in prevalence of lameness ($p < 0.05$), ↓ = significant decrease in prevalence.
(a): Only in primiparous cows.
(b): Only during second lactation (effect of treatment*lactation).
(c): Mastic asphalt is a mixture of crushed stone gravel and bitumen (slip-resistant but abrasive), partially-floored mastic asphalt: 55–66% mastic asphalt, 33–45% rubber or plain concrete.

Table 24: Housing-related hazards affecting claw disorders in cubicle systems

Housing-related hazards affecting claw disorders		Effect	Reference
Lying surface	Peat vs. wood shavings	↑	Häggman and Juga (2015)
	Sawdust vs. wood shavings, waterbed, solid manure, sand	↓	de Jong et al. (2021)
Floor type	Fully floored vs. partially-floored mastic asphalt[a]	↑	Führer et al. (2019)
	Slatted vs. solid	↑	Burgstaller et al. (2016), Häggman and Juga (2015)
	Concrete vs. rubber	↑	Eicher et al. (2013)
	Rubber vs. mastic asphalt and slatted concrete (heel horn erosion) Slatted concrete vs. rubber and mastic asphalt (sole haemorrhage) Rubber vs. mastic asphalt (sole haemorrhage)	↑ ↑ ↑	Haufe et al. (2012)
	Warm housing with slatted floor vs. cold housing with heavy straw bedding and solid floor	↑	Kujala et al. (2010)

↑ = significant increase in prevalence of claw disorders ($p < 0.05$), ↓ = significant decrease in prevalence.
(a): Mastic asphalt is a mixture of crushed stone gravel and bitumen (slip-resistant but abrasive), partially floored mastic asphalt: 55–66% mastic asphalt, 33–45% rubber or plain concrete.

Table 25: Housing-related hazards affecting integument alterations in cubicle systems

Housing-related hazards affecting integument alterations		Effect	Reference
Lying surface	Shallow (vs. deep-bedded)	↑	Brenninkmeyer et al. (2013), Barrientos et al. (2013)
	Shallow (vs. deep-bedded)	ns	Cook et al. (2016)
	Concrete (vs. soft mats or deep-bedded)	↑	de Vries et al. (2015)
	Concrete/mats (vs. mattresses or deep-bedded) Hard surface (vs. soft surface)	↑	Burow et al. (2013b)
	Harder surface (rear part)	↑	Brenninkmeyer et al. (2013)
	Mats (vs. deep-bedded)	↑	Armbrecht et al. (2019), Gieseke et al. (2020), Cook et al. (2016)

Housing-related hazards affecting integument alterations		Effect	Reference
	Mattresses (vs. deep-bedded: sand, straw, compost or manure)	↑	Andreasen and Forkman (2012), Cook et al. (2016), van Gastelen et al. (2011), Husfeldt and Endres (2012), Potterton et al. (2011)
	Mattresses (vs. shallow concrete)	↑	Potterton et al. (2011)
	Saw dust bedding (vs. straw or sand)	↑	
	Mats (vs. mattresses)	↑	Ekman et al. (2018)
	Saw dust, straw or combination (vs. peat bedding)	↑	
	Saw dust (vs. straw whole or chopped) bedding depth < 2 cm (vs. > 5 cm)	↑ ↑	Potterton et al. (2011)
	Compost (vs. sand)	↓	van Gastelen et al. (2011)
	Sawdust (vs. straw)	↑	Lardy et al. (2021)
	Wet litter on the belly area (vs. dry)	↓	
	No litter (vs. straw)	↑	
	Mat thicker than 1 cm (vs. < 1 cm)	↑	
	Last 4 cm of the mat are soft (vs. hard)	↓	
	Stone free soil (vs. concrete)	↓	
	Absence of litter (= presence of mats)	↓	
Cubicle dimension	Shorter lying area	↑	Brenninkmeyer et al. (2013)
	Neck rail to rear 1.88–1.98 m (vs. > 2.08 m)	↑	Potterton et al. (2011)
	Neck rail height 1.11–1.15 m (vs. 0.91–1.1 m)	↑	
	Length 2.33–2.71 m (vs. 1.84–2.18 m)	↑	
	Brisket positioner to rear ≤ 1.78 m (vs. > 1.78 m)	↑	
	Width lower than recommended	↑	Ekman et al. (2018)
	Wider cubicles	(↑)	Gieseke et al. (2020)
	Cubicle floor height	↑	Lardy et al. (2021)
	Height difference between cubicle floor and walking alley relative to the height of the cow Between 0.023 and 0.055 × cow's height (vs. < 0.023)	↑	
	Curb height relative to the height of the cow < 0.11 × cow's height (vs. [0.11, 0.15])	↑	
Cubicle design	Absence of curb Less free space under partitions	↑ ↑	Brenninkmeyer et al. (2013)
	More interrupted bob zones Broken side rails Less cubicles facing wall	↑ ↑ ↑	Potterton et al. (2011)
	Obstacle on the cubicle lateral plane Obstacle in the cubicle median plane	↑ ↓	Lardy et al. (2021)
	More than one sharp edge on the curb	↑	
	Absence of brisket board (vs. presence of brisket board)	↑	
	Round brisket board (vs. rectangle brisket board)	↓	

↑ = significant increase in prevalence of integument alterations ($p < 0.05$), (↑) = marginal increase ($p < 0.1$) ↓ = significant decrease in prevalence ($p < 0.05$).

In summary, for cubicle systems, hazards for an increased prevalence of lameness were attributable to aspects of lying surface, floor type, cubicle dimension and feeding alley dimensions. Increased bedding depth and comfort were associated with a reduction in the prevalence of lameness in multiple studies.

Regarding claw disorders, the significant influencing housing hazards were related to lying surface and floor type with slatted floors being identified as disadvantageous compared to solid floors. For integument alterations of the limbs, housing hazards were related to cubicle dimensions, cubicle design and lying surface. Although with regard to cubicle dimensions, results were partly contradictory: Brenninkmeyer et al. (2013) reported a correlation between shorter cubicles and increased prevalence of hock alterations, whereas longer stalls were associated with increased prevalence in the study by Potterton et al. (2011).

4.1.7.3. Specific hazards for foot and leg disorders at pasture

Cows have to walk longer distances while at pasture than when housed and although this aligns with natural locomotory behaviours which may be beneficial to foot health (Krohn, 1994; Hernandez-Mendo et al., 2007), it may also be associated with an increased risk of lameness. In particular, animals walking substantial distances on poorly maintained tracks are at increased risk of lameness (Chesterton et al., 1989; Clarkson et al., 1996; Barker et al., 2009; Burow et al., 2014), with speed of driving (forced movement of cows) a specific hazard. It has been reported that as the speed of forced movement of cows to or from milking increased by 1 km/h, lameness incidence increased by 5% (Bran et al., 2018).

4.1.8. Management-related hazards (not related to physical infrastructure) for locomotory disorders

Over the last 15 years, a variety of epidemiological studies have been conducted related to hazards for foot and leg disorders in dairy cows. These are summarised in review articles by Randall et al. (2018) and Oehm et al. (2019). From 53 selected articles, Oehm et al. (2019) identified 128 hazards for lameness; these related to a multitude of herd- and cow-level characteristics and farm management practices. As pointed out in the review by Randall et al. (2018), most of the hazard studies reported are observational and cross-sectional by design and while significant associations are reported, the results provide weak evidence for causality. It is also notable that hazards identified in the majority of these studies have not been confirmed in follow-up-controlled trials. Therefore, the relevance of individual hazards for lameness, including their effect size and relative importance, remains unclear.

Typically, epidemiological research on lameness has reported that only a small amount of the variability in lameness is explained by hazards identified. For example, one study reported five significant herd level hazards for lameness, but these only explained 12.7% of the total variation in the prevalence of lameness across 197 herds (de Vries et al., 2015). In one study that did report population attributable fractions, a previous case of lameness was found to account for 79–83% of the overall risk of lameness, and by comparison, body condition score only accounted for 4–11% (Randall et al., 2016). The potential confounding influence of lameness history, however, is rarely controlled for in hazard studies and this is an important omission.

While noting these important caveats, the following general areas have been identified in previous research as potential hazards for lameness:

- Management routines: claw trimming, promptness of lameness treatment, foot bathing, a variety of specific dietary inclusions (although there is no clear evidence to support an important effect of laminitis or subacute ruminal acidosis).
- Farm-related: barn age and design, space allowance, ambient temperature.
- Cow-related: parity, body condition score, days in milk, genetics, occurrence of previous lameness, daily time budget, social hierarchy, specific phenotypic traits (e.g. foot angle).
- Calving-related: changes in diet, increased laxity of connective tissue in the foot (associated with hormonal changes around calving), subacute inflammation, use of non-steroidal anti-inflammatory drugs (preventive).
- Farmer-related: psychosocial characteristics, stockmanship.

Randall et al. (2018) summarised the current state of knowledge by suggesting there is an urgent need for further research, particularly intervention studies, to demonstrate causality for hazards identified and also to quantify the impact of hazards at population level.

4.2. Mastitis

4.2.1. Description of mastitis

For this opinion, the descriptions of mastitis relate to cows in first and later lactation as well as pregnant heifers in the last third of gestation kept for milk production. These include dual purpose breeds used for milk production.

Mastitis is a disease, characterised by inflammation of the mammary gland (De Vliegher et al., 2018) commonly caused by an intramammary infection (IMI), typically bacterial but less commonly also fungal. The pathogens enter the mammary gland via the teat canal. The condition can be divided in a clinical and a subclinical form, despite there is no respective definition of the two types. Clinical mastitis (CM) is associated with clinical signs, such as abnormal milk and swelling of the mammary gland. It represents a painful condition which results in e.g. reduced eating and lying time, altered laterality of lying or restlessness at milking (Siivonen et al., 2011); severe cases of clinical mastitis may also lead to hyperalgesia (Fitzpatrick et al., 1998). Clinical mastitis is thus considered a substantial welfare problem. Subclinical mastitis is not associated with clinical signs and has to be detected by the presence of an IMI either (a) directly (through culture of a causative bacterium (BACT)/ pathogen) or (b) indirectly (by detection of an inflammatory response such as an elevated somatic cell count (SCC)). The welfare relevance of subclinical mastitis is less well known. It is usually not considered to be painful and therefore less welfare-relevant; one study, however, has reported a slightly decreased nociceptive thermal threshold in animals with subclinical disease (Peters et al., 2015). Most studies refer to either clinical or subclinical mastitis but commonly do not distinguish between mild and severe clinical mastitis, thus making deductions on the severity in terms of animal welfare difficult.

Bacterial pathogens causing IMI are commonly classified as major or minor pathogens. Major pathogens, such as *S. aureus, E. coli* and *S. uberis*, are commonly associated with clinical or subclinical mastitis. Minor pathogens such as coagulase-negative staphylococci usually do not cause clinical mastitis but may even have a beneficial effect on udder health. Further pathogen classification is made according to routes of transmission; pathogens are typically categorised as contagious (transmission from cow to cow during milking) or environmental (transmission from environmental reservoirs to cow). Because housing systems are more likely to influence environmental than contagious transmission, environmental pathogens are in the focus of this opinion for the evaluation of differences between housing systems.

4.2.2. Animal-based measures for mastitis

Measures commonly used for the assessment of mastitis at the individual cow- and herd-level are described in Table 26.

Table 26: Common measures used for assessment of mastitis

Indicator group	Variable	Methods	Reference
Bacterial culture	Identification of a mastitis pathogen	Based on aseptic quarter milk samples	Duse et al. (2021)
Bacterial culture	Identification of a mastitis pathogen	Based on bulk milk samples	Bauman et al. (2018)
Clinical Mastitis	Cases of cm/cows at risk	Veterinary diagnoses/treatments based on farm records	Bradley et al. (2007)
Clinical Mastitis	Cases of CM/cows at risk	Veterinary diagnoses/treatments based on national databases	Osteras et al. (2007)
Clinical Mastitis	Cases of CM/cows at risk	Including severity of clinical signs: (a) mild: only abnormal milk; (b) moderate: abnormal milk with swelling or redness of mammary gland; (c) severe: includes systemic signs of illness such as apathy, anorexia, dehydration, or fever	Oliveira and Ruegg (2014)

Indicator group	Variable	Methods	Reference
SCC	Bulk milk SCC (bmscc)	Bulk milk scc; mean, geometric mean or geometric weighted mean (weighted by individual cow milk yields)	
SCC	Elevated cow SCC $\geq$ 100,000 cells/mL	Elevated SCC defined to indicate (subclinical) mastitis	Deutsche Veterinärmedizinische Gesellschaft (DVG), 2012
SCC	Elevated cow SCC $\geq$ 150,000 cells/mL	Elevated SCC defined to indicate (subclinical) mastitis in heifers	Santman-Berends et al. (2012)
SCC	Elevated cow SCC $\geq$ 400,000 cells/mL	Proportion of cows $\geq$ 400,000 to indicate herd-level subclinical infection	Welfare Quality® (2009)
SCC	SCC dynamics	e.g. from < 100,000 cells/ml to > 200,000 cells/ml; used to indicate new infections	Valde et al. (2005)
SCC	SCC group averages	Average SCC of cow level milk samples resulting from regular milk recording data, over time; quarterly, monthly, yearly	
SCC	Cell count transformations	log or similar transformations to Normalise or rescale SCC data (reduces impact of outliers)	Wiggans and Shook (1987)
Electrical conductivity (EC)	Conductivity > 7.5 mS/cm or animal-individual time-series dependent detection	Sensors for measuring EC on milk from each quarter, e.g. routinely implemented in automatic milking systems	Khatun et al. (2017), Norberg (2005)

It should be noted that measurements to characterise mastitis are not always defined precisely, e.g. mastitis treatment incidence is sometimes explicitly limited to mastitis with clinical signs but at other times not. In scientific papers, while it is likely that the majority of mastitis cases treated during lactation have shown clinical signs, it cannot be excluded that, on some occasions, subclinical mastitis cases have also been included in treatment analysis. Similarly, the definitions of incidence and prevalence of mastitis differ between studies, specifically regarding level of disease, with recordings varying between quarter-, cow-, lactation- or herd-levels.

Key animal-based measures recommended for the on-farm assessment of clinical mastitis are presented in Table 27.

Table 27: Assessment of ABMs for mastitis in terms of feasibility, sensitivity and specificity

ABM	Description of the ABM
Clinical cases	**Definition:** Incidence rate of clinical mastitis. Increased clinical cases is indicative of more severe welfare impairment. **Feasibility:** High – although dependent on availability and accuracy of vet/farm records **Sensitivity and Specificity:** High sensitivity and high specificity rely on complete and accurate recording of clinical mastitis events on-farm
Bulk milk somatic cell count	**Definition:** Bulk milk somatic cell count (SCC). Increased SCC indicates more severe welfare impairment. **Feasibility:** High – records readily available **Sensitivity and Specificity:** Low sensitivity (because not all cows with acute mastitis will contribute to milk in the bulk tank (milk withdrawn) and in addition, individual cases may not be detectable because of dilution) and low specificity due to e.g. high average age of herd

ABM	Description of the ABM
Individual cow somatic cell count (SCC)	**Definition:** Specified increases in individual cow SCC values between consecutive monthly recordings (or in case of AMS between milkings) to indicate a new infection has occurred. **Feasibility:** High – but information not routinely available in all farms (even fewer farms with AMS) **Sensitivity and Specificity:** Low sensitivity because acute cases of mastitis that occur between sampling time points may be missed. Possibly reduced specificity because other factors may increase SCC (e.g. end of lactation).
Bacterial culture; screening of individual cow milk samples	**Definition:** Screening of individual cow milk samples for pathogens indicative of mastitis. **Feasibility:** Low – it requires exact sampling and lab analysis **Sensitivity and Specificity:** Low sensitivity because most clinical cases might be missed at a one-time herd screening. Low specificity for clinical mastitis because some pathogens do not lead to clinical signs.

4.2.3. Mastitis in different housing systems

Scientific studies indicate that the incidence and prevalence of clinical mastitis, levels of somatic cell count and occurrences of IMI are very variable within each type of housing system; detailed data are provided in Appendix E. This substantial variability within system suggests that no system is likely to be associated with a consistently lower incidence or prevalence of mastitis than another. Management practices are generally considered to play a more important role than housing system itself and management practices to mitigate the risk of mastitis are outlined in Section 4.2.8 of the opinion.

4.2.4. Comparison of housing systems with regard to the occurrence of mastitis

In this section, an evaluation is made of scientific studies that have compared the incidence or prevalence of mastitis between housing systems. Results are outlined in Table 28. It should be noted that in some studies, straw yard and cubicles systems were combined to make comparisons with tie-stalls.

Table 28: Comparison of housing systems regarding mastitis indicators (bacteriological findings, clinical mastitis and somatic cell counts)

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
Bacteriological findings (BACT)						
CH	BACT: environm. pathogens IMI[(a)]	ns	ns			Bludau et al. (2016)
FI	BACT: CNS, S. uberis, S. dysgal., C. bovis	ns	ns			Taponen et al. (2017)
	BACT: E. coli	↓	↑ (with parlour)			
SE	BACT: other pathogens	ns	ns			Duse et al. (2021)
	BACT: T. pyogenes	↓	↑			
DE, DK	BACT: quarter bact. pos. & SCC > 100		↓	↑		Ivemeyer et al. (2018)
Clinical mastitis (CM)						
IT	CM: medical dry-off	↑	↓			Zanon et al. (2021)
NO	CM: mastitis treatments	ns	ns			Simensen et al. (2010)
SE	CM: acute	ns	ns			Nielsen and Emanuelson (2013)
AT	CM: acute or chronic	ns	ns			Firth et al. (2019)

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
AT	CM: CM /cow & year	ns	ns			Schenkenfelder and Winckler (2021)
CAN	CM: CM/100 cow-years at risk	ns	ns			Levison et al. (2016)
USA	CM: CM/305-cow-days	↑	↓	↑		Richert et al. (2013)
USA	CM: CM/week		ns		ns	Eckelkamp et al. (2016a)
ES	CM: CM in 150DIM			↑	↓	Astiz et al. (2014)
USA	CM: CM[(b)]			↓	↑	Sjostrom et al. (2019)
Somatic cell count (SCC)						
FI	SCC: CSCC	ns	ns			Hiitio et al. (2017)
	SCC: SCC ≥ 200 in ≥ 1 of 4 test days	↓	↑			
	SCC: SCC ≥ 200 in ≥ 3 of 4 test days	↓	↑			
NO	SCC: gBMSCC	ns	ns			Simensen et al. (2010)
SE	SCC: Score BMSCC[(c)]	ns	ns (with parlour)			Nielsen and Emanuelson (2013)
SE	SCC: LL; HL; HH herds[(d)]	(↓)	(↑)			Persson Waller et al. (2021)
USA	SCC: SCS[(e)]	↓	↑			Dechow et al. (2011)
CA	SCC: gBMSCC	↑	↓			Bauman et al. (2018)
BE	SCC: SCS[(f)]	↑	↓	↑		Detilleux et al. (2012)
DE, DK	SCC: SCS		↓ (deep-bedded)	↑		Ivemeyer et al. (2018)
	SCC: cure during lactation		↓	↑		
AT, DE, IT, NL, SI, SE	SCC: log_{10}SCC		↓		↑	Emanuelson et al. (2022)
	SCC: high SCC[(g)]		↓		↑	
	SCC: new high SCC[(g)]		↓		↑	
IT	SCC: CSCC		↑		↓	Biasato et al. (2019)
USA	SCC: BMSCC		ns		ns	Eckelkamp et al. (2016a)
	SCC: SCC ≥ 200		ns		ns	
ES	SCC: mean lactation SCC			(↑)	(↓)	Astiz et al. (2014)
USA	SCC: SCS[(b)]			ns	ns	Heins et al. (2019)
USA	SCC: BMSCC	(↓)	(↓)	↑	(↓)	Eckelkamp et al. (2016a)

↓ = significantly less mastitis ($p < 0.05$), (↓) = a tendency for less mastitis ($p < 0.1$), ↑ = significantly more mastitis ($p < 0.05$); (↑) = a tendency for more mastitis ($p < 0.1$); ns = not significant. The housing systems compared are indicated by these arrows and empty cells mean that the corresponding housing system was not included in the comparison.

(a): Primiparous cows, early lactation.
(b): Straw yard outside, compost bedded pack inside.
(c): Score BMSCC: very high, high, medium, low, very low.
(d): CSCC in first two test days: LL = low-low = primiparous cows with SCC ≤ 75 at first and second milk recording (≤ 75 ≤ 75).
(e): Lower SCS in tie-stall confined and tie-stall outdoor + component feed vs. both cubicle systems and to tie-stall with outdoor + TMR.
(f): Tie-stall and straw yard group together as one group.
(g): High SCC: > 150 in primiparous cows, > 200 in multiparous cows, HH = high-high = SCC > 100 at both test days (> 100 > 100); HL = high-low = SCC > 100 ≤ 75. – > % LL, HL, HH cows/herd & year. – > herds above Q2 in year 1 and above Q3 in year 2 and 3 classified as LL, HH, HL herds.

In summary, Table 28 demonstrates variability of results for mastitis comparisons between housing system in terms of e.g. bacteriological findings, clinical mastitis rate or SCC. While there is no clear picture for the comparison between tie-stalls and cubicle systems, there is a tendency for straw yards to be associated with an increased occurrence of mastitis compared to cubicle housing systems and compost-bedded packs. The large number of studies that reported no significant differences between systems, however, suggest that additional hazards other than simply housing system affect udder health. Further housing- and management-related hazards that affect udder health are described in the following sections.

4.2.5. Effects of outdoor or pasture access on mastitis prevalence

When considering the effect of outdoor or pasture access on mastitis, comparisons made between systems are highly dependent on the type and quality of both the housing and outdoor conditions under consideration. It is, therefore, unsurprising that the results from scientific studies are highly variable (Tables 29 and 30), with positive, negative and non-significant associations all reported.

Table 29: Effects of access to pasture (or outdoor loafing) on mastitis prevalence or mean somatic cell count of dairy cows

Country	System[(a)]	Group comparisons	Variable	Analysis[(b)]	Effect	Reference
Bacteriological findings (BACT)						
DE	Tie-stall, loose housing	Heifers on pasture vs. heifers indoors whole gestation	Bacteriological proof of IMI	MA	ns	Krömker et al. (2012)
USA	Loose-housing, tie-stall	Pasture vs. no-pasture	Coliforms in BM	MA	ns	Cicconi-Hogan et al. (2013)
Clinical mastitis (CM)						
AT	Cubicle, straw yard, tie-stall	Regular pasture access	CM	MA	↓	Cicconi-Hogan et al. (2013)
AT	Loose housing, tie-stall	Pasture: 0 day/year, 30–90 day/year, 91–199 day/year, 200–275 day/year	CM/cow and year	MA	ns	Schenkenfelder and Winckler (2021)
		outdoor run: 0 day/week, 1–2 day/week, 3–4 day/week, 5–7 day/week	CM/cow and year	MA	ns	
CA	Cubicle, straw yard, tie-stall	Pasture vs. confined	CM/100 cow-years at risk	MA	ns	Levison et al. (2016)
CA	Tie-stalls, cubicle, straw yards	Pasture access, confined	CM incidence heifers	MA	ns	Elghafghuf et al. (2014)
		Pasture assess during DIM 0–13 confined	CM incidence in primiparous DIM 0–13	MA	↓	
IT	na	Pasture (7 months) vs. zero-grazing	CM	UA	ns	Pugliese et al. (2021)
IT	Tie-stall, cubicles	Pasture access vs. no pasture access	Medial treated CM	MA	↓	Zanon et al. (2021)
			Medical dry-off	MA	↓	
		Pasture period > 45 days vs. ≤ 45 days	Medial treated CM	MA	↓	
			Medical dry-off	MA	↓	

Country	System(a)	Group comparisons	Variable	Analysis(b)	Effect	Reference
PT	na	≥ 8 h/day grazing with mobile milking vs. confined	Estimated score 1–5	UA	ns	Medeiros et al. (2021)
USA	Cubicle, group Straw yard, pasture or dry lot, tie-stall	Grazing vs. Non-grazing	CM/305-cow-days at risk	UA	(↓)	Richert et al. (2013)
Somatic cell count (SCC)						
DE	Tie-stall, loose housing	Heifers on pasture vs. heifers indoors whole gestation	SCC > 100(c)	MA	↓	Krömker et al. (2012)
DE	Cubicles	Pasture access vs. zero-grazing	SCC > 400	MA	↓	Gieseke et al. (2020)
DE	na	Zero-/minor grazing (0 to < 6 h), 6 to < 12 h pasture access, ≥ 12 h pasture access	SCC ≥ 400	MA	(↑) (≥ 12 h)	Wagner et al. (2017)
IT	na	Pasture (7 months) vs. zero-grazing	SCC	UA	↓	Pugliese et al. (2021)
IT	Cubicles	Pasture vs. Confined	log10n SCC	MA	↓	Di Grigoli et al. (2019)
NL	169 cubicle, 4 others	Day & night grazing, during-the-day grazing, zero-grazing	SCC > 150	MA	↓(d)	Santman-Berends et al. (2012)
PT	na	≥ 8 h/day grazing and mobile milking vs. confined	Estimated log_{10}SCC	UA	(↑)	Medeiros et al. (2021)
USA	No-housing, tie-stall, straw yard, cubicle, compost	Pasture = no-housing system vs. different housing systems	BMSCC	MA	(↑)	Eckelkamp et al. (2016a)
USA	Cubicles	Confined vs. any kind of outdoor access (yard or pasture)	SCS	MA	ns	Dechow et al. (2011)
	Tie-stall		SCS	MA	ns (with component feed), ↑ (Total Mixed Ration – TMR)	

↓ = significantly less mastitis during (increased) grazing (p < 0.05), ns = no significant (p ≥ 0.05) or (↑) marginal (p ≥ 0.1) effect.
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Statistical analysis: MA = multivariable analysis; UA = univariable analysis.
(c): Only primiparous cows.
(d): Day and night grazing of lactating cows (–5.9%; 95% CI: –10.6 to –1.3%) compared to zero-grazing (during-the-day-grazing in-between) (p = 0.01).

Table 30 lists studies that evaluated the prevalence of mastitis in relation to different amounts of time cows had access to pasture.

Table 30: Clinical mastitis, bacteriological findings or somatic cell counts reported for different amounts of time of outdoor or pasture access

Country	n[(a)]	Mean herd size (range)	Outdoor access	Variable	Level	Measure	Mean/ prevalence	Reference
Clinical mastitis (CM)								
IT	9	252.3	Zero-grazing	CM	Herd	Prev.	6.2%	Pugliese et al. (2021)
		61.1	Pasture (7 months)				4.9%	
PT	87	213.1	Confined	Estimated Score 1–5[(b)]	Herd	Mean	2.2	Medeiros et al. (2021)
	18	157.8	≥ 8 h/day grazing				2.1	
Somatic cell count (SCC)								
DE	14	114[(c)] (30–726)	0–< 6 h grazing	% cows with SCC ≥ 400	Herd	Prev.	10%, 15%[(d)]	Wagner et al. (2017)
	10	114[(c)] (30–726)	6–< 12 h grazing				12%, 11%[(d)]	
	8	114[(c)] (30–726)	≥ 12 h grazing				20%, 16%[(d)]	
DE	55	374 (47–1,609)	Zero-grazing	% cows with SCC ≥ 400	Herd	Prev.	21.0%	Gieseke et al. (2020)
	9	374 (47–1,609)	Pasture access				15.5%	
IT	9	252.3	Zero-grazing	SCC	Herd	Mean	600	Pugliese et al. (2021)
	9	61.1	Pasture (7 months)				310	
PT	87	213.1	Confined	Estimated log_{10}SCC	Herd	Mean	2.38	Medeiros et al. (2021)
	18	157.8	≥ 8 h/day grazing				2.45	

(a): Number of farms.
(b): % cows with mastitis during 1 year: Score 1:10%; Score 2:10–20%; Score 3:20–30%; Score 4:30–40%; Score 5: > 40%.
(c): Mean (range) for all 32 farms included in the study.
(d): Winter, summer.

In summary, the evidence reported in Tables 29 and 30 does not support the conclusion that outdoor or pasture access consistently leads to improvements in mastitis in dairy herds.

4.2.6. Common hazards and preventive measures

Beyond the housing system, a variety of management-related hazards are known to affect udder health and it should be noted that the literature search for this opinion was limited to studies solely related to housing system and not conducted to identify the entire range of management- and animal-related hazards for udder health. In terms of common hazards identified across different housing systems, studies have reported that type of bedding material (Patel et al., 2019; Hogan et al., 1989) and age of buildings (Cicconi-Hogan et al., 2013) can act as hazards for mastitis. An additional extensive literature search was run on general hazards and preventive measures for mastitis (details in Appendix B, Table B.3) and a summary of the outcomes is provided in Section 4.2.8.

4.2.7. Specific hazards per housing system and preventive measures

The majority of housing-related studies investigating hazards for mastitis within each housing system occurred in cubicle systems, which reflects the fact that in many European (and North American) countries, cubicle systems are the predominant housing for dairy cows (see Section 4). The most commonly investigated housing-related hazards on udder health were cubicle surface and bedding material (Appendix E, Table E.6). Several studies reported that sand (inorganic) as bedding material is beneficial for udder health compared to organic material (Dufour et al., 2012; Esser et al., 2019; Matson et al., 2022; Krömker et al., 2012). Two studies found that cows in cubicles with > 2 cm bedding material had better udder health than cows in more shallow-bedded cubicles (Dufour et al., 2012; Ivemeyer et al., 2018), which concur with the results of three studies that identified rubber surfaces as a hazard (Olde Riekerink et al., 2010; Dufour et al., 2012; Bauman et al., 2018). Again, it should be noted that the limitations of the current scientific search mean that only a small number of hazards for mastitis have been identified; additional information on management-related hazards is provided in the following section.

4.2.8. Management-related hazards (not related to physical infrastructure)

A wide range of management hazards have been reported to be associated with different indicators of mastitis (Appendix E, Table E.6). These include, for example, treatment with antibiotics, frequency of use of blanket or selective dry-cow therapy and use of post-milking teat dipping. However, causal effects are often not assessed, and some of the associations are unexpected. For example, Santman-Berends et al. (2016) observed that post-milking teat disinfection was associated with higher risk of clinical mastitis. The reason may be that a high incidence of clinical mastitis prompts farmers to use post-milking teat disinfection, an example of reverse causality. In general, however, good hygiene, post-milking teat disinfection, culling to keep a low infection pressure, use of selective dry-cow therapy, moderate standing time after milking and adequate nutrition are reported to contribute to a reduced occurrence of mastitis.

The following general areas have been identified as potential hazards for mastitis incidence, i.e. a higher number of mastitis cases:

- **Milking related:** including manual milking machine shut-off; delayed access to feed after milking; poor hygiene of cows and milking systems; lack of post-milking teat disinfection; failure to dry udder cloths; lack of use of fore stripping; air-adsorption during application of teat-cups; lack of separation of new mastitis cases.
- **Hazards related to treatments:** including higher-than-recommended animal-defined daily dose of intramammary antibiotics for mastitis; lack of proactive detection of mastitis in early postpartum cows; lack of selective or blanket dry-cow therapy; treating fewer than 50% of cows with clinical mastitis with antimicrobials; lack of treatment of cows with elevated somatic cell counts with antimicrobials.
- **General management routines:** including lack of hay in dry cow diet; no standard operating procedure for colostrum management; low frequency of cleaning of slatted floors; strategies of over-feeding of concentrates to young calves and heifers; poor management of bedding; lack of immediate culling of cows with repeated cases of clinical mastitis within a lactation; non-clipped udders.
- **Cow-related:** including soiling of udders; decreased standing time after milking; presence of immuno-suppressing factors such as hypocalcaemia and negative energy balance; weaning off milk at an age less than 4 months; breeding decisions not taking resistance mastitis into account.
- **Farm-related:** housing heifers close to calving separate from lactating cows.
- **Calving-related:** including lack of clean bedding material at calving; lack of administration of calcium parenterally at calving; assistance at calving; poor heifer hygiene before calving; lack of mineral/vitamin supplementation prior to calving.
- **Farmer-related:** including farming part time; lack of knowledge of guidelines and awareness of low infection pressure and good hygiene; working fast rather than precisely.

4.3. Restriction of movement and resting problems

4.3.1. Description of restriction of movement and resting problems

Restriction of movement are defined as 'negative affective states experienced by the animal such as pain, fear, discomfort and/or frustration due to the fact that the animal is unable to move freely or is unable to walk comfortably' (EFSA AHAW Panel, 2022). Resting problems are defined as 'the animal experiences negative affective states such as discomfort, fatigue and/or frustration due to the inability to lie or rest comfortably' (EFSA AHAW Panel, 2022).

The need of movement is illustrated by dairy cows performing more locomotor behaviour after a period of lack of opportunity to perform locomotion (e.g. due to tethering), and this rebound effect has been shown to be greater the longer the deprivation (walking: Veissier et al., 2008; walking and trotting: Loberg et al., 2004). The opportunity to move freely (i.e. ample space and non-slip surface) also provides opportunity for other behaviours such as social and comfort behaviour (Loberg et al., 2004). Locomotion at moderate speed covering distances from 4 to 8 km per day have been found to improve cow fitness (physiological and health parameters) (reviewed by Shepley et al., 2020b).

Dairy cows are highly motivated to lie down and often ruminate while lying. Experimental studies showed that cows prioritise lying over feeding after a period of deprivation of both behaviours (review in Cook, 2020; Smid et al., 2020). Resting problems are closely linked to restriction of movement in the lying area. The natural lying down and rising up behaviour is described in detail in Tucker et al. (2021) and Chaplin and Munksgaard (2001), respectively. In brief, before lying down the cow shows intention movements (e.g. sniffing the surface). While the head is lowered she bends one front leg, descends onto one and then the other carpal joint, bends the hind legs underneath the body, stretches the head forward and downward, lowers the body, bends the hind legs underneath the body, lowers the body further and then rests on the brisket and one hind leg, thigh and abdomen. A cow rises by stretching forwards head and neck, shifting the weight from the body to both carpal joints. This head lunging movement allows the cow to stretch the hind legs, followed by stretching and standing on the front legs one by one. The behavioural sequence of movements for rising up and lying down is shown in Figure 4. The horizontal movements during lying down and rising up are sizeable and a dairy cow requires approximately 3 m total longitudinal space to complete the lying down and rising up movements (Ceballos et al., 2004).

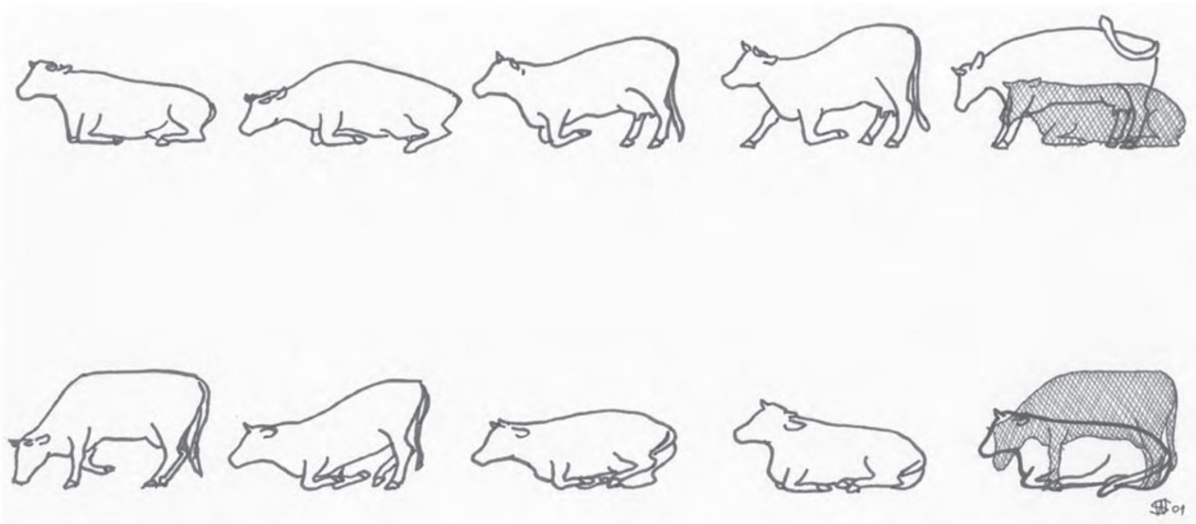

Figure 4: Sequence of rising up and lying down movements (courtesy of Sonja Wlcek)

While lying, cows can assume many lying postures, including resting on the side with all four legs stretched and the head resting on the surface (Figure 5), lying on the sternum with front or hind legs, or both, bent or stretched, and with the head raised or resting on body or surface.

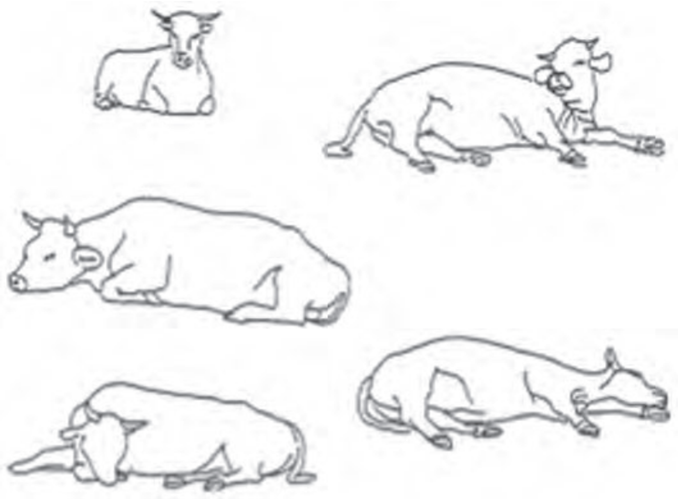

Figure 5: Natural lying postures of cow (© KTBL)

Inability to perform comfort behaviour and inability to perform social behaviour are separate welfare consequences (EFSA AHAW Panel, 2022). In this document, aspects of social behaviour are included here to the extent that it is affected by restriction of movement and related resting problems while inability to perform comfort behaviour is addressed in Section 5.4.

Cattle form preferential social relationships, which provide social support. However, group living also involves group stress due to competition for limited resources such as space. The establishment and maintenance of stable dominance relationships, as well as the ability to respond appropriately to threats by withdrawal, help keep overt aggression at a low level.

4.3.2. Animal-based measures (ABMs) for restriction of movement and resting problems

A cow experiencing restriction of movement and/or resting problems will show alterations of locomotor behaviour (reviewed by Phillips et al., 2013; Mandel et al., 2016; Charlton and Rutter, 2017; Beaver et al., 2020; Mee and Boyle, 2020; Smid et al., 2020; Shepley et al., 2020b; Shepley and Vasseur, 2021), lying behaviour (Beaver et al., 2020; Charlton and Rutter, 2017; Mandel et al., 2016; Mee and Boyle, 2020; Phillips et al., 2013; Shepley et al., 2020b; Shepley and Vasseur, 2021; Smid et al., 2020) and social behaviour (Krawczel et al., 2012; Winckler et al., 2015). These behavioural categories were considered the most sensitive and specific for restriction of movement and ABMs derived from them are therefore discussed in detail in this section.

Additional behavioural and health indicators of restrictive conditions can include foot and leg disorders, integument alterations, mastitis and inability to perform comfort behaviour, which are discussed elsewhere in the document (see Sections 5.1, 5.2 and 5.4). Other aspects such as reproductive behaviour and respiratory health can also be negatively impacted in situations of movement restriction, but these were considered out of scope of this scientific opinion.

Whilst cow dirtiness (i.e. soiled cows) is sometimes referred to as a possible indicator of restriction of movement, it can also result from other characteristics of the environment, such as a dirty lying surface, and therefore, it is also considered out of the scope of this assessment.

4.3.2.1. ABMs for restriction of movement (locomotion)

ABMs for locomotory activity are presented in Table 31.

There are three common technological approaches measuring locomotion behaviour and activity in cattle under different housing systems: global and local positioning systems (GPS and other systems), video recordings and activity meters. The use of GPS has been effective in measuring locomotor activity in (extensively) pastured animals. However, it is not effective for locating position indoors and following the movements of cows in a barn. Video recordings are used to visually determine walking speeds and number of steps taken to traverse specific distances (e.g. in experimental designs on different floor types). Pedometers quantify locomotor activity by measuring step activity. Current systems (accelerometers), record movements on three axes and can thus also distinguish between lying and standing (review in Shepley et al., 2020b).

The sensitivity and specificity of the ABMs were assessed in a qualitative manner, considering a situation of a farm inspection by veterinary authorities to assess the welfare at herd level. For the assessment of the effect of a housing system, these ABMs do not apply if cows spend part of the day on pasture, and during specific times of the production cycle (e.g. parturition).

Table 31: Assessment of ABMs for restriction of movement (locomotion) in terms of feasibility, sensitivity and specificity

ABM	Description of the ABM
Step activity	**Definition:** Number of steps per day; can be measured by pedometers, GPS or video recordings (Shepley et al., 2020a,b). Decreased step activity is indicative of restriction of movement. **Feasibility:** Low - Potential future measure currently not fully implemented due to indoor positioning systems and GPS not consistently available on farm **Sensitivity and Specificity:** High sensitivity but low specificity (low step activity could also be caused by other factors such as lameness– many false positives possible). Specificity will increase if sampled cows are not lame.
Walking distance	**Definition:** Distance walked per day; can be measured by pedometers, GPS or video recordings (Shepley et al., 2020a,b). Decreased walking distance is indicative of restriction of movement. **Feasibility:** Low - Requires GPS technology which is not yet available in all farms – potential future measure **Sensitivity and Specificity:** High sensitivity but low specificity (abnormal walking distance could also be caused by other factors such as lameness/weather conditions/access to feed on pasture/stage of lactation)
Speed	**Definition:** Distance covered per time unit measured using pedometers, GPS or video recordings (Shepley et al., 2020a,b). Decreased speed is indicative of restriction of movement. **Feasibility:** Low - Potential future measure as indoor positioning systems and GPS are not consistently available on farm. **Sensitivity and Specificity:** High sensitivity but low specificity (e.g. speed is affected also by lameness)

4.3.2.2. ABMs for restriction of movement (social behaviour)

Indicators of group stress in cattle resulting from restriction of movement include the frequencies of agonistic and affiliative interactions and their ratio, and the degree of behavioural synchrony (especially of lying and feeding behaviour). An increased frequency of agonistic interactions indicates competition or unstable dominance relationships, is associated with unpleasant, stressful experiences, and can lead to integument alterations. On the other hand, affiliative interactions (e.g. social licking) are not straightforward to interpret. They often indicate preferential relationships, but may also reflect reassurance, or appeasement of a dominant individual. Therefore, in animal welfare research, agonistic interactions are predominantly used. Recording is often done according to the Welfare Quality® (2009) protocol: head butts without displacement, displacement, chasing, fighting, chasing up another cow from a lying posture. Following this protocol, the total number of these agonistic behaviours are continuously counted over a standardised period of 2 h. In other studies, longer observation periods were chosen (e.g. Biasato et al., 2019) or, depending on the research question, specific barn areas were observed, e.g. only the feeding area (e.g. Black and Krawczel, 2016).

Behavioural synchrony refers to the ability of a group of cows to perform certain activities, e.g. lying/resting or feeding/grazing, simultaneously. Behavioural synchrony can be expressed, for instance, by the proportion of observations (direct or video) during which e.g. 100% of the animals in a group are performing a given behaviour at the same time, or by the mean proportion of individuals performing a certain behaviour at the same time (Asher and Collins, 2012). A study of behavioural synchrony in a cattle herd concluded that cows showing less synchrony with other individuals also showed less social motivation when exposed to motivational tests (Gibbons et al., 2010). Thus behavioural synchrony may contribute to good welfare in herd-living animals such as cattle (Miller and Woodgush, 1991a,b).

Table 32: Assessment of ABMs for restriction of movement (social behaviour) in terms of feasibility, sensitivity and specificity

ABM	Description of the ABM
Agonistic interactions	**Definition:** Number of agonistic interactions (head butts without displacement, displacement, chasing, fighting, chasing up from the lying area) per cow and hour (Welfare Quality®, 2009). A high number of agonistic interactions is indicative of a high level of group stress. **Feasibility:** Low - assessment is time-consuming and requiring training. **Sensitivity and Specificity:** Low sensitivity and low specificity (human-animal relationship can also influence it).

In Table 32, the number of agonistic interactions is described as an ABM for restriction of movement related to social behaviour.

4.3.2.3. ABMs for resting problems (lying behaviour)

Measures of lying behaviour include the **duration of time spent lying** within a period of time (e.g. hours or minutes per day), the **frequency of lying bouts** (e.g. number per day) and the **duration of lying bouts** (mean bout duration), all of which can be automatically measured via sensors (Ledgerwood et al., 2010; Nielsen et al., 2010). Dairy cows spend on average 10–12 h/day lying down in e.g. cubicle housing systems (e.g. Tucker et al., 2021). However, in relation to animal welfare, especially the total daily lying time must be interpreted in context. Generally, a lying time of less than 10–12 h/day is considered a sign of high risks to animal welfare, due to unfavourable lying or standing conditions, time constraints (e.g. milking), or heat load (Tucker et al., 2021). However, Tucker et al. (2021) also outlined situations where a lying time at or above 10–12 h/day reflect a threat to welfare due to disease (e.g. lameness, or infectious diseases).

Increased parity (number of lactations) has also been found associated with more lying time in some studies, while others report no or minor differences (review in Tucker et al., 2021). Other situations where the welfare consequences of lying times below 10–12 h/day are unknown, are e.g. oestrus, or parturition. During oestrus, cows show a marked increase in activity and a corresponding drop in lying time of up to 40% (reviewed by Tucker et al., 2021). Parturition is also associated with reduced lying (Jensen, 2011; Miedema et al., 2011), likely due to pain during contractions. Lying is low during the first hours after calving when the cow prioritises licking and nursing the calf (Jensen, 2011; Campler et al., 2015). Several studies have found that lying time increased with days in milk, but recent studies suggest that lying time decreases during the first month after calving after which it increases (see review by Tucker et al., 2021). Another situation with unclear welfare relevance are long grazing times at pasture and subsequently comparatively short lying times (see Section 4.3.5).

In the Welfare Quality® protocol (2009), the **duration of the lying down movement** as well as collisions with the housing equipment while lying down is used as an indicator for reduced lying comfort (resting problems related to restriction of movement in the lying area) in different indoor housing systems. The **length of time** the cow examines the lying area before lying, or lying interruptions (Bak et al., 2016; Boyer et al., 2021a), was also recorded in some studies to draw conclusions about resting problems, i.e. problems when changing posture, and the comfort of the lying area (e.g. Boyer et al., 2021a).

In addition, whether the **rising behaviour** indicates resting problems may be assessed by how fluidly and easily the movement is performed (see sequence of rising movements in Figure 4 in Section 4.3.1). Such assessments take into account whether there is a pause resting on the carpal joints (increasing the duration of the rising movement), whether there is a deviation from the normal sequence of movements, e.g. horse-like rising up, and whether the animal collides with the housing equipment (Chaplin and Munksgaard, 2001; Blanco-Penedo et al., 2020; Brinkmann et al., 2020). Both lying down and rising up behaviours may be assessed by means of continuous direct observation or video recordings.

Information about resting problems may also be obtained from lying postures (see Figure 5 in Section 4.3.1). However, certain lying postures may relate not only to freedom or restriction of movement, but also to the size and degree of filling of the udder or to thermoregulatory responses (review in Tucker et al., 2021). Thus, lying postures, similar to lying duration, may not always be interpreted unambiguously, but are also likely to depend on context (e.g. temperature, stage of lactation). Table 33 provides an overview of the ABMs for resting problems (lying behaviour).

Table 33: Assessment of ABM for resting problems (lying behaviour) in terms of feasibility, sensitivity and specificity

ABM	Description of the ABM
Lying time	**Definition:** Time spent with flank in contact with ground (Winckler et al., 2015). Short lying time (< 10 h) for cows housed indoors indicative of resting problems. The 10-h criterion does not apply to cows on pasture, cows in oestrus and cows in the peri-partum period. **Feasibility:** Low - Validated activity monitors are not widely available on farm yet. Since 24 h observations are required, direct observations are time-consuming. **Sensitivity and Specificity:** High sensitivity and low specificity (lying time can be prolonged in situations of lameness or illness and will be shorter in heat stressed cows)
Frequency of lying bouts	**Definition:** Number of times a cow is lying per day (Ledgerwood et al., 2010). A higher number of lying bouts indicates discomfort and/or disturbances while lying. **Feasibility:** Low - see Lying time. **Sensitivity and Specificity:** Low sensitivity and low specificity (difficult to interpret, lower frequency of lying bouts (and therefore often longer lying bouts) may reflect problems in changing posture but resting uncomfortably may lead to higher frequency of lying bouts).
Duration of lying down movement	**Definition:** Duration of behaviour sequence starting with bending of the first carpal joint and ending with pulling out the front leg after the hindquarter has touched ground (Welfare Quality®, 2009). Longer duration indicative of a higher degree of restriction. **Feasibility:** High - Direct observation of spontaneous lying down movements at individual level; may be time-consuming depending on herd size. **Sensitivity and Specificity:** Low sensitivity (intention to lie and interruptions to lying down movement have a higher specificity than the lying down movement itself) and low specificity (animals with leg problems will take longer to lie down).
Deviation from normal, uninterrupted getting up movement	**Definition:** Degree of deviation ranging from smooth fluid movement/normal sequence of events, over short pause on knees/normal sequence, long pause on knees/normal sequence, long pause on knees and/or some difficulty in rising, e.g. awkward twisting of head and neck/normal sequence to abnormal rising/deviation from the normal sequence of events (Chaplin and Munksgaard, 2001). Observation of getting up movement easily captures the ability of the cow to get up. Degree of welfare impairment increases with score for getting up movement. **Feasibility:** High - Via direct observation at individual level; rising movements can be assessed in a standardised test situation, i.e. encouraging the cows to stand up. **Sensitivity and Specificity:** High sensitivity and high specificity (knee injuries and lameness can cause false positives, but such welfare issues may be accounted for from concurrent assessments).
Lying behaviour synchronisation	**Definition:** Percentage of animals simultaneously exhibiting the same posture (here: lying). Different thresholds of synchronous posture are possible (e.g. 70, 80, or 100%; Stoye et al., 2012). Degree of synchrony positively associated with welfare as it indicates that there are sufficient resources available for all individuals. **Feasibility:** Low - see Lying time **Sensitivity and Specificity:** High sensitivity (more sensitive than lying times for resting problems) and low specificity (competition/group stress may lead to low synchrony).

4.3.3. Restriction of movement and resting problems in different housing systems

The degree of restriction of movement experienced by dairy cows can be related to the general type of housing (i.e. tie-stall vs. different loose housing systems), to the design and dimensions of functional areas within the housing system, especially the lying area (Figure 1), but also to the areas for walking and feeding (including stocking densities). Additionally, it is affected by the duration and type of access to outdoor areas (i.e. all-year indoor housing vs. access to outdoor loafing area and/or pasture). The type of housing and the time spent in it can have important consequences for dairy cows´ welfare, with particular reference to whether the housing system supports the natural behaviour of dairy cows (review in Phillips et al., 2013; Shepley et al., 2020b). However, welfare improvement will especially be achieved if the animals can perform natural behaviours which they value, i.e. are motivated to carry out (Dawkins, 2023).

Several studies have been conducted in this area and they show a large variability in locomotory behaviour, lying behaviour and social behaviour within each system. In terms of decreasing degree of restriction, the different housing systems are ranked from year-round tethering, which is particularly restrictive, to cubicle loose housing and open-bedded systems and finally to pasture, which is the least restrictive (Figure 6).

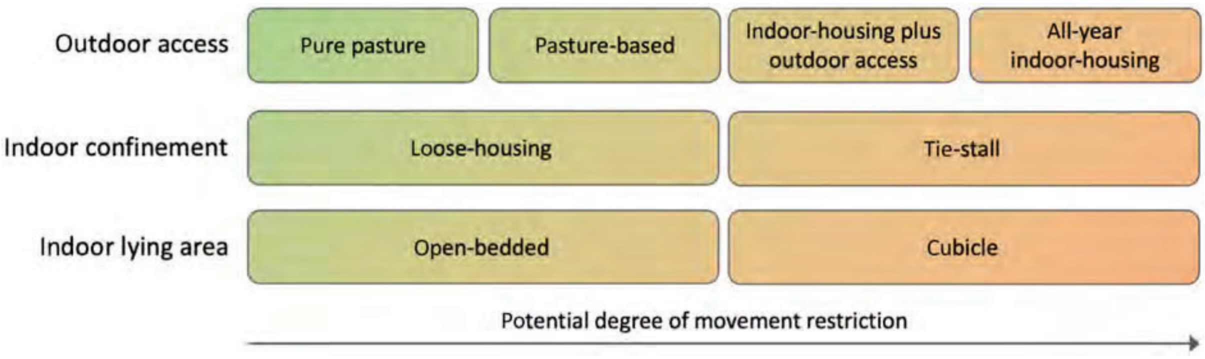

Figure 6: Potential degree of movement restrictions depending on the type of indoor lying area in loose housing systems (bottom), level of indoor confinement (middle) and extent of outdoor access (top)

Tie-stall systems are characterised by at least temporary indoor confinement, as well as confinement to a stall, which refers to structural elements defining an individual lying and feeding space for a cow. The ability to interact with conspecifics is restricted to the neighbours, resulting in very limited opportunities to express social behaviour.

In **loose-housing systems** the cow is not confined in the stall, allowing for movement to other areas of the housing system (i.e. walking alleys, feeding alley, milking parlour). However, **cubicle systems** still use defined lying areas for individual cows, and although cows are not restricted by a tether, cubicles may impose restrictions to the lying down and rising up movements similar to those observed in tie-stall systems. In contrast, **open-bedded systems** (i.e. straw yards, compost–/manure-bedded packs) can be characterised as more open, with a combined walking and lying area free of stall/cubicle hardware (Shepley et al., 2020b) (Figure 4 bottom).

All indoor housing systems can be combined with **outdoor access** (i.e. pasture or an outdoor loafing area) to increase the complexity and size of the accessible environment. Pasture-based systems, in which cows are kept outdoors for the large majority of the year (e.g. used in New Zealand and Ireland) or exclusively kept outdoors (e.g. in New Zealand and on the Azores Islands) are in contrast to indoor housing systems. They may be the least restrictive regarding the animals´ freedom of movement and offer better opportunities for natural behaviours such as lying, except under conditions where the pasture is very wet and muddy (Tucker et al., 2021; Neave et al., 2022).

Various studies have shown that dairy cows have a partial preference for pasture access. When offering outdoor-experienced cows the free choice between daytime pasture and cubicle housing systems (during summer in Canada, with provision of comparable feed options) the cows went to and remained at pasture for most of the time (Shepley et al., 2017). Cows seem also to prefer pasture access in comparison to an outdoor loafing area. When given access to pasture or to a sand pack outdoor loafing area, cows spent a higher proportion of time outdoors at pasture ($90.0 \pm 5.9\%$) than in the sand pack outdoor loafing area ($44.4 \pm 6.3\%$; Smid et al., 2018). Provided free choice between pasture and outdoor loafing area, they spent $90.5 \pm 2.6\%$ of the time available on pasture and $0.8 \pm 0.5\%$ in the outdoor loafing area (Smid et al., 2018).

However, the previous experience of the cows (Charlton et al., 2011a) as well as the time of day play a role in dairy cattle preference for pasture, with night-time access increasing the preference (Charlton et al., 2011a,b, 2013; Falk et al., 2012; von Keyserlingk et al., 2017). By varying the distance to pasture, Charlton et al. (2013) showed that cows were motivated to walk longer distances to maintain access to pasture during the night, but not during the day. In accordance with this, cows with free access to pasture spent approx. 14 h/day on pasture and 79% of this time was spent on pasture during the night (Falk et al., 2012). Characteristics of the outdoor environment may also affect cow's preference to go outside, such as air temperature and humidity, walking or lying surface conditions, availability of shelter or shade and access to water (Jensen and Vestergaard, 2021), with rainfall decreasing the preference (Charlton et al., 2011a, 2013).

In addition, characteristics of the indoor environment – particularly relating to restrictions of movement and resting problems – may also influence the cows' motivation to access pasture. However, in the study by Falk et al. (2012), cow preference for pasture was not influenced by the cow: cubicle ratio (24, 16, 8 or 0 cubicles per group of 24 cows), illustrating that cows preferred to be outside at night even when there was one cubicle per cow available inside.

In conclusion, all-year tethering is considered the most restrictive housing system, restricting normal behaviour and activity (Popescu et al., 2013), even during periods when activity normally increase, e.g. during oestrus (Felton et al., 2012). On the other end of the spectrum are pure pasture and pasture-based systems, which are associated with enhanced opportunity for locomotion. Loose housing systems and different combinations with outdoor access are not as easy to rank in terms of opportunity for locomotory behaviour, because housing- and management-related hazards such as floor type, fixtures, as well as stocking density of cubicles, feed manger and activity areas influence the locomotor activity.

4.3.4. Comparison of housing systems with regard to occurrence of restriction of movement and resting problems

In this section, an evaluation of scientific studies that have compared the occurrence of restriction of movement and resting problems between housing systems is made.

Results of studies comparing locomotor activity (as ABM of restriction of movement) in different housing systems were inconclusive (Biasato et al., 2019; Shepley et al., 2020a).

With regard to social behaviour (as ABM of restriction of movement), no studies comparing tie-stalls and loose housing systems were found. Nevertheless, in epidemiological studies in tie-stall systems (Popescu et al., 2013, 2014), a similar or higher number of agonistic interactions per cow and hour were observed as in a comparable study in loose housing systems (Gieseke et al., 2018); in each case social behaviour was recorded according to Welfare Quality® (2009).

Comparisons of lying behaviour (as ABM for resting problems) in different housing systems are presented in Table 34.

Cubicles and tie-stalls inhibit lying down and rising up movements as indicated by longer durations of these movements, more intentions to lie and lying down interruptions, as well as attempts to get up, compared to open bedded systems. No studies comparing lying behaviour in cubicle and tie-stall housing were found.

Table 34: Comparison of housing systems regarding different variables of lying behaviour (associated to resting problems)

Country	Variable	Tie stall	Cubicle	Straw yard)	Compost-bedded pack	Reference
CAN	Lying (h/day)	ns		ns		Shepley et al. (2019)
	Lying down movement (s)	ns		ns		
	Rising up movement (s)	ns		ns		
	Collision while lying down (%)	↑		↓		
	Collision while rising up (%)	↑		↓		
	Abnormal lying down (%)	↑		↓		
	Abnormal rising up (%)	ns		ns		
	Intention before lying down (s)	↓		↑		
	Attempts before rising up	ns		ns		
	Hindquarter shifting when lying down (%)	ns		ns		
	Prolonged kneeling while rising up (%)	ns		ns		
	Lying posture front legs (% time)	ns		ns		
	Lying hind legs tucked (% time)	↑		↓		
	Lying hind legs extended (% time)	↓		↑		

Country	Variable	Tie stall	Cubicle	Straw yard)	Compost-bedded pack	Reference
SRB	Lying down movement (s)	↑		↓		Ostojić Andrić et al. (2011)
	Collision while lying down (%)	↑		↓		
	Lying outside lying area (%)	↑		↓		
FR	Lying (h/d)		ns	ns		Shepley et al. (2020a)
	Lying bouts (number/d)		↓	↑[1]		
ES	Lying down movement (s)		↑		↓[2]	Fernández et al. (2020)
	Rising up movement (s)		↑		↓[3]	
	Attempts before lying down (%)		↑		↓[2]	
	Interrupted lying down (%)		ns		ns	
	Prolonged kneeling before lying down (%)		↓		↑[4]	
	Attempts before rising up (%)		↑		↓[5]	
	Prolonged kneeling while rising up (%)		ns		ns	
	Interrupted rising up (%)		ns		ns	
ES	Lying down movement (s)		ns		ns[6]	Moreno et al. (2020)
	Collision while lying down (%)		↑		↓	
	Lying outside lying area (%)		ns		ns	
IT	Lying (% cows)		↑		↓	Biasato et al. (2019)
	Lying flat on side (%)		ns		ns	

↑/↓ = significant increase/decrease of the variable ($p < 0.05$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.
1: Only significant during summer.
2: Compared to conventional bedded pack (no details given).
3: Rising up took longer in cubicles vs. compost- and conventional bedded pack, and shorter in conventional vs. to compost-bedded pack.
4: A higher % of cows kneeled during lying down in compost-bedded vs. conventional bedded pack or cubicles.
5: Compared to conventional and compost-bedded pack.
6: Recycled manure solids.

4.3.5. Effects of outdoor or pasture access on restriction of movement and resting problems

This section summarises the effects of outdoor access (i.e. pasture or outdoor loafing area) on locomotor behaviour (as ABM for restriction of movement), lying and standing behaviour, including lying time and lying down and rising up movements (as ABM for resting problems), and social behaviour (as ABM for restriction of movement).

Locomotor behaviour

Cows provided with access to pasture performed more locomotor behaviour (in terms of steps) than zero-grazing cows (Dohme-Meier et al., 2014; Black and Krawczel, 2016; Crump et al., 2019). This is because of more space available and the cows walking to and from pasture for milking. Exercise offers health and welfare benefits (see Section 4.1.5), but long walking distances can negatively impact the animals' time budget due to leaving little time to lie (review in Cook and Nordlund, 2009; Mee and Boyle, 2020). In a recent experimental study, however, Neave et al. (2021) found no effect of walking distance on dairy cows´ lying behaviour in a pasture-based system in New Zealand. Long walking distances on poorly maintained tracks may increase the risk for claw disorders and lameness (see Section 4.1.5).

A single study compared different space allowances in the outdoor loafing area, however, no significant differences were found regarding locomotor activity (Lutz et al., 2019).

Lying time and standing behaviour

In most of the studies reviewed, pasture access reduced the daily lying times (Table 35), except in a study by Crump et al. (2019), where longer lying time was found during overnight pasture compared to indoor housing. The lower lying times on pasture may be due to a reduced motivation to lie when on pasture, because the surface is soft/deformable and more suitable to stand and walk on. This is supported by studies on indoor-housing systems where cows with access to deformable flooring in passageways, such as rubber coated concrete floors had lower lying time than cows housed on concrete floors (Solano et al., 2016). An alternative explanation may be that grazing dairy cows are unable to achieve sufficient lying durations due to time-constraints because of long periods off pasture for milking, or because they spend long periods grazing especially associated with low herbage availability, sward height and nutrient content (review in Mee and Boyle, 2020; Smid et al., 2020). Accordingly, O'Driscoll et al. (2019) found a lower daily lying duration, as well as fewer and shorter lying bouts, in cows on low compared to higher herbage allowances at pasture.

Table 35: Effects of access to pasture or outdoor loafing area (OLA) on different variables for resting problems (lying time, duration and frequency of lying bouts)

Country	System[(a)]	Time[(b)]	Group comparison	Variable	Analysis[(c)]	Effect	Reference
CAN	Cubicle	Summer	Daytime pasture (vs. zero-grazing[(d)])	Lying (% time)	UA	ns	Shepley et al. (2017)
CAN	Cubicle	Aug-Oct	Overnight pasture (vs. all-day indoors or overnight OLA)	Lying (% time)	UA	↓[(e)]	Smid et al. (2018)
			Overnight pasture (vs. overnight OLA)	Lying (% night)	UA	ns	
CAN	Cubicle	May-Jan	Overnight pasture (vs. zero-grazing)	Lying (min/day)	MA	ns	Chapinal et al. (2010)
				Lying bout duration (h/bout)	MA	ns	
				Lying bouts (number/day)	MA	↓[(f)]	
CH	Cubicle	Summer	All-day pasture (vs. zero-grazing[(d)])	Lying (min/day)	MA	↓	Dohme-Meier et al. (2014)
FR	Various	Winter, summer	Summer pasture (vs. winter barn)	Lying bouts (number/day)	MA	ns	Shepley et al. (2020a)
	Cubicle			Lying (h/day)	MA	(↓)	
	Straw yard					ns	
UK	Cubicle	Summer	All-day pasture (vs. zero-grazing)	Lying (min/day)	MA	↓	Roca-Fernández et al. (2013)
IRL	Cubicle	Summer	Overnight pasture (vs. zero-grazing)	Lying (h/daytime)	MA	ns	Crump et al. (2019)
				Lying (h/night)	MA	↑	
				Lying bout duration (h/bout)	MA	↑	
				Lying bouts (number/day)	MA	↓	
				Overnight up and down transitions	MA	↓	
USA	Cubicle	Aug-Nov	All-day pasture (vs. zero-grazing)	Lying (h/day)	MA	↓[(g)]	Black and Krawczel (2016)
				Lying bout duration (min/bout)	MA	ns	

↑/↓ = significant increase/decrease of the variable ($p < 0.05$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Period of data collection.

(c): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
(d): Plus outdoor loafing area.
(e): Lying time was shorter when cows had free access to overnight pasture compared to indoor housing or with access to OLA.
(f): Only significant in primiparous cows.
(g): Not significant during time period of calving.

All studies that measured time standing (i.e. excluding time walking) point in the same direction, with lower standing durations for cows with all-day access to pasture (Roca-Fernández et al., 2013; Dohme-Meier et al., 2014), cows with overnight access to pasture and cows with access to an outdoor loafing area (Smid et al., 2018) compared to cows housed indoors all-day. The impact of changes in the standing behaviour on cow welfare is however not fully understood.

Lying down and rising up

The effect of outdoor access was also evaluated in studies comparing duration of lying down and rising up behaviours, proportion of collisions and lying postures. Details of the literature findings are reported in Appendix F (see Table F.1). In terms of animal welfare, positive effects of outdoor access were found in tie-stall systems with regard to the duration of lying down and rising movements (Corazzin et al., 2010; Popescu et al., 2013), and the occurrence of collisions with the equipment when lying down as well as the proportion of cows lying partly outside the stall, i.e. animals lying with their hind quarter on the edge of the stall (Popescu et al., 2013).

In loose housing systems, no effects of outdoor access on lying down and rising up movement, collisions, or the occurrence of observations of cows lying outside designated lying areas were found. With regard to lying postures, however, van Erp-van der Kooij et al. (2019) observed more wide postures (in lateral recumbency, hind legs stretched) and less short postures (cow lies on its sternum and ventral side of the abdomen, curled up with the head turned back) among cows at pasture compared to cows in cubicles, possibly reflecting the unrestricted lying conditions on pasture. The eventual welfare effects of such (un)restricted lying postures however remain unclear (van Erp-van der Kooij et al., 2019).

Social behaviour

Studies on social behaviour in dairy cows showed an increase in agonistic interactions among cows housed indoors compared to cows at pasture, which can mainly be attributed to the restricted space allowance indoors, and increased competition for access to resources like feed and lying areas (review in Mee and Boyle, 2020). The provision of an outdoor loafing area increases space allowance in loose-housing systems and may make it easier for lower ranking individuals to avoid dominant cows. In tie-stall systems, in contrast, temporary outdoor access provides opportunities to interact socially with conspecifics others than the nearest stall neighbours. Accordingly, also the few studies on effects of outdoor access on social behaviour indicate a positive overall association with animal welfare: at overnight pasture compared to zero-grazing, higher lying synchrony was found in a cubicle system (Crump et al., 2019); and at all-day pasture compared to zero-grazing, fewer displacements occurred at the feed bunk during milking times (Black and Krawczel, 2016). One study in tie-stall systems revealed carry-over effects of the outdoor access: during the late autumn/winter period, i.e. when continuously tethered, cows on farms with spring/summer outdoor access showed fewer displacements from the shared drinker but more head-butts than cows on farms with all-year tethering (Popescu et al., 2013) (for details see Appendix F, Table F.2).

4.3.6. Common hazards and preventive measures

Most hazards affecting restriction of movement and resting problems are system-specific and are therefore dealt within the next section (5.3.7).

4.3.7. Specific hazards per housing system and preventive measures

4.3.7.1. Specific hazards for tie-stall systems

For tie-stall systems, the identified housing-related hazards for restriction of movement and resting problems are mostly associated with tethering, stall dimensions and lying surface. The effects of lying surface are similar to those described for cubicle housing systems (see Section 4.3.7.2).

In the studies included in this scientific opinion, all effects reported in **tie-stall systems** were related to stall characteristics such as dimensions of the stalls and tethering equipment (Table 36). Dairy cows in tie-stalls had longer daily lying durations when the lying surface was covered with rubber mats compared to bare concrete (Rushen et al., 2007; Haley et al., 2001).

Table 36: Farm hazards affecting lying behaviour in tie-stall systems

Stall characteristics	Variable	Analysis[(a)]	Effect	Reference
Wider stalls	Lying (h/day)	MA	↑	Bouffard et al. (2017)
Wider stalls	Lying bouts (number/day)	MA	↓	Boyer et al. (2021b)
	Lying bout duration (h/bout)	MA	↑	
	Collision while rising up (%)	MA	↓	
	Lying with extended hind legs (%)	MA	↑	
Longer stalls	Lying (h/day)	MA	↑	McPherson and Vasseur (2021)
	Lying bout duration (min/bout)	MA	↑	
	Collision while rising up (%)	MA	↓	
Tie-rail further forward	Lying (h/day)	MA	(↑)	Bouffard et al. (2017)
	Lying bouts (number/day)	MA	↑	
Higher tie-rail	Lying (h/day)	MA	↓	Bouffard et al. (2017)
	Lying bouts (number/day)	MA	↓	
Longer beds	Lying bouts (number/day)	MA	↑	Bouffard et al. (2017)
Longer chains	Intention before lying (s)	MA	↓	Boyer et al. (2021a)

↑/↓ = significant increase/decrease of the variable ($p < 0.05$), (↑)/(↓) = by tendency higher/lower ($p < 0.1$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.

(a): statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).

4.3.7.2. Specific hazards for cubicle housing systems

4.3.7.2.1. Specific hazards for restriction of movement (locomotion)

Specific hazards within a housing system influencing the locomotor behaviour and activity of the cows were investigated for cubicle housing systems. Significant effects were found with regard to space available, stocking density and floor properties.

Space available and stocking density

Large pen sizes were found to be associated with increased locomotor activity in terms of the daily distance moved and the percentage of movement events, i.e. scans in which the cows had changed their position in the barn (Telezhenko et al., 2012). Increased stocking densities, in contrast, were associated with reduced daily movement and increased time standing in the alley and the cubicle (Gomez and Cook, 2010; Winckler et al., 2015; Fujiwara et al., 2019). The study by Winckler et al. (2015) accordingly showed a shift in the time budget towards longer times lying with reduced stocking density of cubicles (Table 37).

Table 37: Farm hazards affecting locomotion behaviour/activity in cubicle systems

Farm hazards	Variable	Effect	Analysis[(a)]	Reference
Space allowance				
Larger pens (24 vs. 12 cubicles)	Distance moved (m/day)	↑	MA	Telezhenko et al. (2012)
	Movement events (%)	↑	MA	
Stocking density				
Increased stocking density[(b)]	Standing in cubicle (h/day)	↓	MA	Gomez and Cook (2010)
Overstocking density[(c)] (150% vs. 100%)	Standing in cubicle, front legs (h/day)	↓	MA	Winckler et al. (2015)

Farm hazards	Variable	Effect	Analysis[(a)]	Reference
Understocking density[(c)] (75% vs. 100%)	Standing in alley between two rows of stalls (h/day)	↓	MA	Winckler et al. (2015)
Understocking density[(c)] (67% vs. 100%)	Standing in alley (min/3 h after feeding)	↓	MA	Fujiwara et al. (2019)[(d)]
Understocking density[(c)] (25% vs. 100%)	Movement events (%)	↑	MA	Telezhenko et al. (2012)
Lying surface				
Dry bedding	Standing in alley (h/day)	↓	MA	Reich et al. (2010)
Mattress (vs. sand)	Standing in cubicle (h/day)	↑	MA	Gomez and Cook (2010)

↑/↓ = significant increase/decrease of the variable ($p < 0.05$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.
(a): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).
(b): Study of 16 farms with cubicles, in cows/cubicle.
(c): Stocking density expressed in cows/cubicle (e.g. 150% means 1.5 cow/cubicle).
(d): Cubicle system at dry-off, straw yard before calving.

Floor properties

In loose-housing systems deformable and/or slip-resistant floor types, such as rubber flooring and mastic asphalt, improved walking speed and stride length compared to concrete (Franco-Gendron et al., 2016). Overlaying solid concrete, as well as slatted concrete floor, with rubber mats increased walking speed and stride length compared to when walking on concrete (Telezhenko and Bergsten, 2005), and walking speed and stride length were improved on pasture compared to mastic asphalt floor (Alsaaod et al., 2017).

Restricted space allowance and **inappropriate flooring** may also alter other behaviour types such as oestrus behaviour that was found to be expressed less in housed cows compared to cows at pasture (e.g. Palmer et al., 2012).

4.3.7.2.2. Specific hazards for resting problems (lying behaviour)

In cubicle systems, lying behaviour was affected by cubicle characteristics including dimensions, lying surface characteristics and depth and moist of bedding (Table 38), stocking densities and space allowance (Table 39), floor type and management hazards (Table 40).

Cubicle dimensions

In an epidemiological study in Switzerland, collisions with equipment and various other indicators of difficulty of performing the lying down or rising up movement were associated with lower bed length ratios (in relation to cow body measurements). However, the proportion of lying with element contact was higher with higher bed length ratios, and repeated hind leg stepping while lying was increased in cubicles with increased ratio of lunge space to length of resting area (Dirksen et al., 2020).

Table 38: Cubicle characteristics affecting lying behaviour in cubicle systems

Hazards	Variable	Effect	Reference
Hazards related to cubicle dimensions			
Increased bed length ratio	Collision while lying down or rising up (%)	↓	Dirksen et al. (2020)
	Hesitant head lunge while rising up (%)	↓	
	Backwards shifting or sideways head lunge while rising up (%)	↓	
	Repeated head pendulum or front leg stepping while lying down (%)	↓	
	Lying with curb board or partitions contact (%)	↓	
Increased lunge space ratio	Repeated hind leg stepping while lying down (%)	↓	Dirksen et al. (2020)
Increased curb height	Lying (h/day)	↑	Morabito et al. (2017)

Hazards	Variable	Effect	Reference
Increased cubicle width		↑	
Increased curb height Increased cubicle width	Lying (h/day)	↑ ↑	Solano et al. (2016)
Hazards related to lying surface characteristics			
Mattress (vs. concrete)	Lying bouts (min/bout)	↓	Solano et al. (2016)
	Lying bouts (bouts/day)	↓	
Mattress (vs. sand)	Lying (h/day)	↓	Gomez and Cook (2010)
	Lying bouts (h/bout)	↓	
	Lying bouts (bouts/day)	↑	
Mats (vs. deep-bedded)	Duration of lying down movement (s)	↓	Gieseke et al. (2020)
Concrete (vs. soft/mat(tress))	Narrow lying posture (%)	↑	van Erp-van der Kooij et al. (2019)
Mat(tress) (vs. soft/concrete) Hanging dividers	Wide lying posture (%)	↑ ↑	van Erp-van der Kooij et al. (2019)
Soft mat(tress) (vs. concrete/ mat(tress)) English dividers	Long lying posture (%)	↑ ↑	van Erp-van der Kooij et al. (2019)
Soft mat(tress) (vs. concrete mat(tress)) R-shape dividers	Short lying posture (%)	↓ ↑	van Erp-van der Kooij et al. (2019)
Deep-bedded	Lying (h/day)	↑	Ito et al. (2014)
	Lying bouts (min/bout)	↑	
	Lying bouts (bouts/day)	↓	
Deep-bedded (vs. mattress)	Lying bouts (min/bout)	↑	King et al. (2016)
	Lying (h/day)	(↑)	Robles et al. (2021)
Sand (vs. wood shavings)	Lying (h/day)	↑	Solano et al. (2016)
Soiled lying surface	Lying (h/day)	↓	Robles et al. (2021)
Increased % soiled cubicles	Lying bouts (bouts/day)	↓	Ito et al. (2014)
Hazards related to depth and moist of bedding			
Bedding depth < 2 cm	Lying (h/day)	↓	Morabito et al. (2017)
Bedding depth > 2 cm	Lying bouts (min/bout)	↑	Solano et al. (2016)
	Lying (h/day)	↑	
Drier bedding	Lying (h/day)	↑	Reich et al. (2010)

↑/↓ = significant increase/decrease of the variable ($p < 0.05$); (↑)/(↓) = by tendency higher/lower ($p < 0.1$). The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.

Lying surface characteristics

Hard lying surfaces reduce dairy cows' lying time. Among cows housed in cubicles, a larger study including 141 Canadian farms reported that a deep bed of sand was associated with a 1.4 h/day longer lying time than other surfaces, but only if the stall curbs were high (Solano et al., 2016). Accordingly, Ito et al. (2014) and Westin et al. (2016b) reported from epidemiological studies that lying time was on average 0.8 h longer on farms that had deep bedding compared to farms that did not. In experimental studies several surfaces have been compared (reviewed by Tucker et al., 2021). Generally, lying durations were longer when the cubicles were deep-bedded with straw, sawdust or sand compared to cubicles covered with mats or mattresses with no, or minimal, shallow bedding of straw or sawdust. For example, cows lay for longer when housed in cubicles with deep bedding of 30–40 cm sawdust compared to cubicles with mattresses bedded with 2–3 cm sawdust (Tucker et al., 2003), when housed in cubicles with deep bedding of 20 cm of sand or straw compared to in cubicles with 20 cm thick mattresses (Calamari et al., 2009), and when housed in cubicles with sand compared to mattresses (Cook et al., 2004). Contrary to this, some studies found that cows lay for a shorter time in cubicles with deep bedding of sand than in cubicles with rubber mats bedded with cut straw bedding (Manninen et al., 2002; Norring et al., 2010), and Tucker et al. (2010) suggested that these discrepancies regarding sand were related to thermal factors, or lack of previous experience with sand.

Depth of bedding

Deeper bedding increases lying time. Two studies investigated the effect of different amounts of straw or sawdust in cubicles with mattresses. Firstly, Tucker and Weary (2004) investigated the effect of increasing the amount of sawdust from nothing to 1 and 7.5 kg/cubicle/day in a preference study with simultaneous access to cubicles with all three bedding amounts and found that cows preferred cubicles with 7.5 kg of sawdust. In a follow-up study, Tucker et al. (2009) investigated the effect on lying time of various bedding amounts (of respectively sawdust and straw) in cubicles with 6 cm thick mattresses. Since the suppressibility of the two materials are different, the height of the bedding was measured after it had been compressed in a standardised way. An increase in amount of sawdust (respectively 3, 9, 15, 24 kg/cubicle/day, corresponding to 2, 4, 5 and 9 cm of compressed material) increased lying time, while an increase in the amount of straw (respectively 1, 3, 5, 7 kg/cubicle/day, corresponding to 2, 7, 8 and 15 cm of compressed material) increased both the lying time and the number of lying periods. However, increasing the amount of straw from 0.5 to 3 kg (corresponding to 2 and 7 cm of compressed material) had no effect on lying behaviour. The lying time increased more, for each additional kg of bedding, for straw than for sawdust. However, when cows' lying time was related to the height of the compressed material, a correlation was found between this height and lying times; for every extra 1 cm height, an increase in the lying time of 9 min was seen for sawdust and of 6 min for straw. The results show that for straw there was an effect of going from 2 to 15 cm of compressed material, while for sawdust there was an effect of going from 2 to 9 cm of compressed material (both on top of the mattress). The cows in this study weighed between 500 and 800 kg, but there was no effect of the animals' weight. In deep-bedded cubicles with sand, lying time decreased by 11 min. for every 1 cm decrease in sand depth relative to the curb (from 0 to 6 cm). Similarly, a difference in height of 14 cm from the curb to the sand surface at the deepest point led to a reduction in lying time of 2.3 h compared to when the sand height was at the height of the curb (Drissler et al., 2005). A similar relationship was shown for straw, with cows preferring cubicles with concrete surface with 4–5 kg of straw to cubicles with mats containing 1 kg of straw when the bedding was fresh, but not later in the day when the bedding had been used and had partly disappeared (Jensen et al., 1988). In a recent study, effect of bedding type and depth was studied comparing cubicles with deep (8–10 cm) sand, with deep recycled manure solids (RMS), with mattresses with shallow RMS bedding and with mattresses with shallow sawdust bedding (Leach et al., 2022). Both the lying time and the number of lying bouts were higher on mats covered with sawdust compared to either of the RMS-types, which may be at least partly explained by a lower DM percentage of RMS (see below). On the other hand, the lying bout duration was longer on both types of deep bedding than on mattresses.

Moist of bedding

Moist bedding reduces dairy cows' lying time. Fregonesi et al. (2007) found that cows reduced their lying time from 13.8 to 8.8 h per day when the dry matter percentage of sawdust bedding was reduced from 86% to 26%. Similarly, Reich et al. (2010) showed that cows reduced their daily lying time from 11.5 to 10.4 h and increased their standing time in the alleys when the dry matter of bedding was reduced from 90% to 35%. Also, wet bedding caused the cows to stand with their forelegs in the cubicle and their hind legs in the alleyway (perching), a behaviour that has been related to increased risk of lameness (Bernardi et al., 2009; Dippel et al., 2009a).

Since the above reported literature does not provide a simple measure for thickness of the layer of bedding, the WG considers, based on data from the literature and on expert opinion, a layer of 5–7 cm of compressed material (i.e. compressed once the animal has lied on it) provides a comfortable lying surface and prevents resting problems. For instance, this corresponds to 3 kg of straw per day. When using mats and mattresses, bedding on top of these is required to improve cow comfort (e.g. supporting lying behaviour and comfortable lying).

Stocking density at the cubicles

The number of cows per cubicle (stocking density) affects lying time. Experimental studies of stocking density of lactating cows are reviewed in Tucker et al. (2021), showing that with increasing stocking density, the average lying time decreases. The studies found that average lying time was reduced when stocking density was above 1.2 cows per cubicle, while one (Fregonesi et al., 2007) among four studies (Hill et al., 2009; Krawczel et al., 2012; Friend et al., 1977) found that increasing the stocking density from 1 to 1.2 cows per cubicle reduced average lying time. It is worth noting that all these experimental studies manipulated stocking density by blocking off cubicles and did not change the stocking of the feed manger and alleyways. Under practical conditions, increased stocking of cubicles would usually mean increased stocking density in general and therefore the experimental studies may be underestimating the effect going from 1 to 1.2 cow per cubicle under practical conditions.

Does understocking the cubicles increase lying time above the level seen with 1 cow per cubicle? Three studies understocked cubicles, and while Telezhenko et al. (2012) found lying time to be increased when going from 100% to 50% stocking density, Cortés Fernández de Arcipreste et al. (2018) and Winckler et al. (2015) found no effect of going from 100% to 75% stocking density. Again, these experimental studies did not vary stocking of other areas, which may also affect lying time (total area: Thompson et al., 2022); feed manger: Deming et al., 2013), and thus similar percentwise reductions in overall stocking densities may yield different results.

Another variable of relevance for the assessment of effect of stocking density is displacements from cubicles (i.e. by agonistic behaviour, one cow causes a cubicle-occupying cow to leave the cubicle; as recorded by Winckler et al., 2015 and Witaifi et al., 2018). Reducing stocking density from 150% to 100% reduced displacement from cubicles and reducing it further to 75% reduced displacement further (1.9, 1.1, 0.6 displacements per 24 h; Winckler et al., 2015). Witaifi et al. (2018) only investigated overstocking and varied stocking of cubicles and feed manger. Here cows were displaced more from cubicles at 150% stocking compared to 100% or 120%, with no difference between 100% and 120%.

All the cited studies considered average lying times, but subordinate cows are more likely to be displaced (Val-Laillet et al., 2008a) and their lying time may be affected at lower stocking densities than that of dominant cows. That is, subordinate cows may benefit more from reducing the stocking density to 1 cow per cubicle than dominant cows.

The working group experts considering the available evidence and based on their expert opinion, concluded (with 90% certainty) that at least 1 cubicle per cow is needed in order to provide cows with sufficient space to avoid restriction of movement and resting problems. Although less information is available, it is also concluded that cows, and especially the subordinate cows, benefit from understocking i.e. providing more cubicles than cows (with 66% certainty).

Table 39: Hazards related to stocking density/space allowance affecting lying behaviour in cubicle systems

Hazards related to stocking density and space allowance	Variable	Effect	Reference
Overstocking density[(a)] (142% and 131% vs. 113% and 100%)	Lying (h/day)	↓	Krawczel et al. (2012)
Overstocking density[(a)] (150% vs. 100%)	Lying (h/day)	↓	Winckler et al. (2015)
	Lying (% daytime)	↑	
Understocking density[(a)] (75% vs. 100%)	Latency to lie after milking (min)	↑	Winckler et al. (2015)
Understocking density[(a)] (25% vs. 100%)	Lying (h/day)	↑	Telezhenko et al. (2012)
Increased area/cow	Lying bouts (min/bout)	(↑)	Charlton et al. (2014)
	Lying bouts (bouts/day)	(↓)	
Increased pen size (24 vs. 12 cubicles)	Lying (h/day)	↑	Talebi et al. (2014)
Increased space at feed bunk/cow	Lying (h/day)	↑	Deming et al. (2013)
	Lying bouts (min/bout)	(↑)	
Wider feeding alley	Lying (h/day)	↑	Solano et al. (2016)
	Lying bouts (min/bout)	↑	

↑/↓ = significant increase/decrease of the variable ($p < 0.05$); (↑/↓) = by tendency higher/lower ($p < 0.1$). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.
(a): Stocking density expressed in cows/cubicle (e.g. 150% means 1.5 cow/cubicle).

Total space allowance

Studies on the effect of total space allowance in cow housing are few. Average daily lying times were longer with increased pen size i.e. in terms of total space and space per animal available (Talebi et al., 2014) in terms of i.e. total space and space per animal available, increased space, increased space per cow in the feeding area (Deming et al., 2013; Solano et al., 2016). A recent study found that an increase in space in the passageways in a cubicle system from 3 to 6.5 m^2 per cow (equivalent to 9–14 m^2 per cow total area) increased cow lying times by 65 min/day and reduce standing/walking time in passageways by 64 min/day (Thompson et al., 2022). Maybe of less relevance for cubicle housing systems, a New Zealand study found that in groups of 5 cows, housed temporarily in pens with rubber covered floor during periods with wet pasture, lying times were higher and aggressive interactions were lower with higher space allowance (3.0, 4.5, 6.0, 7.5, 9.0 and 10.5 m^2/cow; Schutz et al., 2015).

In order to calculate the total indoor space available for the cows when they are not away for milking, the WG experts consulted the best practice recommendations for a number of countries (DK, UK, FR, SE, DE). The dimensions of cubicles, feeder space and alleys retrieved through these recommendations were appraised by the experts and considered reflecting the current knowledge regarding animal welfare and thus useful to calculate the total space needed by the cows. The experts applied the equation below to calculate total space, assuming cow cubicle ratio 1:1 and feeder space 1:1.

$$\begin{aligned}\text{Total space} = {} & (\text{feeder space/cow} \times \text{alley width}) + (\text{cubicle width} \times \text{cubicle length}) \\ & + (50\%\ \text{cubicle width} \times \text{alley width}) + \text{drinker area}\end{aligned}$$

Using the data from the above-mentioned recommendations, the equation was calculated to be:

$$\begin{aligned}& [0.85\ \text{m (feeder space)} \times 3.5\ \text{m (feed alley)}] + [1.25\ \text{m (cubicle width)} \times 2.85\ \text{m (cubicle length)}] \\ & + [0.63\ \text{m } (50\%\ \text{cubicle width}) \times 2.6\ \text{m (alley width between cubicle rows)}] + 1.5\ \text{m}^2\ \text{(drinker area)} \\ & = 9.7\ \text{m}^2\end{aligned}$$

In conclusion, the equation results in a total indoor space allowance of approximately 9–10 m^2.

Floor types

Regarding floor type, Solano et al. (2016) found longer lying times and increased lying bout frequencies on Canadian dairy farms with rubber floor compared to farms with concrete floor.

4.3.7.2.3. Specific hazards for restriction of movement (social behaviour)

With regard to system-specific hazards influencing indicators of social behaviour, only studies in cubicle systems were available in the selected literature. Significant effects were related to stocking densities, space allowance and other housing and management hazards (Table 40).

Table 40: Farm hazards affecting social behaviour in cubicle systems

Hazards	Variable	Analysis[(a)]	Effect	Reference
Space allowance				
Increased space allowance in OLA[(b)]	Agonistic interaction (n/h)	MA	↓	Lutz et al. (2019)
	Agonistic interaction without body contact (%)	MA	↑	
Space allowance in OLA[(b)]	Successful head butt (%)	MA	↑/↓[(c)]	
Lower cow:cubicle ratio	Displacement (n/h)	MA	↓	de Vries et al. (2015)
Stocking density				
Overstocking density[(d)] (150% vs. 100%)	Behaviour synchrony (Kappa)	MA	↓	Winckler et al. (2015)
Overstocking density at feed bunk (200% vs. 100%)	Displacement from feed place (n/h)	MA	↑	Collings et al. (2011)
Increased stocking density[(d)] (100%, 113%, 131%, 142%)	Displacement from feed place (n/2 h)	UA	↑	Krawczel et al. (2012)
Understocking density[(d)] (75% vs. 100%)	Head butt at feed place (n/2 h)	MA	↑	Winckler et al. (2015)
	Displacement from cubicle (n/2 h)	MA	↓	

Hazards	Variable	Analysis[(a)]	Effect	Reference
Understocking density[(d)] (80% vs. 100%)	Displacement from feed place (n/3 h)	MA	↓	Lobeck-Luchterhand et al. (2015)
Decreased stocking density[(d)]	Displacement from feed place (n/3 h)	MA	↓	Talebi et al. (2014)
Others				
No cow brushes (vs. rotating brushes)	Displacement (n/h)	MA	↓	de Vries et al. (2015)
Heifer integration before calving (vs. after calving)	Displacement (n/h)	MA	↓	de Vries et al. (2015)
Increased manure scraping frequency	Displacement (n/h)	MA	↓	de Vries et al. (2015)
Ad libitum roughage availability	Displacement (n/h)	MA	↑	de Vries et al. (2015)
Restricted access to feed	Displacement from feed place (n/h)	MA	↑	Collings et al. (2011)
Increased group size	Displacement from feed place (n/3 h)	MA	↑	Talebi et al. (2014)

↑/↓ = significantly higher/lower ($p < 0.05$). The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.

(a): Statistical analysis: MA = multivariable analysis (in the case of univariable preselection of factors, only effects of the final models were considered).

(b): OLA = outdoor loafing area (5, 8, 12, 15 m^2/cow).

(c): Percentage of successful head butts increased with an increase in space allowance up to 12 m^2/cow in the OLA, but decreased with 15 m^2.

(d): Stocking density expressed in cows/cubicle (e.g. 150% means 1.5 cow/cubicle).

Other factors reducing the frequency of agonistic interactions were the omission of cow brushes versus rotating brushes and the integration of heifers into the lactating group before calving, and less explainable, an increased frequency of manure scraping of alley ways (de Vries et al., 2015). Regarding feeding management, more displacements were found on farms providing roughage feed for ad libitum intake (de Vries et al., 2015) compared to restrictive feeding. In contrast, an experimental study Collings et al., (2011) found less displacements from the feeding area when feed was available for 24 h per day compared to 14 h per day.

Space allowance/stocking density

As expected, increased stocking of cubicles (i.e. higher cow:cubicle ratio) was associated with increased frequencies of agonistic interactions in several studies (Collings et al., 2011; Krawczel et al., 2012; Talebi et al., 2014; de Vries et al., 2015; Lobeck-Luchterhand et al., 2015; Winckler et al., 2015).

With increased space allowance in the outdoor loafing area, Lutz et al. (2019) found lower frequencies of agonistic interactions and an increased proportion of agonistic interactions without physical contact (e.g. withdrawal after threat).

4.3.8. Management-related hazards (not related with physical infrastructure)

An important management factor is the access to an exercise area, especially the duration (h/day) and frequency (d/week) of outdoor access, and more broadly, its general organisation (i.e. duration of time spent confined between periods of outdoor access). For instance, 1 h/day of daily exercise allowed tethered cows to express levels of locomotor activity observed when they were loose-housed (Veissier et al., 2008), whereas 1 h/day of access one to three times per week led to a rebound of locomotor behaviours (Loberg et al., 2004).

Management factors that had an influence on lying behaviour in cubicle systems were the duration of milking, frequency of feed push-ups and manure scraping, and group size (Table 41). The time spent away for milking, e.g. in the holding area, may impose restriction of movement and cause resting problems by reducing the time available for lying. Dairy cows spend 3–8 h/day feeding at the feed manger and depending on management they can spend several hours at milking or waiting to be milked which may affect lying time (Tucker et al., 2021). In a study including 111 dairy farms with cubicle housing systems (Charlton et al., 2014), the time dairy cows spent away from the home pen to be milked varied between 1 and + 8 h. No farm with a time spent away to be milked longer than 3.7 h/day had a lying time of 12 h/day or more, and an increased 'milking time' above 3.3 h/day was associated with a reduction in lying time. Thus, spending more than 3–4 h waiting for and being milked appears to pose a risk of reduced lying time.

Table 41: Hazards related to floor type and management affecting lying behaviour in cubicle systems

Hazard related to floor type and management	Variable	Effect	Reference
Rubber (vs. concrete floor)	Lying (h/day)	↓	Solano et al. (2016)
	Lying bouts (bouts/day)	↓	
Increased manure scraping frequency	Lying bouts (bouts/day)	↑	Solano et al. (2016)
Increased feed push-up frequency	Lying (h/day)	↑	King et al. (2016)
	Lying (% daytime)	↑	
Shorter milking time	Lying (h/day)	↑	Gomez and Cook (2010)
Longer milking time	Lying bouts (min/bout)	↓	Charlton et al. (2014)
Increased group size	Lying bouts (bouts/day)	↑	Charlton et al. (2014)
	Lying bouts (min/bout)	↓	
Increased group size	Lying outside cubicle (%)	↓	Gieseke et al. (2020)

↑/↓ = significant increase/decrease of the variable ($p < 0.05$); (↑/↓) = by tendency higher/lower ($p < 0.1$). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.

If cows spend a long time eating, this leads to a reduced lying time. Among cows housed in tie stalls, cows on a low-energy diet spent more time feeding than cows on a high-energy diet (6.4 vs. 4.8 h/day) and less time lying (11.1 vs. 12.3 h/day lying; Munksgaard et al., 2006). Tucker et al. (2021) reviewed the relationship between average feeding time and lying time across different studies. They found the lowest lying times at pasture (< 9.3 h/day) among cows with the longest grazing times (> 7.9 h/day). However, in studies where grazing times at pasture were similar to feeding times in tie stall and loose housing (3.1–7.7 h/day), the lying times were also similar between pastured and housed dairy cows (10.4–12.1 h/day; Tucker et al., 2021), thus the lower lying times reported for cows at pasture compared with housed cows are associated with greater time spent grazing than time spent eating indoors.

In addition, other management factors that may reduce the time available for lying is if cows are restrained in headlocks, for example when waiting for health checks or insemination.

4.4. Inability to perform comfort behaviour

4.4.1. Description of comfort behaviour

Comfort behaviour is involved in body hygiene and care such as removal of mud, faeces, insects and parasites from the animals´ skin and hair coat, and is also referred to as grooming behaviour in this context (Spruijt et al., 1992; Albright and Arave, 1997; Broom and Fraser, 2015). Comfort behaviour may also include thermoregulatory behaviour when the environmental temperature, humidity, wind speed or precipitation pose a challenge to the animals´ comfort (Broom and Fraser, 2015). In this section, according to the definition of comfort behaviour given in the EFSA guidance (EFSA AHAW Panel, 2022), the focus is only on those comfort behaviours that relate directly to the animals' integument, i.e. self-grooming, brush use and allo-grooming.

4.4.1.1. Grooming behaviour

The species-specific grooming behaviour of cattle includes self-grooming and allo-grooming, i.e. social grooming between group mates (Sambraus et al., 1978; Albright and Arave, 1997; Broom and Fraser, 2015).

For **self-grooming**, cattle use their own body parts, such as the tongue, for licking other parts of the body (self-licking), and the hind claws or horns for scratching. In order to reach various parts of the body, the animals sometimes adopt atypical postures, such as the three-legged stance (Sambraus et al., 1978; Albright and Arave, 1997) that requires unrestricted movement (e.g. sufficient space and non-slippery flooring). Moreover, particularly to groom body regions that are difficult to reach with the tongue, claw, horns and tail, cattle rub themselves on inanimate objects in their environment: at pasture, cattle make use of bushes, trees, or fence posts (Sambraus et al., 1978; Broom and Fraser, 2015); under housing conditions, or in the absence of trees, cows use partition gates, drinkers or walls. To facilitate self-grooming, especially indoors, cow brushes can be offered. Cow brushes of different designs, e.g. simple one-dimensional wall attached brushes and cylinder formed swinging and rotating brushes, may be provided (Figures 7 and 8). Some rotating brushes are automated and equipped with a switch activated by the cow to start the rotating movement. Brushes are a valued resource for dairy cows enabling them to groom parts of their body that they would otherwise not be able to groom, as it has been shown that the average frequency of displacements was lower in herds without compared to herds with cow brushes (de Vries et al., 2015). It has also been reported that feedlot cattle with access to brushes performed less stereotypic behaviour than animals under control conditions without brush (Park et al., 2020).

Figure 7: Fixed brush (© Jan Brinkmann)

Figure 8: Electric rotating cow brush (© Christoph Winckler)

Allo-grooming in cattle refers to the mutual licking of conspecifics, which is mostly carried out on body regions that are difficult to access for the recipient, such as the head or neck area. For allo-grooming, several functions have been proposed in addition to helping cows to stay clean. In addition, allo-grooming is suggested to play a major role in reinforcing social bonds and reducing social tension within groups of animals (review in Boissy et al., 2007; Endres, 2021). In support of this, Laister et al. (2011) found reduced heart rates in cows while they received allo-grooming compared to the situation before the licking event. Val-Laillet et al. (2009) found that allo-grooming occurs more often between cows that are also neighbours in the feeding area, suggesting that allo-grooming indicates preferential relationships. Correspondingly, Gutmann et al. (2015) found that allo-grooming tends to be performed more often between familiar adult individuals that have previously been housed together. One study related allo-grooming to lameness and found that lame cows received allo-grooming more frequently, but not for a longer duration, than non-lame cows (Galindo and Broom, 2002). The authors suggested that lame cows may have solicited allo-grooming more frequently in order to cope with discomfort and pain, however this interpretation of this study is not clear.

Self-grooming behaviour is considered an activity of low resilience (Littin et al., 2008), implying that the performance of such behaviour that typically decreases when energy resources are limited or when the cost involved in the activity increases. Accordingly in cattle, the occurrence of self-grooming is reduced when the cost of performing it is high, e.g. increased walking distances to grooming devices, and when time budgets or energy resources are limited due to ill health. Because low resilience behaviours are expected to decrease earlier than so called core activities, they have been suggested as useful for early detection of for example diseases such as mastitis (self-grooming: Fogsgaard et al., 2012) or metritis (brush use: Mandel et al., 2017), and has been suggested as promising for early detection of lameness (brush use: Mandel et al., 2018; Weigele et al., 2018). Illustrating the interaction between ill health and cost, Mandel et al. (2018) reported decreased brush usage in lame cows only for brushes installed 16 m away from the feed bunk, but not for brushes near the feed bunk. Brush-use has been shown to be related to dominance (Foris et al., 2021; Lecorps et al., 2021), and ill cows likely loose social status. Both self- and allo-grooming are usually considered indicators of good animal welfare (Albright and Arave, 1997), however, high levels of self-grooming may also indicate high parasite load (Moncada et al., 2020), and high levels of allo-grooming may also indicate under-stimulation or social conflict (Knierim and Winckler, 2009).

Caplen and Held (2021) found no effect of elevated somatic cell counts $>200{,}000$ compared to $<100{,}000$ on brush use, but cows with somatic cell counts $<100{,}000$ directed more allo-grooming to other cows on a 24 h basis, and received more within 60 min after milking, indicating increased somatic cell counts might have an impact on social interactions. Almeida et al. (2008) found no differences between sound and lame cows as regards allo-grooming, but increased durations of self-grooming (self-licking and rubbing on objects) in lame compared to sound cows. Induction of *E. coli* mastitis reduced self-grooming from about 5 bouts per hour to approximately 3 bouts per hour (Fogsgaard et al., 2012). Further details on animal-related hazards associated with self-grooming, brush use and allo-grooming reported for dairy cows in different housing systems were assessed from literature (for further details see Appendix G, Table G.1).

4.4.2. Animal-based measures for inability to perform comfort behaviour

Grooming behaviour, both self- and allo-grooming and brush use are the ABMs for comfort behaviour (Table 42). Self- and allo-grooming are mostly recorded via direct (e.g. Endres and Barberg, 2007; Almeida et al., 2008; Di Grigoli et al., 2019) or video observation (e.g. DeVries et al., 2007; Fogsgaard et al., 2012; Caplen and Held, 2021). Brush use is recorded either by video observation (e.g. DeVries et al., 2007; Mandel et al., 2013; Caplen and Held, 2021) or, in more recent research, via an automatic cow identification system in some brush types (Mandel et al., 2018, 2017; Mandel and Nicol, 2017). However, brush contact of heifers was not always accurately identified by a RFID system (Toaff-Rosenstein et al., 2017).

With regard to **self-grooming**, the number or duration of one to multiple behaviours are either recorded separately (e.g. Newby et al., 2013) or together (e.g. Fogsgaard et al., 2012; Di Grigoli et al., 2019). Observed behaviours include cow licking her body with the tongue (self-licking), scratching her head or body by use of a hind claw or by rubbing against objects. With regard to cow **brush use,** recording includes the number and duration of each occurrence of the behaviour (e.g. Mandel et al., 2013; Müller et al., 2018; Moncada et al., 2020), the percentage of cows using the brush at least once a day (e.g. Mandel et al., 2017; Müller et al., 2018), or the latency until use in test situations of experimental studies (e.g. Lecorps et al., 2021) was recorded. In addition, displacements from the brush were recorded in some studies to assess competition for the resource (DeVries et al., 2007; Val-Laillet et al., 2008).

Since **allo-grooming** is usually studied as an aspect of social behaviour, rubbing on other cows or sniffing each other have been included in some studies, in addition to social licking (Loberg et al., 2004; Almeida et al., 2008; Di Grigoli et al., 2019). Some studies distinguish between received or given allo-grooming events (Galindo and Broom, 2002; von Keyserlingk et al., 2008; Caplen and Held, 2021). However, these studies did not control the heat status of the cows during the observation period, which may induce some bias in result interpretation, as cows in heat display more rubbing on, licking and sniffing other cows. The authors also did not specify which body part was involved during the allo-grooming interactions.

Table 42: ABMs for comfort behaviour

ABM	Description of the ABM
Self-grooming	**Definition:** Licking any part of the cow's own body, scratching with foot or horn or rubbing against object (Horvath and Miller-Cushon, 2019). Absence or low levels of self-grooming indicate the inability to perform comfort behaviour. **Feasibility:** Low - Direct observation of self-grooming at cow individual or group level. Requires long term observations for reliable data. **Sensitivity and Specificity:** High sensitivity and low specificity (in cows with healthy integument, specificity is high but self-grooming may also result from external parasites)
Brush use	**Definition:** Cows touches brush with any part of the body (Newby et al., 2013). It is assumed that brush availability and placement is adequate. Absence or low levels of brush use indicate the inability to perform comfort behaviour. **Feasibility:** Low - Direct observation of brush use at cow individual or group level. Requires long term observations for reliable data. Brush use can also be detected through sensors, but reliability questionable (Toaff-Rosenstein et al., 2017). **Sensitivity and Specificity:** High sensitivity and low specificity (in cows with healthy integument, specificity is high, but brush use may also result from external parasites)
Allo-grooming (at cow individual level)	**Definition:** Repeated licking movements carried out by a cow on any part of the body of another individual, except the ano-genital area (De Freslon et al., 2020). Low levels of allo-grooming are assumed to indicate the inability to perform comfort behaviour. However, the validity of the ABM is unclear as it may also reflect social tension within the herd or lack of other stimuli. **Feasibility:** Low - Direct observation of allo-grooming at cow individual or group level. Requires long term observations for reliable data. **Sensitivity and Specificity:** Low sensitivity and low specificity (in situations of tension within the herd)

4.4.3. Comfort behaviour in different housing systems

In the literature included, with the exception of two studies (Haufe et al., 2009; Weigele et al., 2018), the duration or frequency of comfort behaviour or the proportion of cows performing comfort behaviour were only recorded on one farm in each case – in experimental designs and with different methods applied. The observed values of the experimental studies are presented in the following sections for the different husbandry systems and aspects of comfort behaviour, i.e. self-grooming, brush use and allo-grooming, together with the effects of investigated influencing hazards.

4.4.3.1. Tie-stall systems

Tie-stall systems provide only limited ability to perform comfort behaviours due to the restrictions imposed by side partitions and tethering in the head area. In the study of (Krohn et al., 1999) 30% of cows directed licking behaviour against the hindquarters when tethered, but 56% of the cows did so when they were released into a yard. Brush use is only possible if the animals are temporarily released from the tether.

4.4.3.2. Cubicle systems

In cubicle systems, studies have investigated self-grooming, brush use and allo-grooming.

Self-grooming

Self-grooming, which cattle partly perform in typical body postures such as standing on three legs, requires sufficient space and non-slippery floors. In loose housing, cows are not restricted by the tether. Here, the ability to perform self-grooming is likely to be related to the dimensions of the cubicles and walking areas as well as slip-resistance of the floors.

Providing a cow-brush facilitates comfort behaviour. In a study by DeVries et al. (2007), duration and frequency of all self-grooming (here: rubbing on pen objects or using the brush) increased by 508% and 226%, respectively, after installation of a mechanical brush. At the same time, the duration and frequency of self-grooming on other objects decreased significantly, indicating that cows also substituted self-grooming on objects by using the brush. In a study by Newby et al. (2013), however, no significant differences were found in the duration of self-licking, scratching or rubbing on objects whether a brush was offered or not.

Brush use

Different measures of brush use are reported in Appendix G, Table G.2. DeVries et al. (2007) reported that within 1 week after installation 99% of the cows used a mechanical brush. On average, the brush was used 6.8 min/day with 7.7 events/day. Longer durations of brushing have been recorded around the time of calving (Newby et al., 2013): when grouped in a pre-calving pen, all cows made use of the mechanical brush for 31.5 ± 17.7 (mean ± SD) min/day within 72–48 h before calving. The high usage rate in individual pens might be attributed to no competition over the resource. Although the daily duration of brush use is relatively short, competition for this resource has been reported. At a cow:brush ratio of 12:1, DeVries et al. (2007) observed an average of 0.12 ± 0.39 displacements from the brush per cow per day. In a study by Val-Laillet et al. (2008) using the same cow:brush ratio (12:1), the frequency of displacements at the brush was six times higher compared with displacements at the feeding place when adjusted for time of use (Val-Laillet et al., 2008). Under commercial conditions there are typically more than 12 cows per brush.

Allo-grooming

Val-Laillet et al. (2009) observed 74% of total allo-grooming at the feeding places and 26% in the alleys or cubicles, although the cows spent a lower proportion of time at the feeder (20.5%) than in the cubicles (57.3%).

4.4.3.3. Open-bedded systems

Studies in open-bedded systems predominantly considered self-grooming and brush use (Appendix G, Table G.1), with self-grooming being studied exclusively in individual maternity or hospital pens.

Self-grooming

In a cubicle pre-calving pen of 12 cows, Newby et al. (2013) found no effect of brush availability on self-licking or scratching and rubbing on objects in the open-bedded calving pen. Other factors that had an influence on self-grooming behaviour were calving and the separation of cow and calf (Newby et al., 2013). In hospital pens, lame cows performed more self-grooming on a rubber surface compared to deep-bedded sand and the animals spent more time self-grooming in the area close to neighbouring heifers compared to the area not adjacent to a pen with heifers (Jensen et al., 2015).

Brush use

In experimental studies (Mandel et al., 2018, 2017, 2013; Mandel and Nicol, 2017), the brush use of cows in an open-bedded pack system with dried manure was investigated. The average daily percentage of cows using an automatic brush was 70% with cows using the brush on average 4.5 times per day (Mandel et al., 2013). The duration of daily use averaged 1.8 min/day over 305 days in milk (DIM), and was markedly higher (6 min/day) on the day after calving (Mandel and Nicol, 2017).

Allo-grooming

Allo-grooming in open-bedded systems has only been described in Endres and Barberg et al. (2007): on 12 dairy farms with compost-bedded pack systems and herd sizes ranging from 38 to 177 cows, social licking occurred on average (mean ± SD) 2.3 ± 2.9 times/h and herd, ranging from 0 to 13 events/h and herd.

4.4.3.4. Pasture

No studies were found on the comfort behaviour of dairy cows in pasture-based systems. In the EU, these systems are typically used only in Ireland. One study comparing primi- and multiparous cows on pasture did not find an effect on self-grooming but reported more allo-grooming in multiparous cows (Phillips and Rind, 2001a). When in high-yielding cows on pasture concentrates were withdrawn for 1 week, they used a brush less compared to the period before, which was interpreted to result from an increase in eating time to compensate for the metabolic challenge thus leaving less time for other activities (Müller et al., 2018). Both studies were conducted during all-day grazing in summer.

4.4.4. Comparison of housing systems with regards to comfort behaviour

There is only one comparison of comfort behaviour between husbandry systems (Tresoldi et al., 2015) focussing on allo-grooming in groups of pregnant heifers in an indoor cubicle system compared with all-day grazing. The total number of social licking interactions over 2 × 6 h observation time was significantly higher in the cubicle system than on pasture (67 ± 10 vs. 10 ± 10, p = 0.01). No differences were found between cubicle housing systems and pasture with regard to the proportion of allo-grooming in relation to total social interactions (12 ± 2% vs. 8 ± 2%, p = 0.14), the proportion of heifers involved in allo-grooming as initiators or recipients (70 ± 14% vs. 60 ± 14%, p = 0.58) and with regard to the duration of allo-grooming bouts (37 ± 13 s vs. 39 ± 14 s, p = 0.91).

4.4.5. Effects of outdoor or pasture access

Effects of outdoor access on the performance of comfort behaviours were investigated by Di Grigoli et al. (2019) for cows in a cubicle system (zero-grazing versus 5 h per day on barley grass, see details in Table 42 on hazards associated with self-grooming reported for cows housed in cubicle systems) and Loberg et al. (2004) for cows in a tie-stall system. Cows with access to pasture for 5 h in the morning performed more affiliative social behaviour (allo-grooming and sniffing one another) during an observation period over the day (9 h) compared to zero-grazed cows kept in cubicle housing systems (Di Grigoli et al., 2019). However, self-grooming was more frequently observed in cows kept indoors all day. The authors suggest that this may indicate a state of boredom (intended as lack of stimuli) in the indoor housed cows, but this requires further study. Descriptive data from Loberg et al. (2004) show that animals with varying frequency of being brought to an outdoor area (once/twice a week or daily) spent a higher proportion of time self-grooming while in the outdoor area (7–11% of time) and allo-grooming (4–5% of time) compared to continuously tethered animals (5% and 3% of time for self- and allo-grooming, respectively). Animals which were brought to the exercise area once-weekly spent significantly more time self-grooming than animals brought to the exercise area two or seven times a week, indicating that the motivation to perform comfort behaviour builds-up over time of non-performance (rebound effect; Loberg et al., 2004).

4.4.6. Common hazards and preventive measures

<u>Hazards for self-grooming</u>

Hazards associated with self-grooming relate to flooring and stocking density (Table 43). With regard to flooring, Platz et al. (2008) found almost a fourfold increase in self-licking while standing on three legs and a sevenfold increase in caudal self-licking on rubber floors compared to concrete floors, but the frequency of self-licking did not differ in another study comparing rubber, mastic asphalt and slatted concrete floors (Haufe et al., 2009). Overstocking in the transition pen resulted in a decrease of self-grooming immediately after regrouping (Mazer et al., 2020), but there are no data on the effect of stocking density under stable group conditions.

Table 43: Hazards associated with the occurrence of self-grooming

Hazards	Variable	Analysis[(a)]	Effect	Reference
Solid rubber floor vs. mastic asphalt vs. slatted concrete	Self-licking on three or four legs (events/3 h)	UA	ns	Haufe et al. (2009)
Concrete floor (vs. rubber floor)	Self-licking while standing on 3 legs (events/8 h)	UA	↓	Platz et al. (2008)
	Caudal self-licking (events/8 h)	UA	↓	

Hazards	Variable	Analysis[(a)]	Effect	Reference
Increased stocking density in transition pen	Self-licking (min/h), immediately after integration into lactating herd	MA	↓	Mazer et al. (2020)

↑/↓ = significantly higher/lower ($p < 0.05$); (↑)/(↓) = by tendency higher/lower ($p < 0.1$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red).
(a): UA = univariable, MA = multivariable.

Hazards for Allo-grooming

Hazards associated with allo-grooming are reported in Table 44. When feed bunk space/cow was reduced (0.3 m vs.0.6 m), the duration of social licking per day was significantly lower both at the feeding places and in the alley (Val-Laillet et al., 2009).

Table 44: Hazards associated with different variables of allo-grooming

Hazards	Variable	Analysis[(a)]	Effect	Reference
Higher feed bunk availability (0.6 m/cow vs. 0.3 m/cow)	Social licking (s/day), at the feeding place	UA	↑	Val-Laillet et al. (2009)
	Social licking (s/day), in the alley	UA	↑	
	Social licking (bouts/day), at the feeding place	UA	ns	
	Social licking (bouts/day), in the alley	UA	ns	

↑/↓ = significant increase/decrease ($p < 0.05$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red).
(a): UA = univariable, MA = multivariable.

Hazards for brush use

A lack of brushes is the most obvious hazard for the inability to perform comfort behaviour such as scratching the back or any other part of the body. When available, brush use was significantly higher when the feed was closer to the brush (Mandel et al., 2013). However, in subsequent studies, the distance from the brush to the feed only had an effect among cows with metritis (Mandel et al., 2017) or lameness (Mandel et al., 2018). Brush use was also significantly reduced with increasing temperature and humidity (Mandel et al., 2013). There is a lack of data on an appropriate cow:brush ratio (Table 45).

Table 45: Hazards associated with brush use

Hazards	Variable	Analysis[(a)]	Effect	Reference
Food closer to the brush (food on brush side) (vs. food available on opposite side)	Brush use (number/day)	UA	↑	Mandel et al. (2013)
	Brush use (% cows/day)	UA	↑	
Brush located near feed bunk (3 m) (vs. 16 m)	Brush use (s/day)	MA	ns	Mandel and Nicol (2017)
	Brush use (% cows/day)	MA	ns	

↑/↓ = significantly higher/lower ($p < 0.05$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red).
(a): UA = univariable, MA = multivariable.

4.4.7. Specific hazards per housing system and preventive measures

There are no specific hazards for different housing systems except for tie-stall systems. Depending on the type of tethering (e.g. chain length), the rear parts of the body may be difficult or even impossible to reach for self- or allo-grooming. With regard to allo-grooming the choice of licking partners is also restricted to the neighbouring animals.

4.4.8. Management-related hazards (not related with physical infrastructure)

Management hazards that may lead to the inability to perform comfort behaviour are presented in Appendix G Tables G.3 (hazards for self-grooming) and G4 (hazards for allo-grooming).

Management hazards related to self-grooming

Management hazards that affected the frequency or duration of self-grooming in cubicle systems were the feeding management (Phillips and Rind, 2001a,b) and rearing conditions in early life (Wagner et al., 2012).

Cows provided with fresh TMR on alternate days spent more time grooming themselves than cows fed on a daily basis, which, together with changes in the circadian variation in sleeping and lying ruminating, was interpreted as an indication of less disturbance and thus impaired welfare (Phillips and Rind, 2001b). Similarly, cows offered fresh TMR four times a day groomed themselves less than controls offered fresh feed only once per day.

Heifers reared by their mothers for the first 12 weeks of life self-groomed more frequently than heifers raised with automatic milk feeders when the freshly calved heifers were integrated into the lactating cow group (Wagner et al., 2012). However, the time spent self-grooming did not differ, making the result inconclusive with regard to the welfare impact.

Management hazards related to Allo-grooming

Introduction into a new pen reduced both the number of allo-grooming events initiated and received (von Keyserlingk et al., 2008), while such an effect was not found in cows regrouped with familiar animals (Foris et al., 2021). Moreover, there is more allo-grooming in individuals that have been raised together (Sato et al., 1993; de Freslon et al., 2020).

Management hazards related to brush use

No management related hazards for the inability to use a brush were found.

4.5. Metabolic disorders

4.5.1. Description of metabolic disorders

The animal experiences negative affective states such as inappetence, weakness, fatigue, discomfort, pain and/or distress due to disturbed metabolism (e.g. acidosis and ketosis), deficiencies in several nutrients (e.g. anaemia) or induced by ectoparasites affecting metabolism (anaemia due to red mites) or poisoning (EFSA AHAW Panel, 2022). Metabolic disorders comprise a group of disorders that mainly occur in the peri- and postpartum period. Feeding imbalances are related to all metabolic disorders. The metabolic disorders investigated, ketosis, ruminal acidosis, displaced abomasum and milk fever, have different causes, but all have an increased risk during the peripartum period or in early lactation. Acidosis is caused by a low rumen pH (less than 5.5). To meet high energy demands in early lactation, rapidly fermentable carbohydrate feeds (concentrate) and insufficient long fibre are fed but increase the risk of subacute ruminal acidosis (SARA). Hypocalcaemia, also termed milk fever, is characterised by reduced blood calcium levels and occurs if the calcium requirement in colostrum exceeds the cow's ability to mobilise calcium.

4.5.2. Animal-based measures for metabolic disorders

Metabolic disease can occur with clinical ('c') signs or may remain subclinical ('sc'); these will be differentiated accordingly in this scientific opinion. Measures to evaluate metabolic disorders are not always defined precisely or used in a similar way; e.g. incidence rates for treatments for a metabolic disorder may be limited to disorders with clinical signs or this may not be explicitly defined. For negative energy balance (NEB) and subclinical ketosis in particular, many different indicators have been used (e.g. acetone, beta hydroxybutyrate - BHB, non-esterified fatty acid – NEFA; Dohme-Meier et al., 2014, Kaufmann et al., 2012, Frey et al., 2018, Oetting-Neumann et al., 2018, Berge and Vertenten, 2014, Olmos et al., 2009b). Authors of the studies do not always agree on the interpretation of the indicators, e.g. NEFA may be interpreted simply as a negative energy supply (McArt et al., 2013), or as subclinical ketosis (Olmos et al., 2009b; Kaufmann et al., 2012; Dohme-Meier et al., 2014; Frey et al., 2018; Oetting-Neumann et al., 2018). Furthermore, thresholds to define disease often vary, e.g. elevated BHB to indicate subclinical ketosis differ between studies (BHB $\geq$ 0.96 mmol/L in Ribeiro et al., 2013, $\geq$ 1.0 mmol/L in Berge and Vertenten, 2014; $\geq$ 1.2 mmol/L in Oetting-Neumann et al., 2018). In some experimental studies, significant differences between values for e.g. BHB or NEFA concentrations were described without interpreting the values in terms of exceeding a threshold or remaining within a normal range (Kaufmann et al., 2012; Frey et al., 2018). In addition, prevalence or incidence of metabolic disorders are reported differently in different studies, some being evaluated at cow and some at herd level.

Metabolic disorders have been shown to be interrelated (e.g. positive correlations between subclinical ketosis and clinical hypocalcaemia or displaced abomasum (Berge and Vertenten, 2014) and be associated with other health issues such as claw disorders (Nielsen et al., 2013), metritis, retained placenta (Berge and Vertenten, 2014) and impaired fertility (Ribeiro et al., 2013) (Table 46).

Table 46: ABMs used for assessment of metabolic disorders: ketosis (KETO), acidosis (SARA), displaced abomasum (LDA) and hypocalcaemia (HYPOCAL), divided into clinical ('-c') and subclinical ('-sc') form

ABM	Description of the ABM
ABMs for clinical ketosis (Keto-c)	
Clinical case incidence rate	**Definition:** Incidence rate of clinical ketosis (estimated from veterinary diagnoses, farm records or national databases) (Pryce et al., 2016) **Feasibility:** High - although dependent on accuracy of veterinary/farm records **Sensitivity and Specificity:** Low sensitivity since some cases may remain unrecorded. Specificity low because an accurate cow-side diagnosis can be problematic; other conditions such as dilatation or displacement of the abomasum may be present with similar clinical signs (e.g. reduced appetite, changes in behaviour).
ABMs for subclinical ketosis (Keto-sc)	
Individual cow milk constituents	**Definition:** Individual milk fat:protein ratio or early lactation fat % monitored at routine milk recording **Feasibility:** High - although it would require all farmers to participate in milk recording. **Sensitivity and Specificity:** Low sensitivity and medium specificity (factors other than negative energy balance can influence the fat and protein content of milk)
Individual cow beta-hydroxybutyrate levels or ketones	**Definition:** Individual cow beta-hydroxybutyrate levels (blood sample) or ketones (milk or urine samples). Requires regular sampling of a sufficient number of cows (generally ≥ 12) in early lactation to provide effective herd monitoring (Oetzel, 2003). **Feasibility:** High **Sensitivity and Specificity:** High sensitivity and high specificity (sensitivity for urine samples likely to be lower than for blood)
Body condition scoring	**Definition:** Body condition scoring is used to assess the level of body fat by evaluating overall body shape and fat cover with a scoring from 1 to 5 (Welfare Quality, 2009). **Feasibility:** High - already routinely done **Sensitivity and Specificity:** Medium sensitivity and medium specificity (body condition score over time provides a useful indicator of energy balance which is related to subclinical ketosis. However, changes in body condition may be related to factors other than ketosis which limits sensitivity and specificity)
ABMs for left displaced Abomasum (LDA)	
Clinical case incidence rate	**Definition:** Incidence rate of left displaced abomasum (estimated from veterinary diagnoses, farm records or national databases) (Pryce et al., 2016) **Feasibility:** High - although dependent on availability and accuracy of veterinary/ farm records **Sensitivity and Specificity:** High sensitivity and high specificity (accurate veterinary and/or farm records necessary for high sensitivity and specificity to be obtained)

ABM	Description of the ABM
ABMs for sub-acute ruminal acidosis (SARA)	
Individual cow milk constituents	**Definition:** Individual milk fat%, fat:protein ratio monitored at routine milk recording **Feasibility:** High - although it would require all farmers to participate in milk recording. **Sensitivity and Specificity:** Low sensitivity and low specificity (factors other than SARA influence the fat and protein content of milk, therefore sensitivity and specificity limited)
Rumen pH measured by rumenocentesis	**Definition:** Acidity of the liquid rumen content obtained through puncture of the rumen (Nordlund and Garrett, 1994). A rumen pH measured by rumenocentesis lower than or equal to 5.5 can be considered as a sign of subacute ruminal acidosis (Garrett et al., 1999) **Feasibility:** Low - too invasive to be used for routine monitoring **Sensitivity and Specificity:** High sensitivity and specificity
Rumen pH measured by rumen bolus	**Definition:** Rumen pH can be continually measured by a bolus inserted into the reticulum via a rumen cannula. A bolus pH lower than or equal to 6 is considered as a sign of subacute ruminal acidosis (Neubauer et al., 2018) **Feasibility:** Low - as technology relatively expensive and requires additional validation but may become realistic with advances in technology **Sensitivity and Specificity:** High sensitivity and medium specificity
ABMs for clinical hypocalcaemia (Hypocal-c)	
Clinical case incidence rate	**Definition:** Incidence rate of clinical hypocalcaemia (estimated from veterinary diagnoses, farm records or national databases) (Pryce et al., 2016) **Feasibility:** High - although dependent on availability and accuracy of vet/farm records **Sensitivity and Specificity:** High sensitivity and medium specificity (specificity is medium because some cows treated with calcium on-farm may not be hypocalcaemic)
ABMs for subclinical hypocalcaemia (Hypocal-sc)	
Incidence rate	**Definition:** Incidence rate (estimated from veterinary diagnoses, farm records or national databases) (Houe et al., 2001) **Feasibility:** High - although dependent on availability and accuracy of vet/farm records **Sensitivity and Specificity:** Low sensitivity and low specificity due to very difficult cow-side diagnosis
Blood calcium levels within days post-calving	**Definition:** Blood calcium levels measured by blood sample at 24–48 h after calving. Cows with a serum Ca lower than or equal to 2.14 mM are considered experiencing HYPOCAL-sc (Rodríguez et al., 2017) **Feasibility:** Low - requires regular sampling of a sufficient number of cows very close to calving to provide effective herd monitoring **Sensitivity and Specificity:** High sensitivity and high specificity

Body condition score (BCS) may be considered a proxy animal-based measure for metabolic disease since cows that are over-conditioned in the dry period (BCS > 3.5 on a 5-point scale) are at increased risk of reduced dry matter intakes and metabolic disease (ketosis and LDA) in the subsequent lactation. Therefore, monitoring of BCS throughout the lactation cycle can provide information on the herd risk of metabolic disease.

4.5.3. Metabolic disorders in different housing systems

There are several studies describing metabolic state of dairy herds in different housing systems. Details on prevalence of different metabolic disorders can be found in Table H.1 in Appendix H.

There is only one study on straw yards (Berge and Vertenten, 2014) and one on compost bedded packs (Emanuelson et al., 2022), therefore, the figures are unlikely to be representative of these systems in general.

4.5.4. Comparison of housing systems with regards to metabolic disorders

Comparisons of the prevalence of metabolic disorders between different housing systems are shown in Table 47. In one study (Schenkenfelder and Winckler, 2022), straw yard systems and cubicles systems were analysed as one group compared to tie-stalls.

Table 47: Comparison of housing systems regarding metabolic disorders indicators

Country	Variable	Tie-stall	Cubicle	Straw yard	Compost-bedded pack	Reference
NO	HYPOCAL-c: treatments	ns	ns			Simensen et al. (2010)
	KETO-c: treatments	↑	↓			
SE	KETO-c or DISABO-c: high-incidence	ns	ns			Stengärde et al. (2012)
USA	ACID-sc: FPR < 1.0	(↓)	↑			Dechow et al. (2011)
	KETO-sc: fat Δ 1st test day to nadir	ns	ns			
AT	ACID-sc: FPR < 1	↑	↓			Schenkenfelder and Winckler (2022)
	KETO-sc: FPR > 1.5	ns	ns			
DE, FR, IT, NL, UK	KETO-c: BHB ≥ 100 μmol/L	ns	ns	ns		Berge and Vertenten (2014)
USA	KETO-c: diagnoses	↑	↓	↓		Richert et al. (2013)
	HYPOCAL-c: diagnoses	ns	ns	ns		
AT, DE, IT, NL, SI, SE	KETO-sc: FPR > 1.4		ns		ns	Emanuelson et al. (2022)

(↓) = tendency for fewer metabolic disorders (p < 0.1), ↑ = significantly more metabolic disorders (p < 0.05); ns = not significant.

From 11 comparisons made within the seven studies, the majority of comparisons (7) revealed no differences between the investigated housing systems. No study found housing differences regarding prevalence of hypocalcaemia. Two studies investigated subclinical acidosis, with contradictory results. Two of seven studies on ketosis found more clinical cases in tie-stalls and the remaining five studies reported no significant differences between housing systems. In summary, the majority of studies reported no significant differences between housing systems, which suggests that housing system has a minor impact on metabolic health. The only significant result found consistently in more than one study was a higher risk of clinical ketosis in tie-stalls.

4.5.5. Effects of outdoor or pasture access on metabolic disorders

Ten studies that conducted 19 comparisons of metabolic disorders reported the effects of pasture (or outdoor yard) access on metabolic health (Appendix H, Table H.2). While in 14 cases no (trends or significant) effects were found, in 4 cases positive effects of pasture access on the prevalence of ketosis or acidosis have been described (Dechow et al., 2011; Kaufmann et al., 2012; Richert et al., 2013; Oetting-Neumann et al., 2018). However, differences were only found in population subgroups e.g. 'in heifers' or 'in spring'. One study reported a marginal negative effect of pasture access on subclinical ketosis (in cows but not in heifers) (Oetting-Neumann et al., 2018). Some studies identified significant differences between values, but these remained within the normal range (Dohme-Meier et al., 2014). In summary, the majority of studies and comparisons found no effects of pasture access on metabolic health.

This leads to the conclusion that housing system or access to outdoors/pasture has only a minor effect on metabolic health of dairy cows. However, it is to be noted that some housing systems were not investigated.

4.5.6. Common hazards and preventive measures

There are no common housing related hazards for the development of metabolic disorders.

4.5.7. Specific hazards per housing system and preventive measures

There are no specific hazards per systems.

4.5.8. Management-related hazards (not related with physical infrastructure)

Beyond the housing system, hazards within housing systems or housing- or management-related hazards in general can affect metabolic health. In this section, hazards are summarised from studies originally identified in the search (Table 48), although it is important to note that the search was not conducted to identify the whole range of management- and animal-related hazards for metabolic health. Therefore, the hazards detailed below are solely from studies that also investigated housing-related hazards.

Table 48: Management-related hazards affecting metabolic disorders across various housing systems

Hazards	Variable	Effect	Analysis[(a)]	Reference
Dry cows housed separately (vs. together with lactating cows)	KETO-sc: BHB $\geq$ 1.2 mmol/L	↑	MA	Oetting-Neumann et al. (2018)
High frequency of pushing up the diet in the feed bunk (3 times per day)	KETO-sc: BHB $\geq$ 1.2 mmol/L	↑	MA	Oetting-Neumann et al. (2018)
Two phase dry cow feeding (vs. one-phase)	KETO-sc: BHB $\geq$ 1.2 mmol/L	↑	MA	Oetting-Neumann et al. (2018)
Housing dry cows in more than one group	KETO-c or DISABO-c	↑	MA	Stengärde et al. (2012)
Daily cleaning of heifer feeding platform	KETO-c or DISABO-c	↑	MA	Stengärde et al. (2012)
Feeding roughage and concentrates separately vs. PMR	KETO-sc: BHB $\geq$ 1.0 mmol/L	↑	MA	Berge and Vertenten (2014)
PMR vs. TMR		↑	MA	

↑ = significant better metabolic health; ns = not significant; empty cells = not assessed.
(a): MA = multivariable analysis; UA = univariable analysis; PMR: Partial mixed ration; TMR: Total mixed ration.

Management hazards related to ketosis were mainly associated with feeding management. Furthermore, the hazards of keeping dry cows together or separately from lactating cows or of keeping dry cows in more than one group may be explained by differences in feeding regimes.

5. Assessment 3: farm characteristics to classify a level of risk for dairy cow welfare

5.1. Introduction

The aim of this chapter is to address the final element of the Terms of Reference to:

'Identify the specific relevant hazards, leading to the welfare consequences above-mentioned [inability to perform comfort behaviour, restriction of movement, locomotor disorders, metabolic disorders, mastitis] and which can be used to classify the level of risk for animal welfare based on data currently collected (e.g. milk production, herd size, housing system etc.).'

Therefore, the ToR required the identification of specific relevant hazards (from here on termed 'farm characteristics'), for which data are already (or can easily be) collected at national level (e.g. herd size), that are associated with poor welfare on-farm. In this context, judgement of welfare on-farm was based on presence of the welfare consequences listed in the ToR.

In Sections 5.3–5.6, the value of currently available data for the most commonly collected farm characteristics (primarily herd size and milk yield, but also age of the cows, productive lifespan, culling, mortality rates and udder health indicators) is evaluated in terms of association with the welfare consequences listed in the mandate (inability to perform comfort behaviour, restriction of movement, locomotor disorders, metabolic disorders, mastitis) and thus the usefulness to classify the level of risk of poor welfare on dairy farms. However, since insufficient data were identified or associations were too weak to allow such classification, it was decided to explore an alternative approach. This new approach comprised an expert knowledge elicitation (EKE) to develop a risk-based assessment for cow welfare. The EKE is described in Section 5.8.

5.2. Background to basic farm characteristics recorded at national level in the EU: herd size and milk yield

The EU is one of the most important producers of cow's milk globally, with an annual quantity of 157.5 million tonnes of milk produced in 2020 (USDA, 2021). Within the EU, Germany, France, Poland, Italy and The Netherlands are the largest producers in terms of number of cows and volume of milk. Data on the total number of farms, number of dairy cows and raw milk production are available for all EU-MS for the year 2016 (Eurostat, 2021), from which average herd sizes and milk yields per cow can be calculated (presented in Appendix A Table A.1). Supplementary data on the 3-year trend (2018–2020) of milk quantities delivered to dairies and of the total number of dairy cows are presented in Appendix I Tables I.1.

Comparing EU countries, there are marked differences in average herd sizes. In Romania, for example, where dairy farming mainly serves the family supply and only a small share of the total milk production is delivered to dairies (Zaalmink et al., 2020; European Dairy Association, 2021), herd sizes are commonly below 10 dairy cows. In countries where milk is mainly supplied to dairies, such as The Netherlands or Denmark, average herd sizes are markedly higher (with 97 and 180 cows per farm, respectively, in 2016).

Compared to data from 2016, milk yield has generally increased in recent years. However, it should be noted that milk yield values per cow and per year vary between sources within countries depending on which farms or cattle breeds are included in the calculations. The average milk yield on farms participating in official milk recording schemes (in Germany, for example, 20% of all dairy farms with 42% of all dairy cows) or registered in breeding associations (in Spain, for example, farms that are registered in the Spanish-Holstein breeding association Conafe), are higher than the quantities estimated by the statistical offices at overall national level.

5.3. Associations between milk yield or herd size and foot and leg disorders

Associations between foot and leg disorders and milk yield and/or herd size have been investigated in epidemiological studies, mostly using multivariable analyses taking into account a number of potentially confounding factors.

Regarding associations between milk yield and foot and leg disorders, the results are unclear. In tie-stall systems, Oehm et al. (2020) reported lower percentages of lame cows in herds with higher milk yields. In pasture-based systems, however, O'Connor et al. (2020) reported a higher lameness prevalence in herds with higher milk yields ($\geq$ 6,000 kg/cow*year compared to $<$ 6,000 kg). Other studies reported no associations between milk yield and lameness (Appendix I Table I.4) or between milk yield and claw disorders (Appendix I Table I.5). With regard to integument alterations, negative effects of high milk yields were reported in three studies (Appendix I Table I.6).

In terms of associations between herd size and foot and leg disorders, results are variable (Appendix I Tables I.7–I.9). Whether the research outcome was lameness, claw lesions or integument alterations, there is no convincing scientific literature to suggest that milk yield or herd size are consistent hazards.

5.4. Associations between milk yield or herd size and mastitis

In the search for research papers regarding the effects of housing on udder health, only six out of 47 papers included milk yield in the analysis. Results presented in these studies are heterogeneous and summarised in Appendix I Table I.10; studies reported positive, negative and no association between milk yield and indicators of mastitis. Similarly, most studies relating herd size and udder health reported no significant effects (Appendix I Table I.11).

In summary, no clear evidence was identified to suggest that milk yield or herd size are good indicators of dairy herds at increased risk of mastitis.

5.5. Associations between milk yield or herd size and restriction of movement or resting problems

In the selected scientific literature, associations between milk yield and cow time budgets (i.e. times standing, walking, or lying) and lying behaviour were investigated. In addition, associations between milk yield and cow hygiene scores were assessed.

With respect to times standing or walking, no consistent correlations with milk yield were found (Appendix I Table I.12). With regard to daily lying times, Deming et al. (2013) and Solano et al. (2016) found negative associations with milk yield in cubicle systems, i.e. shorter lying times were associated with higher milk yields, possibly because high yielding cows spend more time feeding. In Deming et al. (2013), the mean duration of lying bouts was negatively associated with milk yield. Other studies, however, found no associations between lying times, bout durations or frequencies and milk yield. In a study by Schenkenfelder and Winckler (2021) involving different housing systems (tie-stall, cubicle, straw yard) in Austria, difficulties in rising behaviour were associated with lower herd milk production, whereas prolonged resting (> 3 s) on the carpal joints during rising up was associated with higher milk production (Appendix I Table I.13). Higher milk yields have been associated with a lower prevalence of dirty hindquarters and dirty lower hind legs (Lardy et al., 2021; Schenkenfelder and Winckler, 2021). With regard to dirty udders, a corresponding association was only found by Lardy et al. (2021) (Appendix I Table I.14).

Associations between herd size and lying behaviour, cow cleanliness and social behaviour have been evaluated in the literature. With regard to lying behaviour (Appendix I Table I.15) and cow cleanliness (Appendix I Table I.16), associations with herd size were found in a study of 80 dairy herds keeping the cows in cubicle systems (Gieseke et al., 2018). In herd sizes of 300–499 cows, the proportion of cows with dirty lower hind legs was lower compared to herd sizes of < 100 cows. However, other studies found no associations between herd size and indicators of lying behaviour or cow cleanliness.

In terms of the relationship between herd size and social behaviour, no evidence of an association was identified (Appendix I Table I.17). However, it should be noted that herd size may be confounded by other management practices such as access to pasture. Therefore, the outcomes of the studies that examined herd size and social behaviour are difficult to interpret.

In summary, the scientific literature selected did not provide clear evidence that milk yield or herd size are consistently associated with restrictions of movement or resting problems.

5.6. Associations between milk yield or herd size and metabolic disorders

Studies that reported associations between milk yield and indicators of metabolic disorders are listed in Appendix I Table I.18; three studies contained relevant information. The majority of metabolic disorder indicators (all of which included clinical ketosis) were positively associated with milk yield although the reported effects were often marginal. One study reported no significant associations between subclinical ketosis and milk yield.

Associations between herd size and metabolic health were reported in four studies identified in the literature search (Appendix I, Table I.19). Results are variable and do not allow firm conclusions to be drawn about consistent associations between herd size and risk of metabolic disorders.

In summary, reported associations between metabolic health and milk yield or herd size are variable and the number of relevant studies/comparisons was small. Therefore, no clear evidence could be identified to suggest that milk yield or herd size is consistently associated with an increased risk of metabolic disorders.

5.7. Other farm characteristics with potential relevance to classify farm-level risk of poor welfare

Since there is no clear evidence that herd size or milk yield could be useful characteristics to identify farms at risk of poor welfare, additional farm characteristics were considered. A small number of factors related to health are available and/or accessible at national level in individual EU-MS. Moreover, exact definitions of these factors vary or are not always clear. Due to the limited availability of these data, only information on age, productive lifespan, culling/mortality and udder health are presented below.

5.7.1. Age and productive lifespan

In addition to the average age of dairy cows (length of life in years/months from birth to the last date of recording in the herd or until slaughter), productive lifespan is a quantity commonly estimated. Productive lifespan refers to the length of time a cow remains in the adult dairy herd - from the time of first calving to the last date of recording in the herd or to slaughter. Productive lifespan may be presented as the mean time or number of lactations at herd, sample or national level. Productive lifespan may also be expressed as a ratio, e.g. as the number of primiparous versus multiparous cows, or as an index of lifetime days in milk divided by length of life (review in Dallago et al., 2021).

The average age or productive lifespan of dairy cows is influenced by decisions made by the farmer and reflects culling strategies as well as involuntary culling. Overall, it is estimated that dairy cows' productive lifespan has decreased worldwide over recent decades; however, data at national level are not available for most EU-MS and very often large differences exist between individual countries with official statistical data available or calculated from secondary data (e.g. Dallago et al., 2021). An overview of available data on average age and average lifespan from individual EU-MS is presented in Appendix I Tables I.20 and I.21, respectively. In almost all cases, the data refer to farms that participate in official milk recording schemes or are registered in a breeding association, and usually only the throughput rates at slaughter are given; these data may not be representative of national populations.

It is clear from literature that insufficient data are readily available for variables based on average cow age or productive lifespan to be used as farm-level risk indicators of poor cow welfare.

5.7.2. Culling and mortality rates

Culling and mortality rates are often defined differently in the literature. Culling is broadly defined as the process of removing an animal from the herd, either sale to another farm or to slaughter. Mortality generally refers to death of an animal on-farm including emergency slaughter. Culling can be classified as voluntary or involuntary based on the reason underlying the culling decision. Voluntary culling includes sales of animals to other dairy farms or culling due to low milk production. Involuntary culling includes removal due to infertility, disease, or accidents (Dallago et al., 2021). While overall culling rates to some extent reflect farm management decisions, an increased number of involuntary culls or increased mortality rates have been suggested as indicators of poor animal welfare (de Vries et al., 2011; Thomsen and Houe, 2018).

Recent review articles that include data from epidemiological studies have reported that the most important reasons (mostly reported by farmers) for involuntary culling are infertility, locomotor disorders and udder diseases, and that these reasons had been consistently the top causes over recent decades. Voluntary culling for low milk yield has decreased, which may be explained by genetic selection for higher milk yield (Compton et al., 2017; Dallago et al., 2021). Data on culling and mortality rates are, with few exceptions, predominantly only available from epidemiological studies, some of which are listed in Appendix I Tables I.22 and I.23.

Current data on culling at national level for all EU MS are only available for slaughtered cattle. For these data, a distinction is made according to age but not for sex or origin (dairy or suckler cow farming) or according to culling reason.

Since culling and on-farm mortality are increasingly recorded on national systems throughout Europe and have been used as proxies for reduced animal welfare (de Vries et al., 2011; Thomsen and Houe, 2018), these variables represent potential indicators to classify farms at risk of compromised cow welfare.

5.7.3. Udder health indicators

To evaluate the overall herd-level udder health on a wide-ranging basis, the somatic cell count (SCC) in milk is a useful indicator, since infections in the mammary gland induce an inflammatory response, which results in an increase in SCC. Although the threshold of SCC used to indicate an intramammary infection varies (commonly between 100 and 200,000 cells/mL), it should be acknowledged that there is no perfect SCC threshold to accurately determine the presence of an infection. Internationally, a value of 200,000 cells/mL is commonly used for distinguishing between healthy and infected mammary glands (IDF, 2013).

National data on mean herd SCC or proportions of dairy cows with increased SCC are available to a limited extent for individual EU-MS; for most countries, only data from epidemiological studies are available. Examples of SCC data from individual countries is provided in Appendix I (Table I.24).

In summary, since availability of data is limited in many EU-MS countries, SCC cannot be used as a readily available risk indicator for cow welfare.

5.8. Development of a new, risk-based approach for farm-level assessment of dairy cow welfare through expert knowledge elicitation

5.8.1. Decision to carry out an expert knowledge elicitation (EKE)

As described in Section 5.1, the terms of reference for this Scientific Opinion contained a request to identify a risk-based approach for the farm-level assessment of dairy cow welfare. However, as reported in Sections 5.3–5.6, insufficient data were available, or it was evident from the scientific literature that simple, readily available farm variables would not provide suitable proxies for farms at high risk of poor cow welfare. It was therefore decided to explore an alternative approach to develop a practical risk-based system; this was based on expert knowledge elicitation (EKE). A risk-based approach has potential to contribute substantially to the improvement of dairy cow welfare in Europe and therefore, in consultation with the European Commission, exploration using this methodology was considered worthwhile.

The sections below summarise the methodological phases of the EKE (Section 5.8.2) and the results of the EKE (Section 5.8.3). Additional technical information regarding the EKE are provided in Appendix B (participants, design, selection of the experts, selection of the elicitation method, preparatory document sent to the experts prior to the elicitation).

5.8.2. Aim, structure and phases of the EKE

The aim of this elicitation was to develop a practical framework for a risk-based assessment of dairy cow welfare that could be applied to farms throughout Europe. The framework was based on defining farm characteristics that could be used to categorise farms at risk of poor welfare. Farms with such characteristics would subsequently be evaluated for the presence of specific welfare consequences through the assessment of specified animal-based measures (ABM). A diagrammatic representation of the risk-based approach is presented in Figure 9.

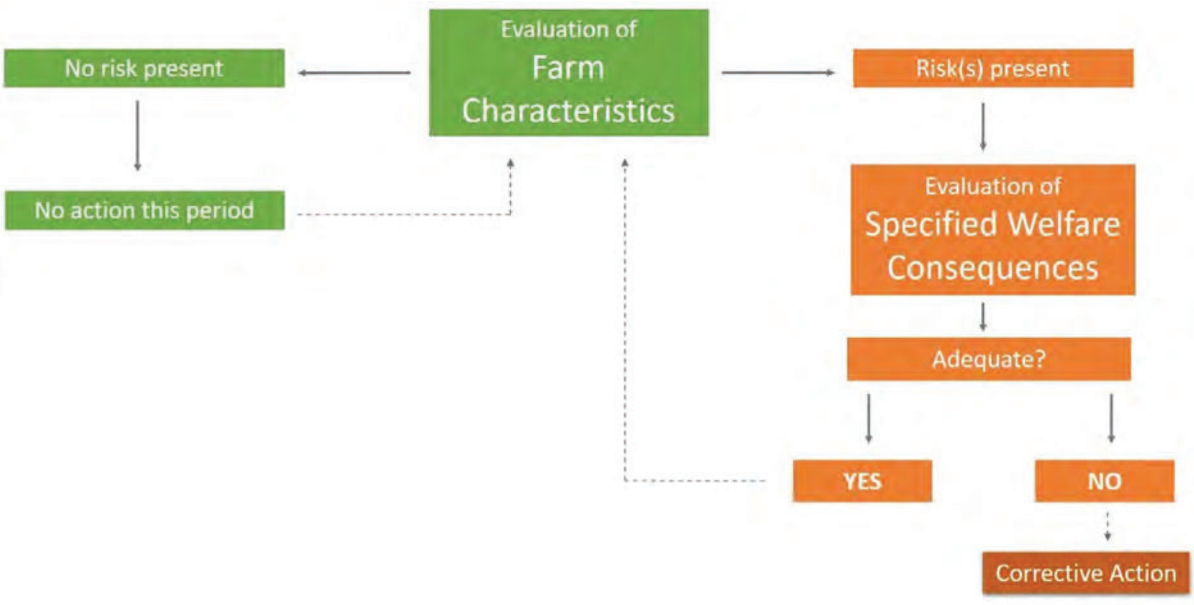

Figure 9: Diagrammatic representation of the proposed risk-based approach to welfare assessment on dairy farms

Farm characteristics, if present, would trigger an evaluation of cow welfare on that farm using pre-defined animal-based measures for specified welfare consequences.

The EKE consisted of three phases:

- Phase 1. Elicitation of farm characteristics: In this phase the WG members identified 5 simple, measurable farm characteristics that were deemed indicative of cows being at a high risk of poor welfare on a farm (e.g. farms with limited space allowance). Farm characteristics had to be measurable across all farms in the EU (i.e. already routinely measured or easily measurable).
- Phase 2. Elicitation of welfare consequences and animal-based measures: In this phase WG members identified, for each farm characteristic, the welfare consequences that were likely to arise from the presence of that characteristic (e.g. group stress). A list of potential welfare consequences had been pre-defined (based on the current EFSA list of welfare consequences, Appendix K Table K.2). Subsequently, WG members identified appropriate ABMs to assess each identified welfare consequence (e.g. number of aggressive interactions) and farm-level measurements for each ABM were defined.
- Phase 3. Elicitation of ABM thresholds: In this final phase, consensus thresholds were elicited for each ABM identified above, to determine whether a farm was deemed to require corrective action for cow welfare (e.g. a farm that had limited space allowance and that exceeded the threshold for the number of aggressive interactions would require corrective action).

5.8.2.1. Phase 1: elicitation of farm characteristics

The elicitation procedure to establish farm characteristics associated with a farm being deemed at high risk of poor welfare was based on an adapted Nominal Group Technique (NGT) (Van de Ven and Delbecq, 1972; Durkin et al., 2019), a structured approach that facilitates idea generation and exploration, and leads to group consensus. The steps of an NGT are as follows. In the first stage, participants are introduced to a topic and invited to engage in an individual 'generation of ideas' phase. In the second stage, each participant is invited in-turn to share ideas with the rest of the group in a 'Round Robin' format. There may be clarification of ideas at this stage but no discussion, and each idea is recorded. In the third stage ideas are discussed, duplicates are removed and clarifications provided such that all participants fully understand and explore the underlying rationale for each of the proposed ideas. An extensive discussion is allowed such that participants can consider and decide on the relative merits of different ideas. The fourth and final stage involves participants' individually prioritising ideas by rating or ranking the ideas listed by the group. Ranks are combined to arrive at a final consensus (Dening et al., 2013).

The elicitation of farm characteristics was conducted with the steps outlined below:

1) The elicitation group members were asked to read a preparatory document containing background information that provided necessary detail prior to the elicitation.
2) Having established the concepts and premise of the elicitation, the group members were asked to individually identify between 3 and 5 farm characteristics that they deemed most likely to be indicative of, or associated with, poor dairy cow welfare. The concept of poor welfare was defined using a number of qualitative statements:
   - 'Farms in which most reasonable, informed, knowledgeable people would consider welfare is inadequate'
   - 'Farms in which many cows are likely to experience physiological or behavioural welfare issues'
   - 'Farms that require immediate support, action or resource to make improvements in welfare'
   - 'Farms in which some or all cows are regularly below what might be considered a minimum acceptable level of welfare (i.e. poor welfare is not confined to only a small portion of the farm or to short time periods)'
   - 'Farms in which the negative impacts on cow welfare occur on a day-to-day or week-to-week basis'
   - 'Farms in which there is a high risk that poor welfare will continue (or get worse) if no corrective measures are implemented'

Prior to the elicitation it was clarified with expert group members that the farm characteristics selected needed to be readily measurable on all European dairy farms.

3) The elicitation was conducted at a face-to-face meeting in Parma on 25th-26th October 2022. The NGT procedure was conducted such that a final group consensus ranking of the importance of the farm characteristics proposed by individual experts was derived. The following steps were undertaken on the morning of 25th October to complete the consensus selection:

   a) Initial farm characteristics chosen individually by expert group members were collated and placed in themes for discussion.
   b) Expert group members each provided brief descriptions of their chosen characteristics.
   c) The elicitation steering and moderation group (SMG) requested clarification and quantification of a farm characteristic when needed.
   d) A general discussion of each characteristic occurred between group members, especially noting strengths, weaknesses and the feasibility of measurement.
   e) The SMG requested removal of characteristics if group members indicated the characteristic was not practically measurable on all European farms.
   f) The SMG encouraged combining characteristics when substantial similarity or overlap existed between characteristics.
   g) Concise definitions for the remaining characteristics were agreed and these were entered into an online tool ('ROODLE', EFSA AHAW Panel, 2017) to allow anonymous ranking by expert group members.
   h) Ranking of farm characteristics was undertaken by group members using the Roodle software. Ranking was conducted with the farm characteristic perceived to be the most useful risk-based indicator of on-farm poor welfare ranked first (rank = 1) to the least useful indicator ranked last (rank = 18).
   i) For each farm characteristic individual expert rankings were combined by calculating the total sum of the rank scores across experts. The summed rank scores were divided by the number of participants to produce a mean rank score for each characteristic. The five farm characteristics ranked highest were carried forward for consideration in the next stage of the elicitation. Since four farm characteristics had very similar summed rank values, an additional vote was taken by the expert group to decide on the fifth characteristic to be carried forward, in addition to the four characteristics with highest ranks.
   j) Notes were taken by the SMG, on key points/issues raised during the elicitation.

5.8.2.2. Phase 2: elicitation of welfare consequences and animal-based measures associated with selected farm characteristics

The five highest ranked farm characteristics were carried forward to Phase 2 of the elicitation, which is described below. Phases 2 and 3 were conducted at the physical group meeting in Parma on 25th and 26th October 2022 and completed online on 25th November 2022.

For each farm characteristic, welfare consequences that could be used to assess the degree of welfare impairment on a farm were elicited. For this elicitation, a list of potential welfare consequences had been pre-defined (based on the current EFSA list of welfare consequences, Appendix K Table K.2), although additional consequences could be added to the list if requested by expert group members.

For each farm characteristic, the elicitation procedure comprised an individual selection from the list of welfare consequences by each group member using the Roodle software. Each welfare consequence selected by $\geq$ 50% of participants was carried forward to be used in the subsequent elicitation steps. For each consequence selected, appropriate animal- and farm-based measures that could be used to evaluate the welfare consequence on-farm were identified. To achieve this, a list of animal-based measures (ABMs) was collated in advance, based on previous EFSA documentation detailing key ABMs for livestock welfare (Appendix K Table K.2). Further ABMs could be added by expert group members if requested.

For each ABM, a farm-level assessment was defined ('farm ABM'), which was a method to evaluate the animal-based measure at farm level; that is a method to measure and quantify the ABM for the herd as a whole. For example, if gait score was the animal-based measure for lameness, a farm ABM may be the proportion of cows in the herd with a gait score > 1. It was recognised that not all ABMs had a straightforward equivalent at farm-level. Hence, the final farm ABMs deemed suitable and feasible to evaluate each welfare consequence were decided by group discussion and agreement; these farm ABMs were carried forward to the next stage of the elicitation.

5.8.2.3. Phase 3: elicitation of consensus thresholds for farm ABMs to determine whether a farm would require corrective action

Having established farm-level ABMs that would be suitable to evaluate 'at risk' farms, a threshold value (the point at which the farm would be required to take corrective action) for each farm ABM was elicited. This was an elicitation with a numeric outcome (generally a herd level incidence or prevalence). Since literature on population distributions was lacking for several farm-level ABMs, an additional EKE procedure preceded the threshold elicitation. The additional elicitation was intended to establish expert knowledge on the distribution of farm ABM values across the EU dairy population.

The threshold elicitation was performed as follows:

I) For each ABM, a short introduction was given to the expert group by one expert with particular knowledge in the relevant area. The introduction covered: why this ABM was important, the ways it could be measured and a summary of literature on the topic including any information on farm-level values of the ABM.
II) The ABM was discussed by the expert group and agreement reached by consensus on the final definition of each ABM and the method of calculation of the equivalent farm-level ABM.
III) Considering each farm ABM individually, each expert was sequentially asked to write down a value for the farm-level ABM (i) that they believed would occur on farms with poor welfare (as defined in the documentation for the elicitation of farm characteristics in Phase 1), (ii) that they believed would occur on farms that implement best welfare practices and achieve the highest levels of cow welfare and (iii) that they believed would occur on 'average' farms implementing the currently most widespread practice in dairy farming. These were termed the 'upper', 'lower' and 'median' elicited values, respectively.

The upper, lower and median values for each farm ABM elicited from each group member were not shared between the group; individual experts entered their own values directly into a table in Sharepoint without seeing the judgements from other elicitation group members. Next, for each farm ABM, the three elicited quantities were shared between the group. At this stage, further discussions were encouraged, and experts were allowed to adjust their quantities if wanted.

Having individually considered these distributional characteristics of the farm ABM, each expert was asked to determine a threshold value for the ABM at which they believed the farm should undergo corrective action to improve cow welfare. That is the level of the farm ABM deemed to be unacceptable and at which additional action was required to improve welfare on-farm. Individual experts added their elicited threshold quantity to their table in Sharepoint and results of all elicited values were collated by the elicitation moderators. A final set of elicited quantities were collated once all experts were satisfied with their choices. The elicitation of farm ABM thresholds was conducted initially at the meeting in Parma on 26th October (with 7 expert group members participating) and completed during an online meeting on 25th November (with 8 expert group members participating).

5.8.3. Results

5.8.3.1. Results of phase 1: elicitation of farm characteristics

The results of the initial task of Phase 1, in which expert group members were asked to identify three to five farm characteristics deemed most likely to be indicative of, or associated with, poor dairy cow welfare, are presented in Appendix K Table K.2. Although in total 39 different characteristics were proposed, it was evident that there were similarities between experts' suggestions. Specifically, cow to cubicle ratio, cubicle comfort/design, space allowances for housed cows, access to pasture/outside areas and farmer attitudes were themes proposed by more than 2 experts.

At the face-to-face meeting in Parma, following extensive clarification and discussion of the initially proposed farm characteristics, a final list of characteristics, with agreed meanings, was collated with the experts (n = 7). Farm characteristics deemed not practical to measure were removed (e.g. those requiring too much time to be measured during a farm visit or requiring extended training of the assessors), and characteristics that were similar were combined by agreement into one unifying characteristic. The final list comprised 18 farm characteristics (Table 49) which were entered into the Roodle software for ranking. The overall rankings, determined from the sum of each individual's ranked score, are presented in Table 49.

Table 49: Final ranking of farm characteristics deemed to be most useful indicators of poor dairy cow welfare at farm level, based on individual ranked values by the group members. Individual ranking scores were between 1 (most useful) to 18 (least useful), therefore lower summed rank scores represent higher ranked farm characteristics. The summed rank score had a possible range between 7 (best rank) and 126 (lowest). Mean rank scores are normalised values and represent the average rank given to each characteristic by each expert

Farm characteristic	Sum Rank Score (ordered: most useful at the top)	Mean Rank Score (Total score divided number of experts (n = 7))
More cows than cubicles (> 1:1)	21	3.0
Limited space for housed cows (< 7 m^2/cow in total)	35	4.9
Inappropriate cubicle dimensions for cows in the herd (defined in Chapter 4)	47	6.6
High on-farm mortality including emergency slaughter (annual incidence including young stock)	49	7.0
No access to pasture for at least 2 months of the year	55	7.8
Cubicle base too hard or insufficient depth (15 cm) of bedding	55	7.9
Lack of access to outside space of at least 1 m^2/cow when housed	57	8.1
Insufficient feed space (65–70 cm per cow depending on breed)	58	8.3
High on farm cow mortality (Death or culling of adult cows in the first 100 days of lactation ≤ 4% per annum)	59	8.4
High somatic cell count (bulk milk > 300,000 cell/mL and > 10% of the cows > 400,000 cells/mL for 6 months/year)	75	10.6
Inadequate pain management (e.g. NSAIDs, sedatives) for routine procedures including disbudding, dehorning and castration	76	10.9
Inadequate procedures for regular foot trimming (at least once per lactation) or mobility scoring	76	10.9
High antimicrobial usage (> 17 mg/PCU - where PCU is a standardised population-corrected unit)	77	11.0
Farmer attitude towards health and welfare is inadequate (to be defined by survey)	81	11.5
Insufficient welfare training of staff – defined by attendance of specified courses on animal welfare	81	11.6
Low staff:cow (not quantified)	94	13.4
Herd calving interval too long (more than two consecutive years, above 400 days)	95	13.5
Inadequate cow tracks (not quantified)	110	15.6

The four characteristics with highest summed rankings (scores; 21, 35, 47, 49) were taken forward in the elicitation procedure. Characteristics ranked next (scores; 55, 56, 57, 58, 59) had similar total sum rank scores and a fifth characteristic was selected through an additional vote by expert group members. The additional characteristic to be included was ‘no access to pasture for at least 2 months of the year’.

Therefore, the characteristics, as briefly defined below, were carried forward to be used in the risk-based scheme and considered further in the elicitation:

1) Farms on which, at maximum stocking density, there are more cows than cubicles (i.e. a ratio of > 1:1)

Definition: Each separate cubicle building is evaluated (including those housing dry and hospital cows). The cow:cubicle ratio is calculated as; the maximum number of cows housed in a building at any time during the year divided by the total number of cubicles available in that building. If any building exceeds a ratio of 1:1, for any period of time, the farm is classed as 'at risk' for cow welfare.

2) Farms with a limited total space (including outdoor loafing areas) for housed cows ($< 7\ m^2$/cow)

Definition: Each separate building is evaluated (yards, cubicles, tie stalls) for each group of cows (including dry and hospital cows). The total space available to cows, at all times throughout the day is measured. This includes lying areas, indoor and outdoor loafing areas, passageways (including crossover passageways) and feeding areas. Collection yards used solely at milking times are not included unless they remain available to cows between milkings. The maximum number of cows that are placed in each building during the year is used. The space per cow is calculated as the total space available divided by the maximum number of cows for each building. If the space allowance in any building is $< 7\ m^2$/cow, for any period of time, the farm is classed as 'at risk' for cow welfare.

3) Farms on which cubicle dimensions are inappropriate

Definition: The length and width of each different type of cubicle on farm is measured and the cubicle with smallest dimensions considered further. The average cow height is estimated for the herd. If the length or width of the smallest cubicle is more than 10% shorter than that recommended for the relevant size of cow (as defined in Section 4.3.4), the farm is classed as 'at risk' for cow welfare. For example, for a head-to-head cubicle, the recommended length in metres is 1.8 × cow height. Therefore, for a herd with an average cow height of 144 cm, the recommended cubicle length is 2.59 m. If the length of the shortest cubicle on farm is less than (2.59 − (0.1 × 2.59)) = 2.33 m, the farm is classed as 'at risk' for cow welfare.

See Section 4.3.4 of this opinion for further details.

4) Farms that have a high on-farm mortality (including stock of all ages and given as a percentage of all the stock on farm over a 1-year period)

Definition: To calculate on farm mortality per annum the numerator is the number of cattle of all ages that die on-farm or are culled through emergency slaughter in a specified 12-month period. Young stock would be included from 48 h after birth (i.e. stillbirths not included). The denominator is the number of cattle-years (of any age) at risk on farm during the 12-month period. If the farm exceeds a specified threshold for annual mortality (see Section 5.8.3.1 for details of the threshold), the farm is classed as 'at risk' for cow welfare.

5) Farms that do not provide access to pasture for at least 60 days of the year

Definition: All lactating cows are required to spend at least 60 days of a calendar year at pasture, although not necessarily for a continuous period. The minimum daily time at pasture during the 60 days is 8 h. A farm not providing such access to pasture is classed as 'at risk' for cow welfare.

5.8.3.2. Results of phase 2: elicitation of welfare consequences and associated animal- and farm-based measures

Results of the elicitation of the welfare consequences and the animal- and farm-based measures associated with each of the five selected farm characteristics are provided below.

FARM CHARACTERISTIC 1: Farms on which, at maximum stocking density, there are more cows than cubicles (i.e. a ratio of > 1:1)

A summary of voting by the expert group for welfare consequences associated with this farm characteristic is provided in Table 50.

Table 50: Selected welfare consequences for farm characteristic 1; more cows than cubicles (shading indicates a majority voted to include the consequence, which was then carried forward)

Welfare consequence	Number of experts (n = 7) that voted to include
Resting problems	6
Group OR handling OR sensory stressors	5
Locomotory disorders	5
Inability to perform comfort behaviour	3
Mastitis	3
Skin or soft tissue damage	3
Inability to perform play behaviour	1
Musculoskeletal disorders	1
Reproduction-related stressors	1
Restriction of movement	1

The ABMs that were agreed to be used to evaluate the selected welfare consequences for farms on which there are more cows than cubicles, are summarised in Table 51.

Table 51: Farm level animal-based measures selected to evaluate welfare consequences associated with farms on which there are more cows than cubicles

Welfare Consequence	Farm level animal-based measure
Resting problems	Hygiene score (% cows with belly score 4; Hughes, 2001; Ruud et al., 2010)
Group, handling or sensory stress	Average occurrence of agonistic interactions in the lying area, e.g. displacements, per cow per hour (Welfare Quality, 2009)
Locomotory disorders	Lameness (gait) scoring; % cows lame (score > 1; Welfare Quality, 2009; Amory et al., 2006)

FARM CHARACTERISTIC 2: Farms on which there is limited total space, < 7 m^2/cow, for housed cows

A summary of voting by the expert group for welfare consequences associated with this farm characteristic is provided in Table 52.

Table 52: Selected welfare consequences for farm characteristic 2; farms with limited space for housed cows (shading indicates a majority voted to include the consequence which was then carried forward)

Welfare consequence	Number of experts (n = 7) that voted to include
Restriction of movement	7
Group, handling or sensory stress	6
Inability to perform feed- and exploration-related behaviours	5
Locomotory disorders	5
Inability to perform comfort behaviour	4
Inability to perform play behaviour	3
Resting problems	3
Skin or soft tissue damage	3
Mastitis	2
Musculoskeletal disorders	2
Reproduction-related stressors	2
Gastro-enteric or Respiratory disorders	1
Metabolic disorders	1
Prolonged hunger OR thirst	1
Thermoregulatory Stress	1

The ABMs that were agreed to be used to best evaluate the selected welfare consequences for farms with limited space (< 7 m^2/cow), are summarised in Table 53.

Table 53: Farm level animal-based measures selected to evaluate welfare consequences associated with farms with limited space

Welfare consequence	Farm level animal-based measure
Restriction of movement	No feasible ABM identified
Group, handling or sensory stressors	Observational scoring of agonistic interactions in the whole area, e.g. head butts, displacements, per cow per h (Welfare Quality, 2009)
Inability to perform feed- and exploration-related behaviours	Observational scoring of agonistic interactions in the feed area, e.g. displacement from the feeder and drinkers, per cow per h (Welfare Quality, 2009)
Locomotory disorders	Lameness (gait) scoring; % cows lame (score >1; Welfare Quality, 2009; Amory et al., 2006)

FARM CHARACTERISTIC 3: Farms on which cubicle dimensions are inappropriate

A summary of voting by the expert group for welfare consequences associated with this farm characteristic is provided in Table 54.

Table 54: Selected welfare consequences for farm characteristic 3; farms on which cubicle dimensions are inappropriate (shading indicates a majority voted to include the consequence which was then carried forward)

Welfare consequence	Number of experts (n = 7) that voted to include
Resting problems	7
Skin or soft tissue damage	7
Locomotory disorders	6
Musculoskeletal disorders	3
Restriction of movement	3
Mastitis	2
Inability to perform comfort behaviour	1

The ABMs that were agreed to be used to best evaluate the selected welfare consequences for farms on which cubicle dimensions are inappropriate, are summarised in Table 55. In addition, for resting problems, ABMs for lying behaviour and perching behaviour were considered suitable but discarded because of a lack of feasibility of measurement on-farm.

Table 55: Farm level animal-based measures selected to evaluate welfare consequences associated with farms on which cubicle dimensions are inappropriate

Welfare consequence	Farm level animal-based measure
Resting problems	Hygiene score (% cows with belly score 4; Ruud et al., 2010)
	% of cows showing deviations from normal rising behaviour (Schenkenfelder and Winckler, 2021)
Skin or soft tissue damage	% of cows with lesions/swellings (Welfare Quality, 2009)
Locomotory disorders	Lameness (gait) scoring; % cows lame (score > 1; Welfare Quality, 2009; Amory et al., 2006)

FARM CHARACTERISTIC 4: Farms that have a high on-farm mortality

For this farm characteristic, the expert group decided that a direct evaluation of on-farm mortality was possible and an indirect ABM was therefore unnecessary. The percentage of cattle of all ages that died or underwent emergency slaughter on-farm per annum was therefore carried forward to be considered as a farm-level animal-based measure for the final stage of the elicitation.

FARM CHARACTERISTIC 5: Farms that do not provide access to pasture for at least 2 months of the year

A summary of voting by the expert group for welfare consequences associated with this farm characteristic is provided in Table 56.

Table 56: Selected welfare consequences for farm characteristic 5; farms that do not provide access to pasture for at least 2 months of the year (shading indicates a majority voted to include the consequence which was then carried forward)

Welfare consequence	Number of experts (n = 7) that voted to include
Locomotory disorders	6
Restriction of movement	6
Inability to perform feed- and exploration-related behaviours	4
Resting problems	4
Skin or soft tissue damage	4
Gastro-enteric OR Respiratory disorders	2
Group OR handling OR sensory stressors	2
Inability to perform comfort behaviour	2
Mastitis	2
Metabolic disorders	2
Prolonged hunger OR thirst	2
Thermoregulatory Stress	2
Inability to perform play behaviour	1
Musculoskeletal disorders	1
Reproduction-related stressors	1

The ABMs that were agreed to be used to best evaluate the selected welfare consequences for farms that do not provide access to pasture for at least 2 months of the year, are summarised in Table 57. In addition, for resting problems, lateral lying behaviour was considered suitable as an ABM but was discarded because of a lack of feasibility of measurement on-farm.

Table 57: Farm level animal-based measures selected to evaluate welfare consequences associated with farms that do not provide access to pasture for at least 2 months of the year

Welfare consequence	Farm level animal-based measure
Locomotory disorders	Lameness (mobility) scoring; % cows lame (score > 1; Welfare Quality, 2009; Amory et al., 2006)
Restriction of movement	No feasible ABM identified
Inability to perform feed- and exploration-related behaviours	No feasible ABM identified
Resting problems	No feasible ABM identified
Skin or soft tissue damage	% of cows with lesions/swellings (Welfare Quality, 2009)

5.8.3.3. Results of phase 3: elicitation of the ABM thresholds for corrective action

For each of the ABMs selected above, a thorough discussion took place, after which consensus on a clear definition and a method to measure the ABMs at farm level was reached. The final definitions used are summarised in Table 58.

Table 58: Definitions of the ABM scoring systems and farm-level measurement used to evaluate whether a farm would require corrective action

ABM	Outline of scoring system	Farm-level measurement
Whole farm annual mortality score	The number of animals that die or are culled through emergency slaughter on farm over a 1-year period, excluding stillbirths, divided by the number of animal-years at risk in that period. Data would be collated from national birth-death recording systems and calculated electronically. Final value calculated as a percentage.	% of cows that die or are culled on-farm per annum; continuous scale
Abdomen hygiene score	A hygiene score based on that reported in Ruud et al. (2010). The number of cows with an abdominal hygiene score of 4 (very dirty) is recorded. Final value calculated as the percentage of cows that score 4 on the day of assessment[(a)].	% of cows with a belly hygiene score = 4; continuous scale
Lameness score	Gait scoring using a 3-point system (e.g. Welfare Quality, 2009; Amory et al., 2006; 1 = sound, 2 = moderately lame, 3 = severely lame). Final value calculated as the percentage of cows that score >1 on the day of assessment[(a)].	% of cows with a gait score > 1; continuous scale
Lesions/ integument alteration score	Visual assessment of one side of the body (head/ears, shoulders/back/neck, tarsus including hocks, hindquarter, carpus, flank/side/udder, tail) according to Welfare Quality (2009). Score 0: The cow has no lesion (> 2 cm), no swelling on all body parts, although it might have a hairless patch Score 1: at least one body part of the cow has at least one lesion or one swelling. Final value calculated as the percentage of cows that score 1 on the day of assessment[(a)].	% of cows with score = 1; continuous scale
Rising behaviour score	Lying animals are gently encouraged to stand up, and rising behaviour is scored as either Score 0: regular (no deviations from normal standing up, fluid movement), or Score 1: deviated (break: resting ≥ 3 s on carpal joint counted from the moment when they have stretched the hind legs – kneeling; difficulties: repeated lunging, colliding with housing equipment; or abnormal: deviation from normal standing up, e.g. horse-like rising (Schenkenfelder and Winckler, 2021). Final value calculated as the percentage of cows that score 1 on the day of assessment[(a)].	% of cows with score 1; continuous scale
Number of agonistic interactions in the feed area	Continuous behaviour sampling (Bateson and Martin, 2021) of displacements in the feed area (i.e. cow is forced by another cow to leave the feeding place/step aside by one cow width, Winckler et al., 2015)) for in total 1 h, starting after morning milking (at least 75% of cows back from milking). Cows in oestrus should be excluded from the assessment. Observations may also be split into periods of minimum 10 min in representative segments of the feed bunk. The number of animals in the (respective) feed area(s) must be counted before and after the observations. Final value calculated as the number of displacements occurring divided by the average number of cows present in the feed area (on a per hour basis).	Number of displacements per cow per hour that occur in the feeding area; continuous scale

ABM	Outline of scoring system	Farm-level measurement
Number of agonistic interactions in the lying area	Continuous behaviour sampling of displacements in the lying area (i.e. cow that is either standing or lying is forced to leave the cubicle by another cow; Winckler et al., 2015) for in total 1 h, starting approx. 1 h after morning milking. Cows in oestrus should be excluded from the assessment. Observations may also be split into periods of minimum 10 min in representative segments of the pen(s). The number of animals in the (respective) lying area(s) needs to be counted before and after the observations. Observations may be combined with the assessment of agonistic interactions in the whole area by recording where displacements occur (i.e. lying area, remainder of the housed area). Final value calculated as the number of displacements occurring divided by the average number of cows present in the lying area (on a per hour basis).	Number of displacements per cow per hour that occur in the lying area; continuous scale
Number of agonistic interactions in the whole area	Continuous behaviour sampling of displacements in the whole housed area (i.e. cow that is either displaced from the lying area, walks away by half a cow length or steps aside by one cow width after forceful physical contact; Winckler et al., 2015; Welfare Quality, 2009) for in total 1 h, starting 1 h after morning milking. Cows in oestrus should be excluded from the assessment. Observations may also be split into periods of minimum 10 min in representative segments of the pen(s). The number of animals in the (respective) area(s) needs to be counted before and after the observations. Final value calculated as the number of displacements occurring in the whole housed area divided by the average number of cows present (on a per hour basis).	Number of displacements per cow per hour that occur in the whole area; continuous scale

(a): In herds up to 30 cows, all animals should be assessed, including those in hospital or maternity pens. In larger herds, a representative sample is scored (including a sample from hospital and maternity pens).

Sample size can be calculated using the following formulae (Cochran, 1977):

1) Sample size for an infinite population n_{inf}:

$$n_{inf} = \frac{(P) * (1-P) * Z^2}{d^2}$$

P = estimated prevalence (as a decimal; e.g. 0.5 for a worst-case scenario).
Z = degree of confidence in estimate, e.g. 1.96 for 95% confidence.
d = desired absolute precision, i.e. maximum difference between observed and true prevalence that is accepted (as decimal; e.g. 0.05 for +/– 5%).

2) Sample adjusted for a finite population n_{fin}:

$$n_{fin} = \frac{n_{inf}}{1 + (n_{inf}-1)/N}$$

N = finite population, i.e. herd size in a given farm.

A summary across experts of the elicited values for each farm ABM is presented in Table 59. The low values of each ABM (i.e. the value of the ABM on dairy farms considered to implement best welfare practices), the high values (i.e. the value of the ABM on dairy farms considered to have the poorest welfare) and the threshold values (i.e. the value of the ABM above which the farm would require corrective action) are reported in the table. Graphs in Appendix C (Figure 6.1a–g) illustrate the corresponding distributions of the elicited individual experts' values.

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Table 59: Summary of the expert elicited distributions for farm-level ABMs. ABMs were elicited for farms (i) that were implementing best welfare practices (low), (ii) that were considered to have the poorest welfare practices (high) and (iii) that should have corrective action to improve cow welfare

Farm-level animal-based measure	Distributional characteristics of the elicited threshold across experts		
	Lower quartile	Median	Upper quartile
Whole farm annual mortality (%): low (best practice)	1	1	1.5
Whole farm annual mortality (%): high (poorest practice)	12	15	16.5
Whole farm annual mortality (%): threshold (corrective action)	7.75	8	9.5
Abdomen hygiene score (% score = 4): low (best practice)	0	0	0.05
Abdomen hygiene score (% score = 4): high (poorest practice)	7.5	10	17.5
Abdomen hygiene score (% score = 4): threshold (corrective action)	3	4	4
Lameness (gait) score (% score > 1): low (best practice)	5	5	5.5
Lameness (gait) score (% score > 1): high (poorest practice)	42.5	45	55
Lameness (gait) score (% score > 1): threshold (corrective action)	20	25	30
Integument alterations (% score = 1): low (best practice)	0.5	2.5	3
Integument alterations (% score = 1): high (poorest practice)	57.5	62.5	65.25
Integument alterations (% score = 1): threshold (corrective action)	15	15	20
Rising behaviour score (% score = 1): low (best practice)	1	1	1.5
Rising behaviour score (% score = 1): high (poorest practice)	35	40	47.5
Rising behaviour score (% score = 1): threshold (corrective action)	11.5	13.5	15
Agonistic interactions in feed area (number/cow/h): low (best practice)	0.025[(a)]	0.2[(a)]	0.3[(a)]
Agonistic interactions in feed area (number/cow/h): high (poorest practice)	3.75[(a)]	5[(a)]	6[(a)]
Agonistic interactions in feed area (number/cow/h): threshold (corrective action)	1[(a)]	1.25[(a)]	1.5[(a)]
Agonistic interactions in lying area (number/cow/h): low (best practice)	0.0075[(a)]	0.01[(a)]	0.0625[(a)]
Agonistic interactions in lying area (number/cow/h): high (poorest practice)	0.2625[(a)]	0.4[(a)]	0.5[(a)]
Agonistic interactions in lying area (number/cow/h): threshold (corrective action)	0.05[(a)]	0.09[(a)]	0.125[(a)]
Agonistic interactions in whole area (number/cow/h): low (best practice)	0.04[(a)]	0.225[(a)]	0.3[(a)]
Agonistic interactions in whole area (number/cow/h): high (poorest practice)	5[(a)]	6.5[(a)]	7.125[(a)]
Agonistic interactions in whole area (number/cow/h): threshold (corrective action)	1[(a)]	1.65[(a)]	2.125[(a)]

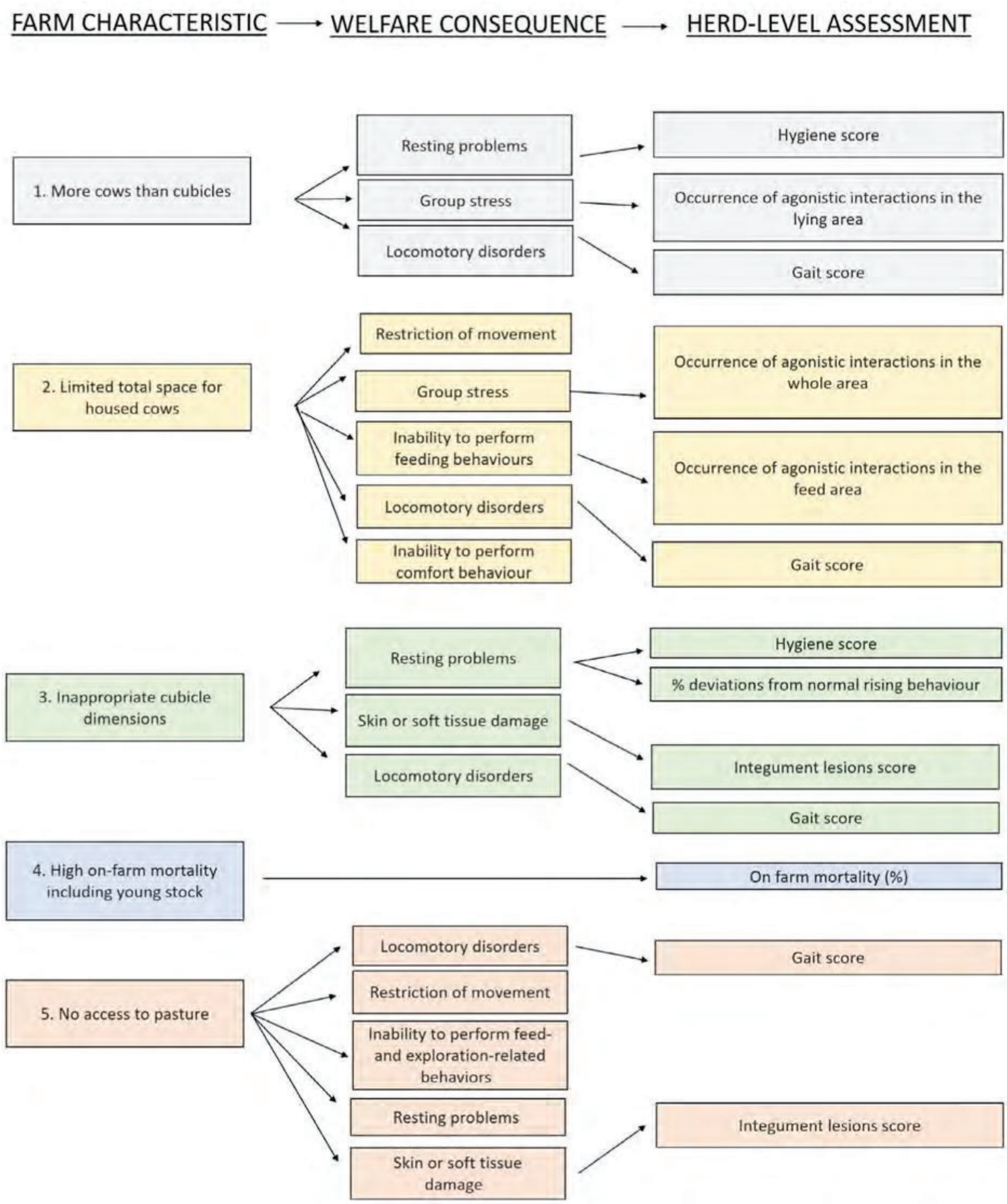
(a): For agonistic interactions, a value of 1.0 means, that on average each cow is displaced once per hour. Likewise, a value of 0.05 indicates that 5 out of 100 cows are displaced from the cubicles within 1 hour.

It should be noted from the distributional characteristics of the elicited thresholds (Table 59) that there was relatively large variation between experts in the behavioural thresholds (agonistic interactions); this was consistent with the discussions that occurred, in which many experts expressed difficulty in evaluating these ABMs. Conversely, variability in the thresholds for mortality, hygiene score, integument score and abnormal rising behaviour were relatively small suggesting more confidence in the assessment of these farm-level measures.

In summary for each farm ABM the median value of the elicited threshold presented in Table 59 provides an EKE-based threshold suitable to define when 'at risk' farms will require corrective action in the risk-based welfare scheme. Although some variability between experts occurred, particularly in behavioural ABMs, the median values represent a reasonable starting point for taking the scheme forward. It is noteworthy that, for some farm ABMs, the median value for the threshold was similar to or just below that elicited for the median farm.

5.8.3.4. Diagrammatic summary on the elicited risk-bask scheme

An outline summary of the final elicited risk-based scheme is presented graphically in Figure 10. The scheme contained 5 farm characteristics with 13 linked ABMs. It is important to note that any farm with at least one characteristic present would have a welfare evaluation carried out and this evaluation would be based only on the herd-level assessment criteria linked to the characteristic(s) present. Therefore, the number of herd-level assessments to be conducted on 'at risk' farms would depend on the number of characteristics present as shown in Figure 5.



Farm characteristics (left side) are considered to lead to specified welfare consequences (central panel) which would be evaluated at herd level using the assessment criteria (right side). Where no herd-level assessment is present, it was deemed by the expert group that no suitable animal or herd-based measures were available/feasible for that specific farm characteristic.

Figure 10: Diagrammatic summary of the elicited risk-based scheme to identify and assess European dairy farms at high risk of poor welfare

6. Conclusions

The certainty of each conclusion statement was assessed following the method described in Section 3.2.2. When a certainty category is added at the end of a paragraph, it is considered that it applies to all sentences within that paragraph.

6.1. Conclusions for assessment 1: most common housing systems for dairy cows (prevalence, strengths, weaknesses and hazards)

1) The most prevalent housing systems in the EU are cubicle (free-stall) housings, followed by open-bedded systems and tie-stalls. Open-bedded systems may also be found in combination with cubicle housing systems (90–100% certainty).
2) The proportion of farms offering access to pasture has declined in several EU MSs in the last decades, with an increasing number of farms converting to zero-grazing housing systems. Currently, the number of grazing days per year varies markedly between and within countries (90–100% certainty).
3) Welfare outcomes vary between farms using any particular housing system. Therefore, the impact on animal welfare of each housing system is highly variable and affected by the quality of the physical environment and management on a specific farm. However, there is substantive evidence that cows permanently tied in stalls have impaired welfare due to behavioural restriction compared to loose-housing systems (90–100% certainty).

Tie-stalls (referred to their use as a permanent system)

4) Strengths of tie-stalls are the potential for reduced prevalence of certain claw disorders and of agonistic interactions within the herd (90–100% certainty).
5) Weaknesses of tie-stalls are the following potential welfare consequences: restriction of movement and consequently the ability to perform comfort, social, oestrus and maternal behaviours including natural pre-partum and calving behaviour. Tie-stalls also cause resting problems (90–100% certainty).
6) The main hazards in tie-stalls are the duration of tethering, the adequacy of tethering design, the dimensions of the stalls and the characteristics of the lying surface. If the tether design is inadequate (too short neck chain or poorly positioned neck rails), the stalls are too short or narrow, or the lying surfaces are not or only little deformable, the resting behaviour of cows is particularly inhibited and the risk of integument alterations increases (90–100% certainty).

Cubicle housing systems

7) Strengths of cubicles are the potential for clean animals and for good udder health (90–100% certainty).
8) Weaknesses of cubicles are the following potential welfare consequences: reduced comfort around resting (difficulties in lying and lying down/rising up movements), claw disorders and lameness and integument alterations (see Section 7.2) (90–100% certainty).
9) The main hazards for reduced cow welfare in cubicle housing systems are a non-deformable lying surface including shallow bedding, inappropriate dimensions and design of the cubicles including positioning of cubicle fittings, rough or slippery flooring in the alleys, low total space allowance and overstocking at the cubicle (90–100% certainty).

Open-bedded systems

1) Strengths are the potential for comfort around resting (natural lying and lying behaviours), good claw health and locomotion, leg and joint health. Some open-bedded systems also offer great space allowance, leading to improved possibility for social interactions and less competition (90–100% certainty).
2) Weaknesses of open bedded systems (straw-bedded and compost-bedded open systems) are the following potential welfare consequences: mastitis and skin disorders associated with soiling (90–100% certainty).
3) The main hazards in open-bedded systems are poor hygiene of the lying areas and a low space allowance per cow (90–100% certainty).
4) Maintaining adequate cow cleanliness in straw yards requires higher quality of management and a larger amount of bedding compared to cubicles (90–100% certainty).

Systems with outdoor area or pasture

1) Strengths of systems with access to loafing area are the potential for thermoregulation, exercise and loafing space for the cows, few agonistic interactions with conspecifics,

increased lying behaviour and lower prevalence of horn-related integument damage (90–100% certainty).
2) Weakness of systems with access to loafing area is the welfare consequence claw disorders (90–100% certainty).
3) The main hazards for reduced cow welfare in systems with access to loafing area are: poor hygienic conditions and lack of shelter in extreme climatic conditions (90–100% certainty).
4) Strengths of managing cows at pasture are the potential for good claw health and locomotion (e.g. low dermatitis and heel horn erosion incidence), good udder health, good fertility, improved comfort around resting, more natural behaviours and good skin conditions and exposure to fresh air and sunlight (90–100% certainty).
5) Weaknesses of managing cows at pasture are the following potential welfare consequences: thermal stress, parasitoses, metabolic disorders, certain locomotory and claw disorders (e.g. sole ulcers) (90–100% certainty).
6) The main hazards for reduced welfare in managing cows at pasture are: insufficient shelter from adverse climatic conditions, insufficient access to water, insufficient or discontinuous nutrient supply, inadequate parasite control, poorly maintained walking tracks or roads and rushing cattle while walking (90–100% certainty).
7) Cows that have access to the outdoors choose to spend more of their time on pasture compared to indoors, except in inclement weather (90–100% certainty).

6.2. Conclusions for assessment 2: welfare consequences (prevalence in different housing systems, comparison among systems, ABMs, hazards and preventive measures)

6.2.1. Locomotory disorders

Description of the WC

1) Lameness is one of the major welfare issues in dairy cows, and is often associated with pain and reduced ability to perform natural behaviour (90–100% certainty).

ABMs

1) Gait scoring systems are feasible ABMs to identify and score lameness (66–100% certainty).
2) Foot lesion scoring is an emerging ABM for lameness monitoring and is used for identifying major lesion types (66–100% certainty).

System comparison

3) There is no clear evidence that one housing system is consistently better in terms of lameness reduction. Foot and leg disorders are multifactorial, resulting from interactions between the farm environment, management, nutrition and animal characteristics including genetic background, age and lactation stage (66–100% certainty).
4) Temporary access to pasture is associated with a lower prevalence of integument damage compared to zero-grazing systems (66–100% certainty).
5) Cubicles with shallow beds or mats (i.e. bedding less than 30 cm on concrete surfaces or less than 5 cm of compressed material on mats (compressed as a result of the animal lying on it) are associated with an increased risk of claw disorders and a higher prevalence of lameness compared to a pasture-based systems (90–100% certainty).

Hazards within housing systems

6) An appropriate design of the lying area(s) and cubicle furniture that accounts for the size of the cow ensures lying comfort, freedom of lying behaviour (natural postural changes) (certainty > 90%) and minimisation of risk of foot and leg injuries (66–100% certainty).
7) Improved lying comfort through provision of dry, soft and deformable lying surfaces reduces standing/walking time and reduces the incidence of lameness (50–100% certainty).
8) Cubicles with shallow beds or mats are associated with an increased risk of claw disorders and a higher prevalence of lameness, compared to year-round housing in deep-bedded cubicles (90–100% certainty).

9) Walking and standing surfaces that are clean, dry, non-slip and without sharp edges minimise lameness (66–100% certainty).
10) Tracks for pasture access that are even surfaced and free from stones and debris minimise lameness (66–100% certainty).

6.2.2. Mastitis

Description of the WC

1) Mastitis is a disease, characterised by inflammation of the mammary gland commonly caused by an intramammary infection (IMI), mainly bacterial. The condition can be divided into clinical mastitis (i.e. associated with visual clinical signs) and subclinical mastitis, despite there is no respective definition of the two types. Clinical mastitis affects dairy cow welfare due to the painfulness of the condition and associated changes in behaviour. The welfare relevance of subclinical mastitis is unknown.

ABMs

2) Suitable ABMs for mastitis are the incidence rate of clinical disease and routine (monthly or daily in case of automatic milking systems) measurement of individual cow somatic cell counts (90–100% certainty).

System comparison

3) Mastitis is a multifactorial disease, the hazards of which are diverse and no housing system (including pasture access) has been consistently identified as superior to others with regards to the incidence or prevalence of mastitis (90–100% certainty).

Hazards specific to housing systems

4) A multitude of hazards for mastitis exist and these relate to aspects of farm management (e.g. milking-related, cow-related, farm-related, calving-related and farmer-related) rather than to housing system (90–100% certainty).
5) Type of bedding is the only housing-related hazard associated with mastitis prevalence. Cows housed in sand-bedded cubicles have lower somatic cell counts than those housed in cubicles with organic bedding materials (66–100% certainty).

6.2.3. Restriction of movement and resting problems

Description of the WC

1) Restriction of movement refers to the inability of the animal to move freely or walk comfortably due to e.g. restrictive space allowance or inadequate floor properties resulting in pain, discomfort or frustration.
2) Closely related to restriction of movement are resting problems due to inadequate design and properties of the lying area resulting in the cow's inability to lie or rest comfortably, or to perform unimpaired lying down or rising up movements.

ABMs

3) Feasible ABMs for restriction of movement and resting problems are gait score, hygiene score, lesion score. More sensitive and specific measures are the observation of deviations from normal lying down and rising up movements and agonistic interactions, but they are more time consuming and therefore less feasible (90–100% certainty).

System comparison

4) Restriction of movement in dairy farming is related to the housing system itself, to the design and features of particular housing systems, to the stocking densities and to the extent of outdoor access (90–100% certainty).
5) In terms of level of restriction, the different housing systems are ranked as follows: year-round tethering, which is particularly restrictive, followed by cubicle housing systems and open-bedded systems and finally pasture, which is the least restrictive (90–100% certainty).

6) Tethering imposes severe restriction of movement. Compared to loose-housing systems, it particularly restricts lying down and rising up movements, lying postures, oestrus, calving and social behaviour (90–100% certainty).
7) Both tie-stalls and cubicles are associated with more resting problems and restriction of the lying down and rising up movement compared to open-bedded systems (straw, compost or dry manure bedded-packs), in particular when the size of stalls and cubicles are inappropriate for the size of the cows (90–100% certainty).

<u>Hazards specific to housing systems</u>

8) Tethering is associated with resting problems (restricts lying postures and lying down and rising up movements) and more so when combined with hard lying surfaces (90–100% certainty).
9) Providing tethered cows with regular access to outdoor areas is beneficial in terms of opportunity for locomotion, grooming and social behaviour (90–100% certainty).
10) When cows are tethered, it is not possible to completely mitigate restriction of movement by changing other aspects of their environment e.g. providing a soft lying surface or ample feeding space per cow (90–100% certainty).
11) Hard surfaces (in the stall or cubicle) are associated with problems in lying down and rising up, as well as reduced lying time. Slippery surfaces are also associated with problems in lying down and rising up (90–100% certainty).
12) Beddings less than 30 cm thick (when placed on bare concrete) or less than 5 cm thick (when placed on the top of mats or mattresses) are not appropriate lying surfaces (90–100% certainty).
13) High stocking densities (more than 1.2 cows per cubicle) have been shown to reduce dairy cow lying time. Other types of behaviour are negatively affected at stocking densities lower than 1.2 cows per cubicle (e.g. less synchronous lying behaviour, more agonistic behaviour) (90–100% certainty).
14) There are few data on the relationship between space allowance (m^2/animal) and dairy cow welfare. However, increasing total space increases cow lying time (66–100% certainty).
15) In cubicle housing systems, locomotion is restricted by the building layout (e.g. number of dead-ends) (90–100% certainty).
16) In cubicle housing systems, the quality of the floor in the alleys affects ease of movement and non-slip surfaces, such as deformable rubber flooring, improve gait characteristics such as walking speed and stride length compared to concrete (90–100% certainty).
17) Access to well-managed outdoor areas (i.e. non-slip floors) offer opportunities for locomotion; and access to pasture offers even better opportunity for locomotion. Access to well-managed pasture (i.e. well-drained, provision of shade, protection from inclement weather) offers additional opportunities to lie comfortably and to express synchronous lying behaviour. Especially compared to tethered or cubicle housing, it offers better opportunities for adopting lateral lying postures and unrestricted lying down and rising up movements (90–100% certainty).
18) Open-bedded housing better allows the expression of natural lying postures compared to tie-stalls and cubicles (66–100% certainty).
19) Access to an indoor or outdoor loafing area partially mitigates the cow restriction of movement associated with tie-stalls (66–100% certainty).

6.2.4. Inability to perform comfort behaviour

<u>Description of the WC</u>

1) Comfort behaviour of dairy cows includes self-grooming by use of tongue, hooves, horns or tail, or objects (e.g. pen fixtures or cow brushes). The function of self-grooming is to maintain the integument, but allo-grooming (e.g. licking a conspecific) also has functions in relation to social behaviour (90–100% certainty).

<u>ABMs</u>

1) ABMs for the inability to perform comfort behaviour are self-grooming, allo-grooming and brush use, but they all require long term observations (90–100% certainty).

System comparison

3) Cubicle housing systems are associated with better hygiene and cow cleanliness compared to tie-stalls (50–100% certainty) and open-bedded systems (66–100% certainty).

Hazards specific to housing systems

4) Tethering thwarts the ability to perform self-grooming (90–100% certainty).
5) Motivation for self-grooming builds up with time when ability to perform the behaviour is restricted. This is a particular problem in tethered cows where rebound effects are observed (90–100% certainty).
6) A slippery concrete floor inhibits self-grooming. This is most problematic in cubicle housing systems where self-grooming cannot take place in the lying area (90–100% certainty).
7) The use of a brush allows the cows to groom body parts not easily reachable compared to the use of pen fixtures or self-grooming actions by the cow (90–100% certainty).
8) Access to brushes is affected by competition. However, there are no studies on the welfare effects of ratio of cows per brush or brush type (90–100% certainty).
9) Cows display fewer allo-grooming interactions when space is reduced in cubicle barns (66–100% certainty) and when unfamiliar animals are mixed (90–100% certainty).
10) Deep-bedded compared to shallow-bedded (or matted) cubicles provide more comfort during resting but require a larger amount of bedding material to maintain hygienic conditions and a comfortable lying surface (90–100% certainty).
11) In year-round pasture systems (i.e. where cows are permanently kept outdoors all seasons) reduced lying times are observed when lying surfaces are wet and or muddy (90–100% certainty).

6.2.5. Metabolic disorders

Description of the WC

1) The metabolic disorders investigated, ketosis, subacute ruminal acidosis, displaced abomasum and hypocalcaemia (milk fever) commonly occur during the peripartum period or in early lactation. Although aetiologies differ, a variety of feeding and farm management practices are associated with an increased risk of these metabolic disorders (90–100% certainty).
2) Metabolic disorders are commonly interrelated. They can be a primary cause of disease but can also be secondary or a precursor to other pathological conditions (90–100% certainty).
3) Sub-clinical forms of ketosis, ruminal acidosis and hypocalcaemia are more prevalent than the clinical forms of the disease (66–100% certainty).

ABMs

4) No single ABM is suitable for all metabolic disorders (90–100% certainty).
5) Suitable ABMs for the occurrence of metabolic disorders are the incidence rate of clinical cases (66–100% certainty).
6) For subclinical ketosis individual cow beta-hydroxybutyrate (in blood) or ketones levels (in milk or urine) are feasible ABMs (90–100% certainty).
7) Except for subclinical ketosis, ABMs for subclinical metabolic disorders are either unfeasible for regular on-farm monitoring or have insufficient sensitivity and specificity to be of practical value (66–100% certainty).
8) Body condition scoring in the dry period (BCS > 3.5 on a 5-point scale) is a useful proxy ABM for metabolic disease since over-conditioned cows are at increased risk of reduced dry matter intakes and metabolic disorders.

System comparison

9) There is no clear evidence that one housing system is consistently superior to another in terms of the incidence or prevalence of metabolic disorders (90–100% certainty).

Hazards specific to housing systems

10) Metabolic diseases are linked to diet composition and feeding management rather than housing system. However, housing systems predispose to metabolic diseases if they affect

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the appropriate feeding of cows or predispose to disorders that affect feeding (e.g. lameness) (90–100% certainty).

6.3. Conclusions for assessment 3: farm characteristics to classify farms at risk of poor welfare

1) There are currently no readily available farm data associated with cow welfare to be useful as farm-level risk-based indicators for poor welfare on-farm (90–100% certainty).
2) In development of a risk-based monitoring approach, five farm characteristics were selected by expert opinion for identification of dairy farms at high risk of poor welfare. In order of importance attributed by the experts, these characteristics were: (1) farms with more than one cow per cubicle at maximum stocking rate, (2) farms with a limited total space for housed cows ($< 7m^2$/cow), (3) farms on which cubicle dimensions are inappropriate for the size of the cows, (4) farms with high on-farm mortality (including emergency slaughter) rates and (5) farms on which cows have less than 2 months per year with access to pasture (66–100% certainty).
3) Cows on farms deemed to be at risk of poor welfare are likely to experience related welfare consequences (90–100% certainty). For farms with each of the characteristics identified above, welfare consequences can be assessed using specific farm-level assessments (using animal-based measures) (90–100% certainty). The farm-level assessments are:

   a) On farms where there are more cows than cubicles ($>$ 1:1) - the assessments are hygiene score, occurrence of agonistic interactions in the lying area and lameness (gait) scoring.
   b) On farms where there is limited total space (including outdoor loafing areas) for housed cows ($< 7\,m^2$/cow) - the assessments are observational scoring of agonistic interactions in the whole area, observational scoring of agonistic interactions in the feed area and lameness (gait) scoring.
   c) On farms where cubicle dimensions are inappropriate - the assessments are hygiene score, deviations from normal rising behaviour, integument lesion score and lameness (gait) scoring.
   d) On farms where there is high annual on-farm mortality (i.e. more than 8% including emergency slaughter) – this farm characteristic is directly measurable and would itself be used as the method of farm assessment.
   e) On farms where cows do not have access to pasture for at least 2 months of the year - the assessments are lameness (gait) scoring and integument lesion score.

4) For all these ABMs, definitions and scoring methods have been identified and are provided in the opinion (see Section 5.8.3.3).

7. Recommendations

7.1. Recommendations for assessment 1: most common housing systems for dairy cows

Recommendations about housing systems are included in the recommendations for Assessment 2 since they mainly regard measures to prevent the specific welfare consequences under assessment.

7.2. Recommendations for assessment 2: welfare consequences, hazards and preventive measures

7.2.1. Locomotory disorders

1) A recommended mitigation strategy includes regular gait scoring with early treatment of lame cows.
2) Whilst there are a variety of systems, the use of a 3-point scale is sufficient to monitor lameness in practice.
3) The ICAR claw health atlas[19] should be used to monitor claw disorders in dairy cows.

[19] Atlas claw health and translations | ICAR

4) Dimensions and design of the lying area(s) and cubicle furniture should match the size of the cow ensuring that comfort is optimised, freedom of lying behaviour (natural postural changes) is allowed and risk of injury is minimised.
5) Dairy cows should be provided with dry, soft and deformable lying surfaces (see recommendation in Section 7.2.3).
6) Walking and standing surface should be clean, dry, non-slip and avoiding sharp edges. Tracks for pasture access should be suitable for long-distance walking (e.g. even surfaced, free from stones and debris).

7.2.2. Mastitis

1) Udder health should be routinely monitored on-farm using both the incidence rate of clinical mastitis and individual cow somatic cell counts in order to timely take appropriate management decisions.
2) Assessment of key management-related mastitis hazards should be undertaken regularly and a farm-specific plan for the control, including treatment and prevention of mastitis, formulated, based on disease patterns and risks present on-farm.

7.2.3. Restriction of movement and resting problems

1) Dairy cows should not be permanently housed in tie-stalls because of the continuous and severe restriction of movement and social behaviour and the risk of thwarting of lying down and rising up movements and prevention of comfortable resting postures.
2) While from a welfare perspective housing in tie-stalls should in general not be practised, in a transition period housing in tie-stalls with regular access to a loafing area, or access to summer pasture, could be used to reduce the impact on restriction of movement, resting and social behaviour.
3) Tethering may be used for limited time periods for events such as veterinary treatments or milking.
4) At least one cubicle per cow should be provided.
5) Dry, soft and deformable lying surfaces, preferably deep bedding (either in cubicles or a deep bedded pack), should be provided because they are associated with longer lying time and ease of lying down and rising up movements.
6) When using bare concrete, bedding of at least 30 cm thickness should be provided.
7) When using mats and mattresses, a bedding with a minimum depth of 5 cm of compressed material (i.e. compressed as a result of the animal lying on it) should be provided. For instance, this corresponds to 3 kg of straw per day to be provided per cubicle space.
8) Studies on appropriate amounts of other bedding materials should be carried out.
9) Access to well-managed pasture (i.e. well-drained, provision of shade) should be provided because it offers opportunity to walk freely, ease of changing posture and a comfortable lying area.
10) Rubber coated floor (or other deformable, non-slip standing and walking surface) at the feed manger and in the alleys should be used because it improves cows' gait and ease of walking, and increases feeding time.
11) A total indoor area – including lying area - of at least 9 m^2/cow should be provided.
12) The effect of total space allowance beyond 9 m^2/cow on cow welfare should be further investigated.
13) The following minimum width and length of cubicles are recommended:
    - Cubicle width: 0.83 × cow height at the withers (in m)
    - Cubicle resting length: 1.1 × cow diagonal length (distance in m between point of shoulder and pin bone)
    - Cubicles head-to-head, if space sharing: 1.8 × cow diagonal length (in m)
    - Non space sharing cubicles (i.e. cubicle against a wall): 2.0 × cow height (in m)
14) Other features that should be provided for cubicles are:
    - Neck rail height: 0.80–0.90 × cow diagonal length (in m)
    - Brisket board height: maximum 10 cm
    - Curb with 15–20 cm height, no sharp edges

- Brisket board either round or without sharp edges
- Partitions should not present obstacles in the head lunging space, and should be flexible
- Slope of the lying area between 2% and 5%

7.2.4. Inability to perform comfort behaviour

1) Tethering should not be practised because it severely restricts the ability to perform comfort behaviour except for limited time periods for events such as veterinary treatments or milking.
2) In cubicle housing systems, flooring should not be slippery to allow postures associated with self-grooming to be adopted
3) Brushes should be available in all loose-housing systems.
4) Research is needed to precisely recommend the characteristics, location and number of brushes to be provided to cows, and on the relationship between allo-grooming and positive welfare states.

7.2.5. Metabolic diseases

1) Preventive strategies based on key risks arising from feeding and management practices should be in place to minimise the occurrence of metabolic disease.
2) Early identification and treatment of cows affected with metabolic disease should be ensured through the assessment of ABMs (e.g. body condition, milk constituents) to mitigate impacts as much as possible.
3) For metabolic conditions associated with clinical signs, clinical cases should be recorded accurately and incidence rates calculated to provide the basis for monitoring clinical metabolic disease.
4) Individual cow beta-hydroxybutyrate levels (in blood) or ketones (in milk or urine) taken from all cows in early lactation should be used to monitor herd-level subclinical ketosis.
5) Routine (e.g. monthly) body condition scoring should be used to provide a measure of nutrient balance in dairy cows, which can be indicative of increased risk of metabolic disease.

7.3. Recommendations for assessment 3: farm characteristics to classify farms at risk of poor welfare

1) It is recommended that the risk-based scheme developed from the EKE is piloted to validate its usefulness in practice prior to implementation. It is preferable that the whole scheme, incorporating all five farm characteristics, is piloted.
2) A pilot/validation of the scheme should include:
   a) Confirmation of definitions and modes of measurement of the farm characteristics that are practical in a commercial setting.
   b) An evaluation of the proportion of farms that would be recorded as 'at risk' (i.e. one or more farm characteristic is present).
   c) Design and testing of a structured farm visit to evaluate the necessary farm-based measures on at risk farms.
   d) An evaluation of the proportion of farms that would be recorded as requiring corrective action.
3) Further practical, close-to-farm research should be encouraged to establish methods to accurately evaluate key behavioural ABMs using minimal time (e.g. using smart technologies) and other resource measures.

References

Ahdb, 2021. Mobility score. Available online: https://projectblue.blob.core.windows.net/media/Default/Dairy/Publications/Dairy%20Mobility%20Scoresheet_200427_WEB.pdf [Accessed: 21 December 2022].

Albright JL and Arave CW, 1997. The behaviour of cattle. CAB International, Wallingford, UK.

Al-Marashdeh O, Cameron KC, Bryant RH, Chen A, McGowan B, Gillé-Perrier C, Carey P, Chrystal J, Hodge S and Edwards GR, 2019. Effects of surface type in an uncovered stand-off pad system on comfort and welfare of non-lactating dairy cows during winter. Applied Animal Behaviour Science, 211, 17–24. https://doi.org/10.1016/j.applanim.2018.11.001

Almeida PE, Weber PSD, Burton JL and Zanella AJ, 2008. Depressed DHEA and increased sickness response behaviors in lame dairy cows with inflammatory foot lesions. Domestic Animal Endocrinology, 34, 89–99. https://doi.org/10.1016/j.domaniend.2006.11.006

Alsaaod M, Römer C, Kleinmanns J, Hendriksen K, Rose-Meierhöfer S, Plümer L and Büscher W, 2012. Electronic detection of lameness in dairy cows through measuring pedometric activity and lying behavior. Applied Animal Behaviour Science, 142, 134–141. https://doi.org/10.1016/j.applanim.2012.10.001

Alsaaod M, Huber S, Beer G, Kohler P, Schüpbach-Regula G and Steiner A, 2017. Locomotion characteristics of dairy cows walking on pasture and the effect of artificial flooring systems on locomotion comfort. Journal of Dairy Science, 100, 8330–8337. https://doi.org/10.3168/jds.2017-12760

Alvåsen K, Roth A, Jansson Mörk M, Hallén Sandgren C, Thomsen PT and Emanuelson U, 2014. Farm characteristics related to on-farm cow mortality in dairy herds: a questionnaire study. Animal, 8, 1735–1742. https://doi.org/10.1017/S1751731114001633

Alvergnas M, Strabel T, Rzewuska K and Sell-Kubiak E, 2019. Claw disorders in dairy cattle: Effects on production, welfare and farm economics with possible prevention methods. Livestock Science, 222, 54–64. https://doi.org/10.1016/j.livsci.2019.02.011

Amory JR, Kloosterman P, Barker ZE, Wright JL, Blowey RW and Green LE, 2006. Risk factors for reduced locomotion in dairy cattle on nineteen farms in The Netherlands. Journal of Dairy Science, 89, 1509–1515. https://doi.org/10.3168/jds.S0022-0302(06)72218-4

Andreasen SN and Forkman B, 2012. The welfare of dairy cows is improved in relation to cleanliness and integument alterations on the hocks and lameness when sand is used as stall surface. Journal of Dairy Science, 95, 4961–4967. https://doi.org/10.3168/jds.2011-5169

Animal Welfare Centre, 2014. Selvitys nautojen parressa ja pihatossa pidon hyvinvointi - ja talousvaikutuksista [Study on the management of cattle kept in paddocks and sheds - Welfare and economic impact of cattle]. Helsinki, Finland. Available online. https://mmm.fi/documents/1410837/1858027/Parsi-pihattoselvitys/d3c98725-74b6-4d3d-bd6d-e4bbf24b8602/Parsi-pihattoselvitys.pdf

Armbrecht L, Lambertz C, Albers D and Gauly M, 2018. Does access to pasture affect claw condition and health in dairy cows? Veterinary Record, 182, 79.

Armbrecht L, Lambertz C, Albers D and Gauly M, 2019. Assessment of welfare indicators in dairy farms offering pasture at differing levels. Animal, 13, 2336–2347. https://doi.org/10.1017/S1751731119000570

Arnott G, Ferris CP and O'Connell NE, 2017. Review: welfare of dairy cows in continuously housed and pasture-based production systems. Animal, 11, 261–273. https://doi.org/10.1017/S1751731116001336

Asher L and Collins LM, 2012. Assessing synchrony in groups: are you measuring what you think you are measuring? Applied Animal Behaviour Science, 138, 162–169. https://doi.org/10.1016/j.applanim.2012.02.004

Astiz S, Sebastian F, Fargas O, Fernández M and Calvet E, 2014. Enhanced udder health and milk yield of dairy cattle on compost bedding systems during the dry period: a comparative study. Livestock Science, 159, 161–164. https://doi.org/10.1016/j.livsci.2013.10.028

Bachinger J, Becherer U, Bee W, Belau T, Blum H, Blumschein A, Brinkmann J, Deerberg F, Dreyer W, Euen S, Frieben B, Fritzsche S, Fröba N, Früh B, Fuchs S, Fügner K and Zankl A, 2015. Faustzahlen für den ökologischen Landbau. Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL), Darmstadt, Germany.

Bak AS, Herskin MS and Jensen MB, 2016. Effect of sand and rubber surface on the lying behavior of lame dairy cows in hospital pens. Journal of Dairy Science, 99, 2875–2883. https://doi.org/10.3168/jds.2015-9937

Barberg AE, Endres MI and Janni KA, 2007. Compost dairy barns in Minnesota: a descriptive study. Applied Engineering in Agriculture, 23, 231–238.

Barkema HW, von Keyserlingk MAG, Kastelic JP, Lam T, Luby C, Roy JP, LeBlanc SJ, Keefe GP and Kelton DF, 2015. Invited review: changes in the dairy industry affecting dairy cattle health and welfare. Journal of Dairy Science, 98, 7426–7445. https://doi.org/10.3168/jds.2015-9377

Barker ZE, Amory JR, Wright JL, Mason SA, Blowey RW and Green LE, 2009. Risk factors for increased rates of sole ulcers, white line disease, and digital dermatitis in dairy cattle from twenty-seven farms in England and Wales. Journal of Dairy Science, 92, 1971–1978. https://doi.org/10.3168/jds.2008-1590

Barker ZE, Leach KA, Whay HR, Bell NJ and Main DCJ, 2010. Assessment of lameness prevalence and associated risk factors in dairy herds in England and Wales. Journal of Dairy Science, 93, 932–941.

Barnouin J, Chassagne M, Bazin S and Boichard D, 2004. Management practices from questionnaire surveys in herds with very low somatic cell score through a national mastitis program in France. Journal of Dairy Science, 87, 3989–3999. https://doi.org/10.3168/jds.S0022-0302(04)73539-0

Barnouin J, Bord S, Bazin S and Chassagne M, 2005. Dairy management practices associated with incidence rate of clinical mastitis in low somatic cell score herds in France. Journal of Dairy Science, 88, 3700–3709. https://doi.org/10.3168/jds.S0022-0302(05)73056-3

Barrientos AK, Chapinal N, Weary DM, Galo E and Von Keyserlingk MAG, 2013. Herd-level risk factors for hock injuries in freestall-housed dairy cows in the northeastern United States and California. Journal of Dairy Science, 96, 3758–3765. https://doi.org/10.3168/jds.2012-6389

Bateson M and Martin P, 2021. Measuring behaviour: an introductory guide. Cambridge University Press.

Bauman CA, Barkema HW, Dubuc J, Keefe GP and Kelton DF, 2018. Canadian National Dairy Study: herd-level milk quality. Journal of Dairy Science, 101, 2679–2691.

Beaver A, Proudfoot KL and von Keyserlingk MAG, 2020. Symposium review: considerations for the future of dairy cattle housing: an animal welfare perspective. Journal of Dairy Science, 103, 5746–5758. https://doi.org/10.3168/jds.2019-17804

Beaver A, Weary DM and von Keyserlingk MAG, 2021. Invited review: the welfare of dairy cattle housed in tiestalls compared to less-restrictive housing types: a systematic review. Journal of Dairy Science, 104, 9383–9417. https://doi.org/10.3168/jds.2020-19609

Becker T, Kayser M, Tonn B and Isselstein J, 2018. How German dairy farmers perceive advantages and disadvantages of grazing and how it relates to their milk production systems. Livestock Science, 214, 112–119. https://doi.org/10.1016/j.livsci.2018.05.018

Bennema SC, Ducheyne E, Vercruysse J, Claerebout E, Hendrickx G and Charlier J, 2011. Relative importance of management, meteorological and environmental factors in the spatial distribution of Fasciola hepatica in dairy cattle in a temperate climate zone. International Journal for Parasitology, 41, 225–233. https://doi.org/10.1016/j.ijpara.2010.09.003

Benvenuti MN, Giuliotti L, Lotti C, Accorsi PA, Petrulli CA and Martini A, 2018. Welfare parameters in dairy cows reared in tie-stall and open-stall farming systems: pilot study. Journal of the Hellenic Veterinary Medical Society, 69, 809. https://doi.org/10.12681/jhvms.16430

Berge AC and Vertenten G, 2014. A field study to determine the prevalence, dairy herd management systems, and fresh cow clinical conditions associated with ketosis in western European dairy herds. Journal of Dairy Science, 97, 2145–2154. https://doi.org/10.3168/jds.2013-7163

Bernardi F, Fregonesi J, Winckler C, Veira DM, Von Keyserlingk MAG and Weary DM, 2009. The stall-design paradox: neck rails increase lameness but improve udder and stall hygiene. Journal of Dairy Science, 92, 3074–3080.

Bernhard JK, Vidondo B, Achermann RL, Rediger R, Müller KE and Steiner A, 2020. Carpal, tarsal, and stifle skin lesion prevalence and potential risk factors in Swiss dairy cows kept in tie stalls: a cross-sectional study. PLOS ONE, 15, e0228808. https://doi.org/10.1371/journal.pone.0228808

Bewley JM, Robertson LM and Eckelkamp EA, 2017. A 100-year review: lactating dairy cattle housing management. Journal of Dairy Science, 100, 10418–10431. https://doi.org/10.3168/jds.2017-13251

Biasato I, D'Angelo A, Bertone I, Odore R and Bellino C, 2019. Compost bedded-pack barn as an alternative housing system for dairy cattle in Italy: effects on animal health and welfare and milk and milk product quality. Italian Journal of Animal Science, 18, 1142–1153. https://doi.org/10.1080/1828051X.2019.1623095

Bielfeldt JC, Badertscher R, Tölle KH and Krieter J, 2005. Risk factors influencing lameness and claw disorders in dairy cows. Livestock Production Science, 95, 265–271. https://doi.org/10.1016/j.livprodsci.2004.12.005

Black R and Krawczel P, 2016. A case study of behaviour and performance of confined or pastured cows during the dry period. Animals, 6, 41. https://doi.org/10.3390/ani6070041

Black RA, Taraba JL, Day GB, Damasceno FA and Bewley JM, 2013. Compost bedded pack dairy barn management, performance, and producer satisfaction. Journal of Dairy Science, 96, 8060–8074. https://doi.org/10.3168/jds.2013-6778

Blanco-Penedo I, Ouweltjes W, Ofner-Schröck E, Brügemann K and Emanuelson U, 2020. Symposium review: animal welfare in free-walk systems in Europe. Journal of Dairy Science, 103, 5773–5782. https://doi.org/10.3168/jds.2019-17315

Bludau MJ, Maeschli A, Leiber F, Klocke P, Berezowski JA, Bodmer M and Vidondo B, 2016. The influence of the rearing period on intramammary infections in Swiss dairy heifers: a cross-sectional study. Preventive Veterinary Medicine, 129, 23–34. https://doi.org/10.1016/j.prevetmed.2016.04.013

Boelling D and Pollott GE, 1998. Locomotion, lameness, hoof and leg traits in cattle I. Livestock Production Science, 54, 193–203. https://doi.org/10.1016/S0301-6226(97)00166-8

Boissy A, Manteuffel G, Jensen MB, Moe RO, Spruijt B, Keeling LJ, Winckler C, Forkman B, Dimitrov I and Langbein J, 2007. Assessment of positive emotions in animals to improve their welfare. Physiology & behavior, 92, 375–397.

Borchers MR, 2018. The effects of housing on dairy cow comfort, immune function, stress, productivity, and milk quality.

Bouffard V, de Passillé AM, Rushen J, Vasseur E, Nash CGR, Haley DB and Pellerin D, 2017. Effect of following recommendations for tiestall configuration on neck and leg lesions, lameness, cleanliness, and lying time in dairy cows. Journal of Dairy Science, 100, 2935–2943. https://doi.org/10.3168/jds.2016-11842

Bouissou M and Boissy A, 2001. The social behaviour of cattle. Neindre Pl and Veissier I. The social behaviour of cattle, CABI International.

Boyer V, de Passillé AM, Adam S and Vasseur E, 2021a. Making tiestalls more comfortable: II. Increasing chain length to improve the ease of movement of dairy cows. Journal of Dairy Science, 104, 3316–3326. https://doi.org/10.3168/jds.2019-17666

Boyer V, Edwards E, Guiso MF, Adam S, Krawczel P, de Passillé AM and Vasseur E, 2021b. Making tiestalls more comfortable: III. Providing additional lateral space to improve the resting capacity and comfort of dairy cows. Journal of Dairy Science, 104, 3327–3338. https://doi.org/10.3168/jds.2019-17667

Bradley AJ, Leach KA, Breen JE, Green LE and Green MJ, 2007. Survey of the incidence and aetiology of mastitis on dairy farms in England and Wales. Veterinary Record, 160, 253–258. https://doi.org/10.1136/vr.160.8.253

Bran JA, Daros RR, von Keyserlingk MAG and Hötzel MJ, 2018. Lameness on Brazilian pasture based dairies—part 1: farmers' awareness and actions. Veterinary Record, 57, 137–141. https://doi.org/10.1016/j.prevetmed.2018.06.007

Brenninkmeyer C, Dippel S, Brinkmann J, March S, Winckler C and Knierim U, 2013. Hock lesion epidemiology in cubicle housed dairy cows across two breeds, farming systems and countries. Preventive Veterinary Medicine, 109, 236–245. https://doi.org/10.1016/j.prevetmed.2012.10.014

Brinkmann JT and Stevens P, 2016. Clinical considerations of observational gait analysis. Atlas of Amputations and Limb Deficiencies Surgical, Prosthetic, and Rehabilitation Principles. 4th Edition. American Academy of Orthopaedic Surgeons, pp. 81–95, Rosemont, IL.

Brinkmann J, March S, Barth K, Becker M, Drerup C, Isselstein J, Klocke D, Krömker V, Mersch F and Müller J, 2011. Status quo der Tiergesundheitssituation in der ökologischen Milchviehhaltung in Deutschland-Ergebnisse einer repräsentativen bundesweiten Felderhebung. 11. Wissenschaftstagung Ökologischer Landbau, Justus-Liebig-Universität Gießen, 15.-18. März 2011.

Brinkmann J, Cimer K, March S, Ivemeyer S, Pelzer A, Schultheiß U, Zapf R and Winckler C, 2020. Tierschutzindikatoren: Leitfaden für die Praxis - Rind. 2nd edn. (KTBL), Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V, Darmstadt.

Broom DM and Fraser AF, 2015. Domestic animal behaviour and welfare. Wallingford, UK, CABI.

BRS (Bundesverband Rind und S), 2020. Rinder- und Schweineproduktion in Deutschland, 2020. Available online: https://www.rind-schwein.de/brs-de/statistik-zahlen.html [Accessed: 21 December 2022].

BRS (Bundesverband Rind Schwein), 2021. Rinder- und Schweineproduktion in Deutschland 2020. Herausgeber: Bundesverband Rind und Schwein e.V. Adenauerallee 174, 53113 Bonn.

Burgstaller J, Raith J, Kuchling S, Mandl V, Hund A and Kofler J, 2016. Claw health and prevalence of lameness in cows from compost bedded and cubicle freestall dairy barns in Austria. The Veterinary Journal, 216, 81–86. https://doi.org/10.1016/j.tvjl.2016.07.006

Burow E, Thomsen PT, Sørensen JT and Rousing T, 2011. The effect of grazing on cow mortality in Danish dairy herds. Preventive Veterinary Medicine, 100, 237–241. https://doi.org/10.1016/j.prevetmed.2011.04.001

Burow E, Rousing T, Thomsen PT, Otten ND and Sørensen JT, 2013a. Effect of grazing on the cow welfare of dairy herds evaluated by a multidimensional welfare index. Animal, 7, 834–842. https://doi.org/10.1017/S1751731112002297

Burow E, Thomsen PT, Rousing T and Sørensen JT, 2013b. Daily grazing time as a risk factor for alterations at the hock joint integument in dairy cows. Animal, 7, 160–166. https://doi.org/10.1017/S1751731112001395

Burow E, Thomsen PT, Rousing T and Sørensen JT, 2014. Track way distance and cover as risk factors for lameness in Danish dairy cows. Preventive Veterinary Medicine, 113, 625–628. https://doi.org/10.1016/j.prevetmed.2013.11.018

Busato A, Trachsel P and Blum JW, 2000. Frequency of traumatic cow injuries in relation to housing systems in Swiss organic dairy herds. Journal of Veterinary Medicine Series A, 47, 221–229. https://doi.org/10.1046/j.1439-0442.2000.00283.x

Calamari L, Calegari F and Stefanini L, 2009. Effect of different free stall surfaces on behavioural, productive and metabolic parameters in dairy cows. Applied Animal Behaviour Science, 120, 9–17. https://doi.org/10.1016/j.applanim.2009.05.013

Campler M, Munksgaard L and Jensen MB, 2015. The effect of housing on calving behavior and calf vitality in Holstein and Jersey dairy cows. Journal of Dairy Science, 98, 1797–1804.

Caplen G and Held SDE, 2021. Changes in social and feeding behaviors, activity, and salivary serum amyloid A in cows with subclinical mastitis. Journal of Dairy Science, 104, 10991–11008. https://doi.org/10.3168/jds.2020-20047

CBS, 2012. Huisvesting van landbouwhuisdieren 2012. Den Haag, Netherlands.

CBS, 2021. StatLine. Available online: https://opendata.cbs.nl/statline/ [Accessed: 21 December 2022].

Ceballos A, Sanderson D, Rushen J and Weary DM, 2004. Improving stall design: use of 3-D kinematics to measure space use by dairy cows when lying down. Journal of Dairy Science, 87, 2042–2050. https://doi.org/10.3168/jds.S0022-0302(04)70022-3

Chambers JP, Waterman AE and Livingston A, 1994. Further development of equipment to measure nociceptive thresholds in large animals. Journal of Veterinary Anaesthesia, 21, 66–72. https://doi.org/10.1111/j.1467-2995.1994.tb00489.x

Chapinal N, Goldhawk C, de Passillé AM, von Keyserlingk MAG, Weary DM and Rushen J, 2010. Overnight access to pasture does not reduce milk production or feed intake in dairy cattle. Livestock Science, 129, 104–110. https://doi.org/10.1016/j.livsci.2010.01.011

Chapinal N, Barrientos AK, von Keyserlingk MAG, Galo E and Weary DM, 2013. Herd-level risk factors for lameness in freestall farms in the northeastern United States and California. Journal of Dairy Science, 96, 318–328. https://doi.org/10.3168/jds.2012-5940
Chaplin S and Munksgaard L, 2001. Evaluation of a simple method for assessment of rising behaviour in tethered dairy cows. Animal Science, 72, 191–197. https://doi.org/10.1017/S1357729800055685
Charlier J, Claerebout E, Mûelenaere ED and Vercruysse J, 2005. Associations between dairy herd management factors and bulk tank milk antibody levels against Ostertagia ostertagi. Veterinary Parasitology, 133, 91–100. https://doi.org/10.1016/j.vetpar.2005.05.030
Charlton GL and Rutter SM, 2017. The behaviour of housed dairy cattle with and without pasture access: a review. Applied Animal Behaviour Science, 192, 2–9. https://doi.org/10.1016/j.applanim.2017.05.015
Charlton GL, Rutter SM, East M and Sinclair LA, 2011a. Preference of dairy cows: indoor cubicle housing with access to a total mixed ration vs. access to pasture. Applied Animal Behaviour Science, 130, 1–9. https://doi.org/10.1016/j.applanim.2010.11.018
Charlton GL, Rutter SM, East M and Sinclair LA, 2011b. Effects of providing total mixed rations indoors and on pasture on the behavior of lactating dairy cattle and their preference to be indoors or on pasture. Journal of Dairy Science, 94, 3875–3884. https://doi.org/10.3168/jds.2011-4172
Charlton GL, Rutter SM, East M and Sinclair LA, 2013. The motivation of dairy cows for access to pasture. Journal of Dairy Science, 96, 4387–4396. https://doi.org/10.3168/jds.2012-6421
Charlton GL, Haley DB, Rushen J and de Passillé AM, 2014. Stocking density, milking duration, and lying times of lactating cows on Canadian freestall dairy farms. Journal of Dairy Science, 97, 2694–2700. https://doi.org/10.3168/jds.2013-6923
Chen JM, Stull CL, Ledgerwood DN and Tucker CB, 2017. Muddy conditions reduce hygiene and lying time in dairy cattle and increase time spent on concrete. Journal of Dairy Science, 100, 2090–2103. https://doi.org/10.3168/jds.2016-11972
Chesterton RN, Pfeiffer DU, Morris RS and Tanner CM, 1989. Environmental and behavioural factors affecting the prevalence of foot lameness in New Zealand dairy herds — a case-control study. New Zealand Veterinary Journal, 37, 135–142. https://doi.org/10.1080/00480169.1989.35587
Cicconi-Hogan KM, Gamroth M, Richert R, Ruegg PL, Stiglbauer KE and Schukken YH, 2013. Risk factors associated with bulk tank standard plate count, bulk tank coliform count, and the presence of *Staphylococcus aureus* on organic and conventional dairy farms in the United States. Journal of Dairy Science, 96, 7578–7590. https://doi.org/10.3168/jds.2012-6505
CIGR (International Commission of Agricultural and Biosystems Engineering), Zappavigna P, Lensink J, Flaba J, Ventorp M, Greaves R, Heiko G, Ofner-Schrock E, Ryan T and Van Gaenegem L, 2014. The Design of Dairy Cow and Replacement Heifer Housing Report of the CIGR Section II Working Group.
CLAL, 2021. CLAL Italian Dairy Economic Consulting. Available online: https://www.clal.it/en/ [Accessed: 22 December 2022].
Clarkson MJ, Downham DY, Faull WB, Hughes JW, Manson FJ, Merritt JB, Murray RD, Russell WB, Sutherst JE and Ward WR, 1996. Incidence and prevalence of lameness in dairy cattle. Veterinary Record, 138, 563–567.
Cochran WG, 1977. Sampling techniques. John Wiley & Sons.
Collings LKM, Weary DM, Chapinal N and Von Keyserlingk MAG, 2011. Temporal feed restriction and overstocking increase competition for feed by dairy cattle. Journal of Dairy Science, 94, 5480–5486. https://doi.org/10.3168/jds.2011-4370
Compton CWR, Heuer C, Thomsen PT, Carpenter TE, Phyn CVC and McDougall S, 2017. Invited review: a systematic literature review and meta-analysis of mortality and culling in dairy cattle. Journal of Dairy Science, 100, 1–16. https://doi.org/10.3168/jds.2016-11302
Conafe, 2021. Resultados del control de rendimiento lechero. Available online: https://www.conafe.com/estadisticas.aspx [Accessed: 22 December 2022].
Cook NB, 2020. Symposium review: the impact of management and facilities on cow culling rates. Journal of Dairy Science, 103, 3846–3855. https://doi.org/10.3168/jds.2019-17140
Cook NB and Nordlund KV, 2009. The influence of the environment on dairy cow behavior, claw health and herd lameness dynamics. The Veterinary Journal, 179, 360–369. https://doi.org/10.1016/j.tvjl.2007.09.016
Cook NB, Bennett TB and Nordlund KV, 2004. Effect of free stall surface on daily activity patterns in dairy cows with relevance to lameness prevalence. Journal of Dairy Science, 87, 2912–2922. https://doi.org/10.3168/jds.S0022-0302(04)73422-0
Cook NB, Hess JP, Foy MR, Bennett TB and Brotzman RL, 2016. Management characteristics, lameness, and body injuries of dairy cattle housed in high-performance dairy herds in Wisconsin. Journal of Dairy Science, 99, 5879–5891. https://doi.org/10.3168/jds.2016-10956
Corazzin M, Piasentier E, Dovier S and Bovolenta S, 2010. Effect of summer grazing on welfare of dairy cows reared in mountain tie-stall barns. Italian Journal of Animal Science, 9, e59. https://doi.org/10.4081/ijas.2010.e59
Cortés Fernández de Arcipreste N, Mancera KF, Miguel-Pacheco GG and Galindo GG, 2018. Plasticity and consistency of lying and ruminating behaviours of heifers exposed to different cubicle availability: a glance at individuality. Applied Animal Behaviour Science, 205, 1–7.

Crossley RE, Bokkers EAM, Browne N, Sugrue K, Kennedy E, de Boer IJM and Conneely M, 2021. Assessing dairy cow welfare during the grazing and housing periods on spring-calving, pasture-based dairy farms. Journal of Animal Science, 99, skab093. https://doi.org/10.1093/jas/skab093

Crump A, Jenkins K, Bethell EJ, Ferris CP and Arnott G, 2019. Pasture access affects behavioral indicators of wellbeing in dairy cows. Animals, 9, 902. https://doi.org/10.3390/ani9110902

Dallago GM, Wade KM, Cue RI, McClure JT, Lacroix R, Pellerin D and Vasseur E, 2021. Keeping dairy cows for longer: a critical literature review on dairy cow longevity in high milk-producing countries. Animals, 11, 808. https://doi.org/10.3390/ani11030808

Dawkins MS, 2023. Farm animal welfare: Beyond "natural" behavior. Science, 379, 326–328.

de Almeida AM, Alvarenga P and Fangueiro D, 2021. The dairy sector in the Azores Islands: possibilities and main constraints towards increased added value. Tropical Animal Health and Production, 53, 40. https://doi.org/10.1007/s11250-020-02442-z

de Boyer des Roches A, Veissier I, Coignard M, Bareille N, Guatteo R, Capdeville J, Gilot-Fromont E and Mounier L, 2014. The major welfare problems of dairy cows in French commercial farms: an epidemiological approach. Animal Welfare, 23, 467–478. https://doi.org/10.7120/09627286.23.4.467

de Boyer des Roches A, Lardy R, Capdeville J, Mounier L and Veissier I, 2019. Do International Commission of Agricultural and Biosystems Engineering (CIGR) dimension recommendations for loose housing of cows improve animal welfare? Journal of Dairy Science, 102, 10235–10249. https://doi.org/10.3168/jds.2018-16154

De Freslon I, Peralta J, Strappini AC and Monti G, 2020. Understanding allogrooming through a dynamic social network approach: an example in a group of dairy cows. Frontiers in Veterinary Science, 535.

de Jong E, Frankena K and Orsel K, 2021. Risk factors for digital dermatitis in free-stall-housed, Canadian dairy cattle. Veterinary Record Open, 8, e19. https://doi.org/10.1002/vro2.19

De Vliegher S, Ohnstad I and Piepers S, 2018. Management and prevention of mastitis: a multifactorial approach with a focus on milking, bedding and data-management. Journal of Integrative Agriculture, 17, 1214–1233.

de Vries M, Bokkers EAM, Dijkstra T, van Schaik G and de Boer IJM, 2011. Invited review: associations between variables of routine herd data and dairy cattle welfare indicators. Journal of Dairy Science, 94, 3213–3228. https://doi.org/10.3168/jds.2011-4169

de Vries M, Bokkers EAM, van Reenen CG, Engel B, van Schaik G, Dijkstra T and de Boer IJM, 2015. Housing and management factors associated with indicators of dairy cattle welfare. Preventive Veterinary Medicine, 118, 80–92. https://doi.org/10.1016/j.prevetmed.2014.11.016

Dechow CD, Smith EA and Goodling RC, 2011. The effect of management system on mortality and other welfare indicators in Pennsylvania dairy herds. Animal Welfare, 20, 145–158. https://doi.org/10.1017/S0962728600002633

Deming JA, Bergeron R, Leslie KE and DeVries TJ, 2013. Associations of housing, management, milking activity, and standing and lying behavior of dairy cows milked in automatic systems. Journal of Dairy Science, 96, 344–351. https://doi.org/10.3168/jds.2012-5985

Dendani-Chadi Z, Saidani K, Dib L, Zeroual F, Sammar F and Benakhla A, 2020. Univariate associations between housing, management, and facility design factors and the prevalence of lameness lesions in fourteen small-scale dairy farms in Northeastern Algeria. Veterinary World, 13, 570–578. https://doi.org/10.14202/vetworld.2020.570-578

Dening KH, Jones L and Sampson EL, 2013. Preferences for end-of-life care: a nominal group study of people with dementia and their family carers. Palliative Medicine, 27, 409–417.

Desrochers A and Francoz D, 2014. Clinical management of Septic Arthritis in cattle. Veterinary Clinics of North America: Food Animal Practice, 30, 177–203. https://doi.org/10.1016/j.cvfa.2013.11.006

Desrochers A, St-Jean G and Anderson DE, 1995. Use of facilitated ankylosis in the treatment of septic arthritis of the distal interphalangeal joint in cattle: 12 cases (1987–1992). Journal of the American Veterinary Medical Association, 206, 1923–1927.

Detilleux J, Theron L, Beduin JM and Hanzen C, 2012. A structural equation model to evaluate direct and indirect factors associated with a latent measure of mastitis in Belgian dairy herds. Preventive Veterinary Medicine, 107, 170–179.

DeVries TJ, Vankova M, Veira DM and von Keyserlingk MAG, 2007. Short communication: usage of mechanical brushes by lactating dairy cows. Journal of Dairy Science, 90, 2241–2245. https://doi.org/10.3168/jds.2006-648

Di Grigoli A, Di Trana A, Alabiso M, Maniaci G, Giorgio D and Bonanno A, 2019. Effects of grazing on the behaviour, oxidative and immune status, and production of organic dairy cows. Animals, 9, 371. https://doi.org/10.3390/ani9060371

Dillon E, Donnellan T, Moran B and Lennon J, 2021. Teagasc National Farm Survey 2020 Preliminary Results. Place Teagasc, Agriculture and Food Development Authority, Teagasc, Agriculture and Food Development Authority.

Dippel S, Dolezal M, Brenninkmeyer C, Brinkmann J, March S, Knierim U and Winckler C, 2009a. Risk factors for lameness in cubicle housed Austrian Simmental dairy cows. Preventive Veterinary Medicine, 90, 102–112. https://doi.org/10.1016/j.prevetmed.2009.03.014

Dippel S, Dolezal M, Brenninkmeyer C, Brinkmann J, March S, Knierim U and Winckler C, 2009b. Risk factors for lameness in freestall-housed dairy cows across two breeds, farming systems, and countries. Journal of Dairy Science, 92, 5476–5486.

Dirksen N, Gygax L, Traulsen I, Wechsler B and Burla JB, 2020. Body size in relation to cubicle dimensions affects lying behavior and joint lesions in dairy cows. Journal of Dairy Science, 103, 9407–9417. https://doi.org/10.3168/jds.2019-16464

Dohme-Meier F, Kaufmann LD, Görs S, Junghans P, Metges CC, van Dorland HA, Bruckmaier RM and Münger A, 2014. Comparison of energy expenditure, eating pattern and physical activity of grazing and zero-grazing dairy cows at different time points during lactation. Livestock Science, 162, 86–96. https://doi.org/10.1016/j.livsci.2014.01.006

Drissler M, Gaworski M, Tucker C and Weary D, 2005. Freestall maintenance: effects on lying behavior of dairy cattle. Journal of Dairy Science, 88, 2381–2387. https://doi.org/10.3168/jds.S0022-0302(05)72916-7

Dufour S, Dohoo IR, Barkema HW, Descoteaux L, Devries TJ, Reyher KK, Roy JP and Scholl DT, 2012. Manageable risk factors associated with the lactational incidence, elimination, and prevalence of Staphylococcus aureus intramammary infections in dairy cows. Journal of Dairy Science, 95, 1283–1300.

Durkin J, Usher K and Jackson D, 2019. Using consensus from experts to inform a shared understanding of subjective terms. Nurse Researcher, 27, 46–49. https://doi.org/10.7748/nr.2019.e1622

Duse A, Persson-Waller K and Pedersen K, 2021. Microbial Aetiology, Antibiotic susceptibility and pathogen-specific risk factors for udder pathogens from clinical mastitis in dairy cows. Animals (Basel), 11.

Duval E, Von Keyserlingk MAG and Lecorps B, 2020. Organic dairy cattle: do European Union regulations promote animal welfare? Animals, 10, 1786. https://doi.org/10.3390/ani10101786

DVG, 2012. Leitlinien Bekämpfung der Mastitis des Rindes als Bestandsproblem. 5th edn. Giessen, Germany, Deutsche Veterinärmedizinische Gesellschaft (DVG).

Eckelkamp EA, Gravatte CN, Coombs CO and Bewley JM, 2014. CASE STUDY: characterization of lying behavior in dairy cows transitioning from a freestall barn with pasture access to a compost bedded pack barn without pasture access. The Professional Animal Scientist, 30, 109–113. https://doi.org/10.15232/S1080-7446(15)30092-9

Eckelkamp EA, Taraba JL, Akers KA, Harmon RJ and Bewley JM, 2016a. Understanding compost bedded pack barns: interactions among environmental factors, bedding characteristics, and udder health. Livestock Science, 190, 35–42. https://doi.org/10.1016/j.livsci.2016.05.017

Eckelkamp EA, Taraba JL, Akers KA, Harmon RJ and Bewley JM, 2016b. Sand bedded freestall and compost bedded pack effects on cow hygiene, locomotion, and mastitis indicators. Livestock Science, 190, 48–57. https://doi.org/10.1016/j.livsci.2016.06.004

EFSA (European Food Safety Authority), Hart A, Maxim L, Siegrist M, Goetz V, da Cruz C, Merten C, Mosbach-Schulz O, Lahaniatis M, Smith A and Hardy A, 2019. Guidance on communication of uncertainty in scientific assessments. EFSA Journal 2019;17(1):5520, 73 pp. https://doi.org/10.2903/j.efsa.2019.5520

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2009a. Scientific opinion on the overall effects of farming systems on dairy cow welfare and disease. EFSA Journal 2009;1143, 38 pp. https://doi.org/10.2903/j.efsa.2009.1143

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2009b. Scientific opinion on welfare of dairy cows in relation to leg and locomotion problems based on a risk assessment with special reference to the impact of housing, feeding, management and genetic selection. EFSA Journal 2009;7(7):1142, 57 pp. https://doi.org/10.2903/j.efsa.2009.1142

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2012. Guidance on risk assessment for animal welfare. EFSA Journal 2012;10(1):2513, 30 pp. https://doi.org/10.2903/j.efsa.2012.2513

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), More S, Bicout D, Bøtner A, Butterworth A, Calistri P, Depner K, Edwards S, Garin-Bastuji B, Good M, Gortazar Schmidt C, Miranda MA, Nielsen SS, Sihvonen L, Spoolder H, Willeberg P, Raj M, Thulke H-H, Velarde A, Vyssotski A, Winckler C, Cortiñas Abrahantes J, Garcia A, Muñoz Guajardo I, Zancanaro G and Michel V, 2017. Scientific Opinion on the low atmospheric pressure system for stunning broiler chickens. EFSA Journal 2017;15(12):5056, 86 pp. https://doi.org/10.2903/j.efsa.2017.5056

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen SS, Alvarez J, Bicout DJ, Calistri P, Canali E, Drewe JA, Garin-Bastuji B, Gonzales Rojas JL, Gortazar Schmidt C, Herskin M, Miranda Chueca MÁ, Michel V, Padalino B, Pasquali P, Roberts HC, Spoolder H, Stahl K, Velarde A, Viltrop A, Edwards S, Ashe S, Candiani D, Fabris C, Lima E, Mosbach-Schulz O, Gimeno CR, Van der Stede Y, Vitali M and Winckler C, 2022. Scientific Opinion on the methodological guidance for the development of animal welfare mandates in the context of the Farm to Fork Strategy. EFSA Journal 2022;20(7):7403, 29 pp. https://doi.org/10.2903/j.efsa.2022.7403

Egger-Danner C, Nielsen P, Fiedler A, Müller K, Fjeldaas T, Döpfer D, Daniel V, Bergsten C, Cramer G and Christen AM, 2020. ICAR Claw Health Atlas. ICAR Technical Series.

Eicher SD, Lay DC, Arthington JD and Schutz MM, 2013. Effects of rubber flooring during the first 2 lactations on production, locomotion, hoof health, immune functions, and stress. Journal of Dairy Science, 96, 3639–3651. https://doi.org/10.3168/jds.2012-6049

Eilers U (Landwirtschaftliches Zentrum für Rinderhaltung, Grünlandwirtschaft, Milchwirtschaft, Wild und Fischerei Baden-Württemberg), 2018. Planungshilfen für den Rinder-Stallbau. Aulendorf, Germany.

Ekman L, Nyman A-K, Landin H and Persson Waller K, 2018. Hock lesions in dairy cows in freestall herds: a cross-sectional study of prevalence and risk factors. Acta Veterinaria Scandinavica, 60, 47. https://doi.org/10.1186/s13028-018-0401-9

Elghafghuf A, Dufour S, Reyher K, Dohoo I and Stryhn H, 2014. Survival analysis of clinical mastitis data using a nested frailty Cox model fit as a mixed-effects Poisson model. Preventive Veterinary Medicine, 117, 456–468.

Ellis KA, Innocent GT, Mihm M, Cripps P, McLean WG, Howard CV and Grove-White D, 2007. Dairy cow cleanliness and milk quality on organic and conventional farms in the UK. Journal of Dairy Research, 74, 302–310.

Emanuelson U, Brügemann K, Klopčič M, Leso L, Ouweltjes W, Zentner A and Blanco-Penedo I, 2022. Animal health in compost-bedded pack and cubicle dairy barns in Six European countries. Animals, 12, 396.

Endres MI, 2017. The relationship of cow comfort and flooring to lameness disorders in dairy cattle. Veterinary Clinics: Food Animal Practice, 33, 227–233.

Endres M, 2021. Understanding the behaviour and improving the welfare of dairy cattle. UK, Burleigh Dodds Science Publishing, Cambridge.

Endres MI and Barberg AE, 2007. Behavior of dairy cows in an alternative bedded-pack housing system. Journal of Dairy Science, 90, 4192–4200. https://doi.org/10.3168/jds.2006-751

Esser NM, Su H, Coblentz WK, Akins MS, Kieke BA, Martin NP, Borchardt MA and Jokela WE, 2019. Efficacy of recycled sand or organic solids as bedding sources for lactating cows housed in freestalls. Journal of Dairy Science, 102, 6682–6698.

European Dairy Association, 2021, online. Dairy focus. Available online: https://eda.euromilk.org/publications/dairy-focus.html [Accessed: 22 December 2022].

Eurostat, 2021. Eurostat database.

Evans NJ, Murray RD and Carter SD, 2016. Bovine digital dermatitis: current concepts from laboratory to farm. The Veterinary Journal, 211, 3–13. https://doi.org/10.1016/j.tvjl.2015.10.028

Falk AC, Weary DM, Winckler C and von Keyserlingk MAG, 2012. Preference for pasture versus freestall housing by dairy cattle when stall availability indoors is reduced. Journal of Dairy Science, 95, 6409–6415. https://doi.org/10.3168/jds.2011-5208

Felton CA, Colazo MG, Ponce-Barajas P, Bench CJ and Ambrose DJ, 2012. Dairy cows continuously-housed in tie-stalls failed to manifest activity changes during estrus. Canadian Journal of Animal Science, 92, 189–196. https://doi.org/10.4141/cjas2011-134

Fernández A, Mainau E, Manteca X, Siurana A and Castillejos L, 2020. Impacts of compost bedded pack barns on the welfare and comfort of dairy cows. Animals, 10, 431. https://doi.org/10.3390/ani10030431

Firth CL, Laubichler C, Schleicher C, Fuchs K, Käsbohrer A, Egger-Danner C, Köfer J and Obritzhauser W, 2019. Relationship between the probability of veterinary-diagnosed bovine mastitis occurring and farm management risk factors on small dairy farms in Austria. Journal of Dairy Science, 102, 4452–4463. https://doi.org/10.3168/jds.2018-15657

Fitzpatrick JL, Young FJ, Eckersall D, Logue D, Knight C and Nolan A, 1998. Recognising and controlling pain and inflammation in mastitis. Proceedings of the Proc of the British mastitis conference, 36–44.

Flower FC and Weary DM, 2006. Effect of hoof pathologies on subjective assessments of dairy cow gait. Journal of Dairy Science, 89, 139–146. https://doi.org/10.3168/jds.S0022-0302(06)72077-X

Fogsgaard KK, Røntved CM, Sørensen P and Herskin MS, 2012. Sickness behavior in dairy cows during *Escherichia coli* mastitis. Journal of Dairy Science, 95, 630–638. https://doi.org/10.3168/jds.2011-4350

Forbes AB, Vercruysse J and Charlier J, 2008. A survey of the exposure to Ostertagia ostertagi in dairy cow herds in Europe through the measurement of antibodies in milk samples from the bulk tank. Veterinary Parasitology, 157, 100–107. https://doi.org/10.1016/j.vetpar.2008.06.023

Foris B, Haas HG, Langbein J and Melzer N, 2021. Familiarity influences social networks in dairy cows after regrouping. Journal of Dairy Science, 104, 3485–3494. https://doi.org/10.3168/jds.2020-18896

Franco-Gendron N, Bergeron R, Curilla W, Conte S, DeVries T and Vasseur E, 2016. Investigation of dairy cattle ease of movement on new methyl methacrylate resin aggregate floorings. Journal of Dairy Science, 99, 8231–8240. https://doi.org/10.3168/jds.2016-11125Co

Frankena K, Somers J, Schouten WGP, van Stek JV, Metz JHM, Stassen EN and Graat EAM, 2009. The effect of digital lesions and floor type on locomotion score in Dutch dairy cows. Preventive Veterinary Medicine, 88, 150–157. https://doi.org/10.1016/j.prevetmed.2008.08.004

Fregonesi JA and Leaver JD, 2001. Behaviour, performance and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. Livestock Production Science, 68, 205–216. https://doi.org/10.1016/S0301-6226(00)00234-7

Fregonesi JA and Leaver JD, 2002. Influence of space allowance and milk yield level on behaviour, performance and health of dairy cows housed in strawyard and cubicle systems. Livestock Production Science, 78, 245–257. https://doi.org/10.1016/S0301-6226(02)00097-0

Fregonesi JA, Veira DM, von Keyserlingk MAG and Weary DM, 2007. Effects of bedding quality on lying behavior of dairy cows. Journal of Dairy Science, 90, 5468–5472. https://doi.org/10.3168/jds.2007-0494

Fregonesi JA, von Keyserlingk MAG, Tucker CB, Veira DM and Weary DM, 2009. Neck-rail position in the free stall affects standing behavior and udder and stall cleanliness. Journal of Dairy Science, 92, 1979–1985. https://doi.org/10.3168/jds.2008-1604

Frey H-J, Gross JJ, Petermann R, Probst S, Bruckmaier RM and Hofstetter P, 2018. Performance, body fat reserves and plasma metabolites in Brown Swiss dairy cows: indoor feeding versus pasture-based feeding. Journal of Animal Physiology and Animal Nutrition, 102, e746–e757. https://doi.org/10.1111/jpn.12829

Fuertes E, Seradj AR, Maynegre Santaularia J, Villalba Mata D, de la Fuente OG and Balcells Teres J, 2021. Annual nitrogen balance from dairy barns, comparison between cubicle and compost-bedded pack housing systems in the Northeast of Spain. Animals, 11, 2136. https://doi.org/10.3390/ani11072136

Führer G, Majoroš Osová A, Vogl C and Kofler J, 2019. Prevalence of thin soles in the hind limbs of dairy cows housed on fully-floored vs. partially-floored mastic asphalt areas in Austria. The Veterinary Journal, 254, 105409. https://doi.org/10.1016/j.tvjl.2019.105409

Fujiwara M, Haskell M, Macrae A and Rutherford K, 2019. Effects of stocking density during the dry period on dairy cow physiology, metabolism and behaviour. Journal of Dairy Research, 86, 283–290. https://doi.org/10.1017/S002202991900058X

Fukasawa M and Tsukada H, 2010. Relationship between milk cortisol concentration and the behavioral characteristics of postpartum cows introduced to a new group. Animal Science Journal, 81, 612–617. https://doi.org/10.1111/j.1740-0929.2010.00770.x

Fulwider WK, Grandin T, Garrick DJ, Engle TE, Lamm WD, Dalsted NL and Rollin BE, 2007. Influence of free-stall base on tarsal joint lesions and hygiene in dairy cows. Journal of Dairy Science, 90, 3559–3566. https://doi.org/10.3168/jds.2006-793

Fulwider WK, Grandin T, Rollin BE, Engle TE, Dalsted NL and Lamm WD, 2008. Survey of dairy management practices on one hundred thirteen North Central and Northeastern United States dairies. Journal of Dairy Science, 91, 1686–1692.

Galama P, 2014. On farm development of bedded pack dairy barns in The Netherlands. Wageningen UR Livestock Research. Report, 707, 1570–8616.

Galama PJ, Ouweltjes W, Endres MI, Sprecher JR, Leso L, Kuipers A and Klopčič M, 2020. Symposium review: future of housing for dairy cattle. Journal of Dairy Science, 103, 5759–5772. https://doi.org/10.3168/jds.2019-17214

Galán E, Llonch P, Villagrá A, Levit H, Pinto S and del Prado A, 2018. A systematic review of non-productivity-related animal-based indicators of heat stress resilience in dairy cattle. PLOS ONE, 13, e0206520. https://doi.org/10.1371/journal.pone.0206520

Galindo F and Broom DM, 2002. The effects of lameness on social and individual behavior of dairy cows. Journal of Applied Animal Welfare Science, 5, 193–201. https://doi.org/10.1207/S15327604JAWS0503_03

Garrett E, Pereira M, Nordlund K, Armentano L, Goodger W and Oetzel G, 1999. Diagnostic methods for the detection of subacute ruminal acidosis in dairy cows. Journal of Dairy Science, 82, 1170–1178.

Gibbons JM, Lawrence AB and Haskell MJ, 2010. Measuring sociability in dairy cows. Applied Animal Behaviour Science, 122, 84–91. https://doi.org/10.1016/j.applanim.2009.11.011

Gieseke D, Lambertz C and Gauly M, 2018. Relationship between herd size and measures of animal welfare on dairy cattle farms with freestall housing in Germany. Journal of Dairy Science, 101, 7397–7411. https://doi.org/10.3168/jds.2017-14232

Gieseke D, Lambertz C and Gauly M, 2020. Effects of cubicle characteristics on animal welfare indicators in dairy cattle. Animal, 14, 1934–1942. https://doi.org/10.1017/S1751731120000609

Goldberg JJ, Wildman EE, Pankey JW, Kunkel JR, Howard DB and Murphy BM, 1992. The influence of intensively managed rotational grazing, traditional continuous grazing, and confinement housing on bulk tank milk quality and udder health. Journal of Dairy Science, 75, 96–104. https://doi.org/10.3168/jds.S0022-0302(92)77743-1

Gomez A and Cook NB, 2010. Time budgets of lactating dairy cattle in commercial freestall herds. Journal of Dairy Science, 93, 5772–5781. https://doi.org/10.3168/jds.2010-3436

Griffiths BE, Grove White D and Oikonomou G, 2018. A cross-sectional study into the prevalence of dairy cattle lameness and associated herd-level risk factors in England and Wales. Frontiers in Veterinary Science, 5, 65. https://doi.org/10.3389/fvets.2018.00065

Gutmann AK, Špinka M and Winckler C, 2015. Long-term familiarity creates preferred social partners in dairy cows. Applied Animal Behaviour Science, 169, 1–8. https://doi.org/10.1016/j.applanim.2015.05.007

Häggman J and Juga J, 2015. Effects of cow-level and herd-level factors on claw health in tied and loose-housed dairy herds in Finland. Livestock Science, 181, 200–209. https://doi.org/10.1016/j.livsci.2015.07.014

Haley DB, Rushen J and Passillé AM, 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Canadian Journal of Animal Science, 80, 257–263. https://doi.org/10.4141/A99-084

Haley DB, de Passillé AM and Rushen J, 2001. Assessing cow comfort: effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Applied Animal Behaviour Science, 71, 105–117. https://doi.org/10.1016/S0168-1591(00)00175-1

Haskell MJ, Rennie LJ, Bowell VA, Bell MJ and Lawrence AB, 2006. Housing system, milk production, and zero-grazing effects on lameness and leg injury in dairy cows. Journal of Dairy Science, 89, 4259–4266. https://doi.org/10.3168/jds.S0022-0302(06)72472-9

Haskell MJ, Masłowska K, Bell DJ, Roberts DJ and Langford FM, 2013. The effect of a view to the surroundings and microclimate variables on use of a loafing area in housed dairy cattle. Applied Animal Behaviour Science, 147, 28–33. https://doi.org/10.1016/j.applanim.2013.04.016

Haufe HC, Gygax L, Steiner B, Friedli K, Stauffacher M and Wechsler B, 2009. Influence of floor type in the walking area of cubicle housing systems on the behaviour of dairy cows. Applied Animal Behaviour Science, 116, 21–27. https://doi.org/10.1016/j.applanim.2008.07.004

Haufe HC, Gygax L, Wechsler B, Stauffacher M and Friedli K, 2012. Influence of floor surface and access to pasture on claw health in dairy cows kept in cubicle housing systems. Preventive Veterinary Medicine, 105, 85–92. https://doi.org/10.1016/j.prevetmed.2012.01.016

Heins BJ, Sjostrom LS, Endres MI, Carillo MR, King R, Moon RD and Sorge US, 2019. Effects of winter housing systems on production, economics, body weight, body condition score, and bedding cultures for organic dairy cows. Journal of Dairy Science, 102, 706–714.

Henderson JP and Ball HJ, 1999. Polyarthritis due to Mycoplasma bovis infection in adult dairy cattle in Northern Ireland. The Veterinary Record, 145, 374–376. https://doi.org/10.1136/vr.145.13.374

Hennessy D, Delaby L, van den Pol-van DA and Shalloo L, 2020. Increasing grazing in dairy cow milk production systems in Europe. Sustainability, 12, 2443. https://doi.org/10.3390/su12062443

Heppelmann M, Kofler J, Meyer H, Rehage J and Starke A, 2009. Advances in surgical treatment of septic arthritis of the distal interphalangeal joint in cattle: a review. The Veterinary Journal, 182, 162–175. https://doi.org/10.1016/j.tvjl.2008.06.009

Hernandez-Mendo O, von Keyserlingk MAG, Veira DM and Weary DM, 2007. Effects of pasture on lameness in dairy cows. Journal of Dairy Science, 90, 1209–1214. https://doi.org/10.3168/jds.S0022-0302(07)71608-9

Hiitio H, Vakkamaki J, Simojoki H, Autio T, Junnila J, Pelkonen S and Pyorala S, 2017. Prevalence of subclinical mastitis in Finnish dairy cows: changes during recent decades and impact of cow and herd factors. Acta Veterinaria Scandinavica, 59, 22.

Hogan JS, Smith KL, Hoblet KH, Todhunter TA, Schoenberger PS, Hueston WD, Pritchard DE, Bowman GL, Heider LE, Brockett BL and Conrad HR, 1989. Bacterial counts in bedding materials used on nine commercial dairies. Journal of Dairy Science, 72, 250–258.

Hörning B, Aubel E and Simantke C (Bundesanstalt für Landwirtschaft und Ernährung (BLE)), 2003. Ökologische Milch- und Rindfleischproduktion; Struktur, Entwicklung, Probleme, politischer Handlungsbedarf [Organic dairy and beef production: Structure, development, problems, political need for action], Final Report Project 514-020E348. Bonn, Germany Available online: https://orgprints.org/id/eprint/13434/1/13434-02OE348-bleuni-%0Dkassel-2003-rinderproduktion.pdf

Horvath KC and Miller-Cushon EK, 2019. Characterizing grooming behavior patterns and the influence of brush access on the behavior of group-housed dairy calves. Journal of Dairy Science, 102, 3421–3430. https://doi.org/10.3168/jds.2018-15460

Houe H, Østergaard S, Thilsing-Hansen T, Jørgensen RJ, Larsen T, Sørensen JT, Agger JF and Blom JY, 2001. Milk fever and subclinical hypocalcaemia--an evaluation of parameters on incidence risk, diagnosis, risk factors and biological effects as input for a decision support system for disease control. Acta Veterinaria Scandinavica, 42, 1–29.

Hughes J, 2001. A system for assessing cow cleanliness. In Practice, 23, 517–524. https://doi.org/10.1136/inpract.23.9.517

Husfeldt AW and Endres MI, 2012. Association between stall surface and some animal welfare measurements in freestall dairy herds using recycled manure solids for bedding. Journal of Dairy Science, 95, 5626–5634. https://doi.org/10.3168/jds.2011-5075

Huxley JN, 2013. Impact of lameness and claw lesions in cows on health and production. Livestock Science, 156, 64–70. https://doi.org/10.1016/j.livsci.2013.06.012

IDELE, 2021. Dossier Technique - Diversité des bâtiments et des pratiques d'élevage. Available online: https://idele.fr/?eID=cmis_download&oID=workspace%3A%2F%2FSpacesStore%2F84a87b3a-8a42-4460-8af8-4699ed668d13&cHash=7859d6ea4f62ecf43d7f910340ce6adc

IDF, 2013. Guidelines for the use and interpretation of bovine milk somatic cell count. Bulletin of the International Dairy Federation, 466.

Ito K, Chapinal N, Weary DM and von Keyserlingk MAG, 2014. Associations between herd-level factors and lying behavior of freestall-housed dairy cows. Journal of Dairy Science, 97, 2081–2089. https://doi.org/10.3168/jds.2013-6861

Ivemeyer S, Knierim U and Waiblinger S, 2011. Effect of human-animal relationship and management on udder health in Swiss dairy herds. Journal of Dairy Science, 94, 5890–5902. https://doi.org/10.3168/jds.2010-4048

Ivemeyer S, Simantke C, Ebinghaus A, Poulsen PH, Sorensen JT, Rousing T, Palme R and Knierim U, 2018. Herd-level associations between human–animal relationship, management, fecal cortisol metabolites, and udder health of organic dairy cows. Journal of Dairy Science, 101, 7361–7374. https://doi.org/10.3168/jds.2017-13912

Janni KA, Endres MI, Reneau JK and Schoper WW, 2007. Compost dairy barn layout and management recommendations. Applied Engineering in Agriculture, 23, 97–102. https://doi.org/10.13031/2013.22333

Jensen MB, 2011. The early behaviour of cow and calf in an individual calving pen. Applied Animal Behaviour Science, 134, 92–99. https://doi.org/10.1016/j.applanim.2011.06.017

Jensen MB and Vestergaard M, 2021. Invited review: freedom from thirst—do dairy cows and calves have sufficient access to drinking water? Journal of Dairy Science, 104, 11368–11385.

Jensen MB, Herskin MS, Thomsen PT, Forkman B and Houe H, 2015. Preferences of lame cows for type of surface and level of social contact in hospital pens. Journal of Dairy Science, 98, 4552–4559. https://doi.org/10.3168/jds.2014-9203

Kara NK, Galic A and Koyuncu M, 2011. Effects of stall type and bedding materials on lameness and hygiene score and effect of lameness on some reproductive problems in dairy cattle. Journal of Applied Animal Research, 39, 334–338. https://doi.org/10.1080/09712119.2011.607890

Katzenberger K, Rauch E, Erhard M, Reese S and Gauly M, 2020. Evaluating the need for an animal welfare assurance programme in South Tyrolean dairy farming. Italian Journal of Animal Science, 19, 1146–1156. https://doi.org/10.1080/1828051X.2020.1823897

Kaufmann LD, Dohme-Meier F, Münger A, Bruckmaier RM and van Dorland HA, 2012. Metabolism of grazed vs. zero-grazed dairy cows throughout the vegetation period: hepatic and blood plasma parameters. Journal of Animal Physiology and Animal Nutrition, 96, 228–236. https://doi.org/10.1111/j.1439-0396.2011.01142.x

Keil NM, Wiederkehr TU, Friedli K and Wechsler B, 2006. Effects of frequency and duration of outdoor exercise on the prevalence of hock lesions in tied Swiss dairy cows. Preventive Veterinary Medicine, 74, 142–153. https://doi.org/10.1016/j.prevetmed.2005.11.005

Kester E, Holzhauer M and Frankena K, 2014. A descriptive review of the prevalence and risk factors of hock lesions in dairy cows. The Veterinary Journal, 202, 222–228. https://doi.org/10.1016/j.tvjl.2014.07.004

Khangura S, Konnyu K, Cushman R, Grimshaw J and Moher D, 2012. Evidence summaries: the evolution of a rapid review approach. Systematic reviews, 1, 1–9.

Khatun M, Clark CEF, Lyons NA, Thomson PC, Kerrisk KL and García SC, 2017. Early detection of clinical mastitis from electrical conductivity data in an automatic milking system. Animal Production Science, 57, 1226–1232. https://doi.org/10.1071/AN16707

King MTM, Pajor EA, LeBlanc SJ and DeVries TJ, 2016. Associations of herd-level housing, management, and lameness prevalence with productivity and cow behavior in herds with automated milking systems. Journal of Dairy Science, 99, 9069–9079. https://doi.org/10.3168/jds.2016-11329

Klaas IC, Bjerg B, Friedmann S and Bar D, 2010. Cultivated barns for dairy cows-an option to promote cattle welfare and environmental protection in Denmark? Dansk Veterinærtidsskrift, 93, 20–29.

Knierim U and Winckler C, 2009. On-farm welfare assessment in cattle: validity, reliability and feasibility issues and future perspectives with special regard to the Welfare Quality® approach. Animal Welfare, 18, 451–458.

Knierim U, Johns J, Ebinghaus A, Mück U and Sixt D, 2020. Poddey E and Kremer H-J. Begleitung von Milchviehherden bei der Umstellung von enthornten auf behornte Tiere oder von Anbinde- auf Laufställe unter Einbeziehung von Modellbetrieben als Basis für eine qualifizierte Beratung in der Milchviehhaltung, Schlussbericht.

Krawczel PD, Klaiber LB, Butzler RE, Klaiber LM, Dann HM, Mooney CS and Grant RJ, 2012. Short-term increases in stocking density affect the lying and social behavior, but not the productivity, of lactating Holstein dairy cows. Journal of Dairy Science, 95, 4298–4308. https://doi.org/10.3168/jds.2011-4687

Krohn CC, 1994. Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments. III. Grooming, exploration and abnormal behaviour. Applied Animal Behaviour Science, 42, 73–86.

Kromker V, Pfannenschmidt F, Helmke K, Andersson R and Grabowski NT, 2012. Risk factors for intramammary infections and subclinical mastitis in post-partum dairy heifers. Journal of Dairy Research, 79, 304–309.

Kujala M, Dohoo IR and Soveri T, 2010. White-line disease and haemorrhages in hooves of Finnish dairy cattle. Preventive Veterinary Medicine, 94, 18–27. https://doi.org/10.1016/j.prevetmed.2009.12.006

Laister S, Stockinger B, Regner A-M, Zenger K, Knierim U and Winckler C, 2011. Social licking in dairy cattle—effects on heart rate in performers and receivers. Applied Animal Behaviour Science, 130, 81–90. https://doi.org/10.1016/j.applanim.2010.12.003

Lambertz C, Sanker C and Gauly M, 2014. Climatic effects on milk production traits and somatic cell score in lactating Holstein-Friesian cows in different housing systems. Journal of Dairy Science, 97, 319–329. https://doi.org/10.3168/jds.2013-7217

Langford FM, Bell DJ, Nevison IM, Tolkamp BJ, Roberts DJ and Haskell MJ, 2021. What type of loafing areas do housed dairy cattle prefer? Applied Animal Behaviour Science, 245, 105511. https://doi.org/10.1016/j.applanim.2021.105511

Lardy R, des Roches AB, Capdeville J, Bastien R, Mounier L and Veissier I, 2021. Refinement of international recommendations for cubicles, based on the identification of associations between cubicle characteristics and dairy cow welfare measures. Journal of Dairy Science, 104, 2164–2184. https://doi.org/10.3168/jds.2019-17972

LAVES Tierschutzdienst (Niedersächsisches Ministerium für den ländlichen Raum, Ernährung, Landwirtschaft und Verbraucherschutz), 2007. Tierschutzleitlinie für die Milchkuhhaltung. Hannover, Germany.

Leach KA, Huber J, Whay H, Winckler C, March S and Dippel S, 2008. Assessing lameness in tied cows. Proceedings of the 15th International Symposium and 7th Conference on Lameness in Ruminants, Kuopio, Finland, 9–13 June, 126–128 pp.

Leach KA, Dippel S, Huber J, March S, Winckler C and Whay HR, 2009. Assessing lameness in cows kept in tie-stalls. Journal of Dairy Science, 92, 1567–1574. https://doi.org/10.3168/jds.2008-1648

Leach KA, Charlton GL, Green MJ, Lima E, Gibbons J, Black D and Bradley AJ, 2022. Bedding system influences lying behaviour in dairy cows. Veterinary Record, 190, e1066. https://doi.org/10.1002/vetr.1066

Lecorps B, Welk A, Weary DM and von Keyserlingk MAG, 2021. Postpartum stressors cause a reduction in mechanical brush use in dairy cows. Animals, 11, 3031. https://doi.org/10.3390/ani11113031

Ledgerwood DN, Winckler C and Tucker CB, 2010. Evaluation of data loggers, sampling intervals, and editing techniques for measuring the lying behavior of dairy cattle. Journal of Dairy Science, 93, 5129–5139. https://doi.org/10.3168/jds.2009-2945

Leonard FC, O'Connell J and O'Farrell K, 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Veterinary Record, 134, 490–494. https://doi.org/10.1136/vr.134.19.490

Leso L, Uberti M, Morshed W and Barbari M, 2013. A survey on Italian compost dairy barns. Journal of Agricultural Engineering, 44, e17. https://doi.org/10.4081/jae.2013.282

Leso L, Pellegrini P and Barbari M, 2019. Effect of two housing systems on performance and longevity of dairy cows in Northern Italy.

Leso L, Barbari M, Lopes MA, Damasceno FA, Galama P, Taraba JL and Kuipers A, 2020. Invited review: compost-bedded pack barns for dairy cows. Journal of Dairy Science, 103, 1072–1099. https://doi.org/10.3168/jds.2019-16864

Levison LJ, Miller-Cushon EK, Tucker AL, Bergeron R, Leslie KE, Barkema HW and DeVries TJ, 2016. Incidence rate of pathogen-specific clinical mastitis on conventional and organic Canadian dairy farms. J Dairy Sci, 99, 1341–1350.

Livesey CT, Harrington T, Johnston AM, May SA and Metcalf JA, 1998. The effect of diet and housing on the development of sole haemorrhages, white line haemorrhages and heel erosions in Holstein heifers. Animal Science, 67, 9–16. https://doi.org/10.1017/S1357729800009747

Lobeck KM, Endres MI, Shane EM, Godden SM and Fetrow J, 2011. Animal welfare in cross-ventilated, compost-bedded pack, and naturally ventilated dairy barns in the upper Midwest. Journal of Dairy Science, 94, 5469–5479. https://doi.org/10.3168/jds.2011-4363

Lobeck-Luchterhand KM, Silva PRB, Chebel RC and Endres MI, 2015. Effect of stocking density on social, feeding, and lying behavior of prepartum dairy animals. Journal of Dairy Science, 98, 240–249. https://doi.org/10.3168/jds.2014-8492

Loberg J, Telezhenko E, Bergsten C and Lidfors L, 2004. Behaviour and claw health in tied dairy cows with varying access to exercise in an outdoor paddock. Applied Animal Behaviour Science, 89, 1–16. https://doi.org/10.1016/j.applanim.2004.04.009

Logue DN and Mayne CS, 2014. Welfare-positive management and nutrition for the dairy herd: A European perspective. The Veterinary Journal, 199, 31–38. https://doi.org/10.1016/j.tvjl.2013.10.027

Lora I, Zidi A, Magrin L, Prevedello P and Cozzi G, 2020. An insight into the dairy chain of a protected designation of origin cheese: the case study of Asiago cheese. Journal of Dairy Science, 103, 9116–9123. https://doi.org/10.3168/jds.2019-17484

Lundmark Hedman F, Hultgren J, Röcklinsberg H, Wahlberg B and Berg C, 2018. Non-compliance and follow-up in Swedish official and private animal welfare control of dairy cows. Animals, 8, 72. https://doi.org/10.3390/ani8050072

Lutz J, Burla J-B, Gygax L, Wechsler B, Würbel H and Friedli K, 2019. Horned and dehorned dairy cows differ in the pattern of agonistic interactions investigated under different space allowances. Applied Animal Behaviour Science, 218, –104819. https://doi.org/10.1016/j.applanim.2019.05.008

Maasikmets M, Teinemaa E, Kaasik A and Kimmel V, 2015. Measurement and analysis of ammonia, hydrogen sulphide and odour emissions from the cattle farming in Estonia. Biosystems Engineering, 139, 48–59. https://doi.org/10.1016/j.biosystemseng.2015.08.002

Maher P, Good M and More SJ, 2008. Trends in cow numbers and culling rate in the Irish cattle population, 2003 to 2006. Irish Veterinary Journal, 61, 1–9.

Mandel R and Nicol CJ, 2017. Re-direction of maternal behaviour in dairy cows. Applied Animal Behaviour Science, 195, 24–31. https://doi.org/10.1016/j.applanim.2017.06.001

Mandel R, Whay HR, Nicol CJ and Klement E, 2013. The effect of food location, heat load, and intrusive medical procedures on brushing activity in dairy cows. Journal of Dairy Science, 96, 6506–6513. https://doi.org/10.3168/jds.2013-6941

Mandel R, Whay HR, Klement E and Nicol CJ, 2016. Invited review: Environmental enrichment of dairy cows and calves in indoor housing. Journal of Dairy Science, 99, 1695–1715. https://doi.org/10.3168/jds.2015-9875

Mandel R, Nicol CJ, Whay HR and Klement E, 2017. Short communication: Detection and monitoring of metritis in dairy cows using an automated grooming device. Journal of Dairy Science, 100, 5724–5728. https://doi.org/10.3168/jds.2016-12201

Mandel R, Harazy H, Gygax L, Nicol CJ, Ben-David A, Whay HR and Klement E, 2018. Short communication: Detection of lameness in dairy cows using a grooming device. Journal of Dairy Science, 101, 1511–1517. https://doi.org/10.3168/jds.2017-13207

Matson RD, King MTM, Duffield TF, Santschi DE, Orsel K, Pajor EA, Penner GB, Mutsvangwa T and DeVries TJ, 2022. Farm-level factors associated with lameness prevalence, productivity, and milk quality in farms with automated milking systems. Journal of Dairy Science, 105, 793–806.

Mattiello S, Arduino D, Tosi MV and Carenzi C, 2005. Survey on housing, management and welfare of dairy cattle in tie-stalls in western Italian Alps. Acta Agriculturae Scandinavica, Section A-Animal Science, 55, 31–39.

Mazer KA, Knickerbocker PL, Kutina KL and Huzzey JM, 2020. Changes in behavior and fecal cortisol metabolites when dairy cattle are regrouped in pairs versus individually after calving. Journal of Dairy Science, 103, 4681–4690. https://doi.org/10.3168/jds.2019-17593

McDonald PV, von Keyserlingk MAG and Weary DM, 2020. Hot weather increases competition between dairy cows at the drinker. Journal of Dairy Science, 103(4), 3447–3458. https://doi.org/10.3168/jds.2019-17456

McPherson SE and Vasseur E, 2021. Making tiestalls more comfortable: IV. Increasing stall bed length and decreasing manger wall height to heal injuries and increase lying time in dairy cows housed in deep-bedded tiestalls. Journal of Dairy Science, 104, 3339–3352. https://doi.org/10.3168/jds.2019-17668

Medeiros I, Fernandez-Novo A, Astiz S and Simões J, 2021. Production and health management from grazing to confinement systems of largest dairy bovine farms in Azores: A Farmers&rsquo Perspective. Animals, 11, 3394.

Mee JF, 2012. Reproductive issues arising from different management systems in the dairy industry. Reproduction in Domestic Animals, 47, 42–50. https://doi.org/10.1111/j.1439-0531.2012.02107.x

Mee JF and Boyle LA, 2020. Assessing whether dairy cow welfare is "better" in pasture-based than in confinement-based management systems. New Zealand Veterinary Journal, 68, 168–177. https://doi.org/10.1080/00480169.2020.1721034

Miedema HM, Cockram MS, Dwyer CM and Macrae AI, 2011. Behavioural predictors of the start of normal and dystocic calving in dairy cows and heifers. Applied Animal Behaviour Science, 132(1), 14–19. https://doi.org/10.1016/j.applanim.2011.03.003

Miller K and Woodgush DGM, 1991a. Some effects of housing on the social behavior of dairy cows. Animals Production, 53, 271–278.

Miller K and Woodgush DGM, 1991b. Some effects of housing on the social behavior of dairy cows. Animals Production, 53, 271–278.

Ministerio de Agricultura Pesca y A, 2020. Caracterización del sector español de vacuno de leche, Madrid, Spain.

Molina L, Agüera EI, Pérez-Marín CC and Maroto-Molina F, 2020. Comparing welfare indicators in dairy cattle under different loose housing systems (deep litter vs cubicle barns) using recycled manure solids for bedding. Spanish Journal of Agricultural Research, 18, –e0501.

Moncada AC, Neave HW, von Keyserlingk MAG and Weary DM, 2020. Use of a mechanical brush by dairy cows with chorioptic mange. Applied Animal Behaviour Science, 223, 104925. https://doi.org/10.1016/j.applanim.2019.104925

Moons CPH, Sonck B and Tuyttens FAM, 2014. Importance of outdoor shelter for cattle in temperate climates. Livestock Science, 159, 87–101.

Morabito E, Barkema HW, Pajor EA, Solano L, Pellerin D and Orsel K, 2017. Effects of changing freestall area on lameness, lying time, and leg injuries on dairy farms in Alberta, Canada. Journal of Dairy Science, 100, 6516–6526. https://doi.org/10.3168/jds.2016-12467

Müller E, Münger A, Mandel R, Eggerschwiler L, Schwinn AC, Gross JJ, Bruckmaier RM, Hess HD and Dohme-Meier F, 2018. Physiological and behavioural responses of grazing dairy cows to an acute metabolic challenge. Journal of Animal Physiology and Animal Nutrition, 102, 1120–1130. https://doi.org/10.1111/jpn.12931

Munksgaard L, Reenen CG and Boyce RE, 2006. Automatic monitoring of lying, standing and walking behavior in dairy cattle. Journal of Dairy Science, 89(Suppl 1), 304.

Navarro G, Green LE and Tadich T, 2013. Effect of lameness and lesion specific causes of lameness on time budgets of dairy cows at pasture and when housed. The Veterinary Journal, 197, 788–793.

Neave HW, Edwards JP, Thoday H, Saunders K, Zobel G and Webster JR, 2021. Do walking distance and time away from the paddock influence daily behaviour patterns and milk yield of grazing dairy cows? Animals, 11, 2903. https://doi.org/10.3390/ani11102903

Neave HW, Schütz KE and Dalley DE, 2022. Behavior of dairy cows managed outdoors in winter: Effects of weather and paddock soil conditions. Journal of Dairy Science, 105, 8298–8315. https://doi.org/10.3168/jds.2022-21819

Neubauer V, Humer E, Kröger I, Braid T, Wagner M and Zebeli Q, 2018. Differences between pH of indwelling sensors and the pH of fluid and solid phase in the rumen of dairy cows fed varying concentrate levels. Journal of Animal Physiology and Animal Nutrition, 102, 343–349. https://doi.org/10.1111/jpn.12675

Newby NC, Duffield TF, Pearl DL, Leslie KE, LeBlanc SJ and von Keyserlingk MAG, 2013. Short communication: use of a mechanical brush by Holstein dairy cattle around parturition. Journal of Dairy Science, 96, 2339–2344. https://doi.org/10.3168/jds.2012-6016

Nielsen C and Emanuelson U, 2013. Mastitis control in Swedish dairy herds. Journal of Dairy Science, 96, 6883–6893.

Nielsen LR, Pedersen AR, Herskin MS and Munksgaard L, 2010. Quantifying walking and standing behaviour of dairy cows using a moving average based on output from an accelerometer. Applied Animal Behaviour Science, 127, 12–19. https://doi.org/10.1016/j.applanim.2010.08.004

Nielsen BH, Thomsen PT and Sørensen JT, 2011. Identifying risk factors for poor hind limb cleanliness in Danish loose-housed dairy cows. Animal, 5, 1613–1619. https://doi.org/10.1017/S1751731111000905

Nielsen C, Stengärde L, Bergsten C and Emanuelson U, 2013. Relationship between herd-level incidence rate of energy-related postpartum diseases, general risk factors and claw lesions in individual dairy cows recorded at maintenance claw trimming. Acta Veterinaria Scandinavica, 55, 55. https://doi.org/10.1186/1751-0147-55-55

Nipers A, Pilvere I, Valdovska A and Proskina L, 2016. Assessment of key aspects of technologies and cow farming for milk production in Latvia. Proceedings of the, 25–27.

Nor NM, Steeneveld W and Hogeveen H, 2014. The average culling rate of Dutch dairy herds over the years 2007 to 2010 and its association with herd reproduction, performance and health. Journal of Dairy Research, 81, 1–8. https://doi.org/10.1017/S0022029913000460

Norberg E, 2005. Electrical conductivity of milk as a phenotypic and genetic indicator of bovine mastitis: a review. Livestock Production Science, 96, 129–139. https://doi.org/10.1016/j.livprodsci.2004.12.014

Nordlund KV and Garrett EF, 1994. Rumenocentesis: a technique for collecting rumen fluid for the diagnosis of subacute rumen acidosis in dairy herds. The Bovine Practitioner. 109–112.

Norring M, Manninen E, de Passillé AM, Rushen J and Saloniemi H, 2010. Preferences of dairy cows for three stall surface materials with small amounts of bedding. Journal of Dairy Science, 93, 70–74. https://doi.org/10.3168/jds.2009-2164

Nuss K and Weidmann E, 2013. Sprunggelenkschäden bei Milchkühen–eine Übersicht. Tierärztliche Praxis Ausgabe G: Großtiere/Nutztiere, 41, 234–244. https://doi.org/10.1055/s-0038-1623177

O'Connell J, Giller PS and Meaney W, 1989. A comparison of dairy cattle behavioural patterns at pasture and during confinement. Irish Journal of Agricultural Research. 65–72.

O'Connor AH, Bokkers EAM, de Boer IJM, Hogeveen H, Sayers R, Byrne N, Ruelle E, Engel B and Shalloo L, 2020. Cow and herd-level risk factors associated with mobility scores in pasture-based dairy cows. Preventive Veterinary Medicine, 181, 105077. https://doi.org/10.1016/j.prevetmed.2020.105077

O'Driscoll K, Boyle L, French P and Hanlon A, 2008. The effect of out-wintering pad design on hoof health and locomotion score of dairy cows. Journal of Dairy Science, 91, 544–553. https://doi.org/10.3168/jds.2007-0667

O'Driscoll K, Hanlon A, French P and Boyle L, 2009. The effects of two out-wintering pad systems compared with free-stalls on dairy cow hoof and limb health. Journal of Dairy Research, 76, 59–65. https://doi.org/10.1017/S0022029908003695

O'Driscoll K, Lewis E and Kennedy E, 2019. Effect of feed allowance at pasture on the lying behaviour of dairy cows. Applied Animal Behaviour Science, 213, 40–46. https://doi.org/10.1016/j.applanim.2019.02.002

Oehm AW, Knubben-Schweizer G, Rieger A, Stoll A and Hartnack S, 2019. A systematic review and meta-analyses of risk factors associated with lameness in dairy cows. BMC Veterinary Research, 15, 346. https://doi.org/10.1186/s12917-019-2095-2

Oehm AW, Jensen KC, Tautenhahn A, Mueller K-E, Feist M and Merle R, 2020. Factors associated with lameness in tie stall housed dairy cows in South Germany. Frontiers in Veterinary Science, 7, 1086. https://doi.org/10.3389/fvets.2020.601640

Oetting-Neumann P, Rohn K and Hoedemaker M, 2018. [Management of the dry and transition periods of dairy cattle in free stall housing systems in Lower Saxony. - Part 2: risk factores for subclinical ketosis, hypocalcaemia and increased lipomobilisation]. Tierarztliche Praxis. Ausgabe G, Grosstiere/Nutztiere, 46, 13–21. https://doi.org/10.15653/tpg-170544

Oetzel GR, 2003. Herd-based biological testing for metabolic disorders. Advance Dairy Technology, 15, 275–285.

Ofner-Schröck E, Zähner M, Huber G, Guldimann K, Guggenberger T and Gasteiner J, 2015. Compost barns for dairy cows—aspects of animal welfare. Open Journal of Animal Sciences, 5, 124–131. https://doi.org/10.4236/ojas.2015.52015

Olde Riekerink RG, Barkema HW, Scholl DT, Poole DE and Kelton DF, 2010. Management practices associated with the bulk-milk prevalence of Staphylococcus aureus in Canadian dairy farms. Preventive Veterinary Medicine, 97, 20–28.

Olechnowicz J and Jaskowski JM, 2011. Behaviour of lame cows: a review. Veterinarni Medicina, 56, 581–588.

Olechnowicz J, Jaśkowski JM, Antosik P, Bukowska D and Urbaniak K, 2010. Claw diseases and lameness in Polish Holstein-Friesian dairy cows. Bulletin of the Veterinary Institute in Pulawy, 54, 93–99.

Oliveira L and Ruegg PL, 2014. Treatments of clinical mastitis occurring in cows on 51 large dairy herds in Wisconsin. Journal of Dairy Science, 97, 5426–5436. https://doi.org/10.3168/jds.2013-7756

Olmos G, Boyle L, Hanlon A, Patton J, Murphy JJ and Mee JF, 2009a. Hoof disorders, locomotion ability and lying times of cubicle-housed compared to pasture-based dairy cows. Livestock Science, 125, 199–207. https://doi.org/10.1016/j.livsci.2009.04.009

Olmos G, Mee JF, Hanlon A, Patton J, Murphy JJ and Boyle L, 2009b. Peripartum health and welfare of Holstein-Friesian cows in a confinement-TMR system compared to a pasture-based system. Animal Welfare, 18, 467–476.

Osteras O, Solbu H, Refsdal AO, Roalkvam T, Filseth O and Minsaas A, 2007. Results and evaluation of thirty years of health recordings in the Norwegian dairy cattle population. Journal of Dairy Science, 90, 4483–4497.

Ostojić Andrić D, Hristov S, Novaković Ž, Pantelić V, Petrović MM, Zlatanović Z and Nikšić D, 2011. Dairy cows welfare quality in loose vs tie housing system. Biotechnology in Animal Husbandry, 27, 975–984.

Otten ND, Nielsen LR, Thomsen PT and Houe H, 2014. Register-based predictors of violations of animal welfare legislation in dairy herds. Animal, 8, 1963–1970. https://doi.org/10.1017/S1751731114001918

Ouweltjes W and Smolders EAA Wageningen UR Livestock Research, 2014. On farm development of bedded pack dairy barns in The Netherlands: animal welfare and milk quality. 1570–8616.

Palmer MA, Olmos G, Boyle LA and Mee JF, 2012. A comparison of the estrous behavior of Holstein-Friesian cows when cubicle-housed and at pasture. Theriogenology, 77, 382–388. https://doi.org/10.1016/j.theriogenology.2011.08.010

Palacio S, Peignier L, Pachoud C, Nash C, Adam S, Bergeron R, Pellerin D, de Passillé AM, Rushen J, Haley D, DeVries TJ and Vasseur E, 2017. Technical note: assessing lameness in tie-stalls using live stall lameness scoring. Journal of Dairy Science, 100(8), 6577–6582. https://doi.org/10.3168/jds.2016-12171

Pastell M, Hänninen L, de Passillé AM and Rushen J, 2010. Measures of weight distribution of dairy cows to detect lameness and the presence of hoof lesions. Journal of Dairy Science, 93(3), 954–960. https://doi.org/10.3168/jds.2009-2385

Peek S and Divers TJ, 2008. 2nd Edition. Rebhun's Diseases of Dairy Cattle-E-Book. Elsevier Health Sciences.

Peek S and Divers TJ, 2017. Rebhun's Diseases of Dairy Cattle-E-Book. Elsevier Health Sciences.

Peeler EJ, Green MJ, Fitzpatrick JL, Morgan KL and Green LE, 2000. Risk factors associated with clinical mastitis in low somatic cell count british dairy herds. Journal of Dairy Science, 83, 2464–2472. https://doi.org/10.3168/jds.S0022-0302(00)75138-1

Peli A, Pietra M, Giacometti F, Mazzi A, Scacco G, Serraino A and Scagliarini L, 2016. Survey on animal welfare in 943 Italian dairy farms. Italian Journal of Food Safety, 5. https://doi.org/10.4081/ijfs.2016.5832

Pelzer A, 2012. NRW-Bauschrift Milchviehhaltung: Beratungsempfehlungen für den Bau und die Ausstattung von Milchviehställen. Münster, Germany, Landwirtschaftskammer Nordrhein-Westfalen.

Penev T, Mitev Y, Iliev A, Borisov I, Miteva T, Gergovska Z and Uzunova K, 2012. Hygienic and technological conditions favouring lameness in dairy cows: a review. Revue de Medicine Veterinaire, 163, 499–504.

Penterman PM, Holzhauer M, van Engelen E, Smits D and Velthuis AGJ, 2022. Dynamics of Mycoplasma bovis in Dutch dairy herds during acute clinical outbreaks. The Veterinary Journal, 283–284, 105841. https://doi.org/10.1016/j.tvjl.2022.105841

Peters MDP, Silveira IDB and Fischer V, 2015. Impact of subclinical and clinical mastitis on sensitivity to pain of dairy cows. Animal, 9(12), 2024–2028. https://doi.org/10.1017/S1751731115001391

Pérez-Cabal MA and Alenda R, 2014. Clinical lameness and risk factors in a Spanish Holstein population. Livestock Science, 164, 168–174. https://doi.org/10.1016/j.livsci.2014.03.012

Perrin JB, Ducrot C, Vinard JL, Hendrikx P and Calavas D, 2011. Analysis of cattle mortality in France, 2003–2009. Inra Producation Animals, 24, 235–244.

Persson Waller K, Lundberg Å and Nyman AK, 2021. Risk and success factors for good udder health of early lactation primiparous dairy cows. Journal of Dairy Science, 104, 4858–4874. https://doi.org/10.3168/jds.2020-19683

Pfützner H and Sachse K, 1996a. Mycoplasma bovis as an agent of mastitis, pneumonia, arthritis and genital disorders in cattle. Revue scientifique et technique (International Office of Epizootics), 15, 1477–1494. https://doi.org/10.20506/rst.15.4.987

Pfützner H and Sachse K, 1996b. Mycoplasma bovis as an agent of mastitis, pneumonia, arthritis and genital disorders in cattle. Revue scientifique et technique (International Office of Epizootics), 15, 1477–1494. https://doi.org/10.20506/rst.15.4.987

Phillips CJC and Rind MI, 2001a. The effects on production and behavior of mixing uniparous and multiparous cows. Journal of Dairy Science, 84, 2424–2429. https://doi.org/10.3168/jds.S0022-0302(01)74692-9

Phillips CJC and Rind MI, 2001b. The effects of frequency of feeding a total mixed ration on the production and behavior of dairy cows. Journal of Dairy Science, 84, 1979–1987. https://doi.org/10.3168/jds.S0022-0302(01)74641-3

Phillips CJC and Schofield SA, 1994. The effect of cubicle and straw yard housing on the behaviour, production and hoof health of dairy cows. Animal Welfare, 3, 37–44.

Phillips CJC, Beerda B, Knierim U, Waiblinger S, Lidfors L, Krohn CC, Canali E, Valk H, Veissier I and Hopster H, 2013. A review of the impact of housing on dairy cow behaviour, health and welfare. Livestock Housing: Modern Management to Ensure Optimal Health and Welfare of Farm Animals. 37–54.

Platz S, Ahrens F, Bendel J, Meyer HHD and Erhard MH, 2008. What happens with cow behavior when replacing concrete slatted floor by rubber coating: a case study. Journal of Dairy Science, 91, 999–1004. https://doi.org/10.3168/jds.2007-0584

Pöllinger A, Zentner A, Brettschuh S, Lackner L, Amon B and Stickler Y, 2018. Erhebung zum Wirtschaftsdüngermanagement aus der landwirtschaftlichen Tierhaltung in Österreich, Abschlussbericht TIHALO II [Surveys on manure management from agricultural livestock farming in Austria, final report TIHALO II]. Place HBLFA Raumberg-Gumpenstein, HBLFA Raumberg-Gumpenstein.

Polsky L and von Keyserlingk MAG, 2017. Invited review: effects of heat stress on dairy cattle welfare. Journal of Dairy Science, 100, 8645–8657. https://doi.org/10.3168/jds.2017-12651

Popescu S, Borda C, Diugan EA, Spinu M, Groza IS and Sandru CD, 2013. Dairy cows welfare quality in tie-stall housing system with or without access to exercise. Acta Veterinaria Scandinavica, 55, 43. https://doi.org/10.1186/1751-0147-55-43

Popescu S, Borda C, Diugan EA, Niculae M, Stefan R and Sandru CD, 2014. The effect of the housing system on the welfare quality of dairy cows. Italian Journal of Animal Science, 13, 2940. https://doi.org/10.4081/ijas.2014.2940

Potterton SL, Green MJ, Harris J, Millar KM, Whay HR and Huxley JN, 2011. Risk factors associated with hair loss, ulceration, and swelling at the hock in freestall-housed UK dairy herds. Journal of Dairy Science, 94, 2952–2963. https://doi.org/10.3168/jds.2010-4084

PraeRi, 2020. Animal health, hygiene and biosecurity in German dairy cow operations – a prevalence study (PraeRi) Final report, June 30, 2020. Message.

Pro Weideland, 2018. Rahmenbedingungen und Kriterien für die Erzeugung und Vermarktung von Weidemilchprodukten im Rahmen des Projektes „Weideland Niedersachsen" Conditions and criteria for the production and marketing of pasture milk products within the project "Pasture Lan. Ovelgönne, Germany.

Pryce JE, Parker Gaddis KL, Koeck A, Bastin C, Abdelsayed M, Gengler N, Miglior F, Heringstad B, Egger-Danner C, Stock KF, Bradley AJ and Cole JB, 2016. Invited review: opportunities for genetic improvement of metabolic diseases. Journal of Dairy Science, 99, 6855–6873. https://doi.org/10.3168/jds.2016-10854

Pugliese M, Biondi V, Passantino A, Licitra F, Alibrandi A, Zanghi A, Conte F and Marino G, 2021. Welfare assessment in intensive and semi-intensive dairy cattle management system in Sicily. Animal Science Journal, 92, e13546. https://doi.org/10.1111/asj.13546

Raboisson D, Cahuzac E, Sans P and Allaire G, 2011. Herd-level and contextual factors influencing dairy cow mortality in France in 2005 and 2006. Journal of Dairy Science, 94, 1790–1803. https://doi.org/10.3168/jds.2010-3634

Randall LV, Green MJ, Green LE and Huxley JN, 2018. Use of statistical modelling to investigate the pathogenesis of claw horn disruption lesions in dairy cattle. The Veterinary Journal, 238, 41–48. https://doi.org/10.1016/j.tvjl.2018.07.002

Randall LV, Green MJ, Chagunda MG, Mason C, Green LE and Huxley JN, 2016. Lameness in dairy heifers; impacts of hoof lesions present around first calving on future lameness, milk yield and culling risk. Preventive Veterinary Medicine, 133, 52–63. https://doi.org/10.1016/j.prevetmed.2016.09.006

Regula G, Danuser J, Spycher B and Wechsler B, 2004. Health and welfare of dairy cows in different husbandry systems in Switzerland. Preventive Veterinary Medicine, 66, 247–264. https://doi.org/10.1016/j.prevetmed.2004.09.004

Reich LJ, Weary DM, Veira DM and von Keyserlingk MAG, 2010. Effects of sawdust bedding dry matter on lying behavior of dairy cows: a dose-dependent response. Journal of Dairy Science, 93, 1561–1565. https://doi.org/10.3168/jds.2009-2713

Reijs JW, Daatselaar CHG, Helming JFM, Jager JH and Beldman ACG, 2013. Grazing dairy cows in North-West Europe: economic farm performance and future developments with emphasis on the Dutch situation. Netherlands, LEI Wageningen UR, The Hague.

Reimus K, Alvåsen K, Emanuelson U, Viltrop A and Mõtus K, 2020. Herd-level risk factors for cow and calf on-farm mortality in Estonian dairy herds. Acta Veterinaria Scandinavica, 62, 15. https://doi.org/10.1186/s13028-020-0513-x

Ribeiro ES, Lima FS, Greco LF, Bisinotto RS, Monteiro APA, Favoreto M, Ayres H, Marsola RS, Martinez N, Thatcher WW and Santos JEP, 2013. Prevalence of periparturient diseases and effects on fertility of seasonally calving grazing dairy cows supplemented with concentrates. Journal of Dairy Science, 96, 5682–5697. https://doi.org/10.3168/jds.2012-6335

Richert RM, Cicconi KM, Gamroth MJ, Schukken YH, Stiglbauer KE and Ruegg PL, 2013. Risk factors for clinical mastitis, ketosis, and pneumonia in dairy cattle on organic and small conventional farms in the United States. Journal of Dairy Science, 96, 4269–4285. https://doi.org/10.3168/jds.2012-5980

Robles I, Zambelis A, Kelton DF, Barkema HW, Keefe GP, Roy JP, von Keyserlingk MAG and DeVries TJ, 2021. Associations of freestall design and cleanliness with cow lying behavior, hygiene, lameness, and risk of high somatic cell count. Journal of Dairy Science, 104, 2231–2242. https://doi.org/10.3168/jds.2020-18916

Roca-Fernández AI, Ferris CP and Gonzalez-Rodriguez A, 2013. Behavioural activities of two dairy cow genotypes (Holstein-Friesian vs. Jersey x Holstein-Friesian) in two milk production systems (grazing vs. confinement). Spanish Journal of Agricultural Research, 11, 120–126.

Rodríguez EM, Arís A and Bach A, 2017. Associations between subclinical hypocalcemia and postparturient diseases in dairy cows. Journal of Dairy Science, 100, 7427–7434. https://doi.org/10.3168/jds.2016-12210

Rowbotham RF and Ruegg PL, 2016. Associations of selected bedding types with incidence rates of subclinical and clinical mastitis in primiparous Holstein dairy cows. Journal of Dairy Science, 99, 4707–4717.

Rushen J, Haley D and de Passillé AM, 2007. Effect of softer flooring in tie stalls on resting behavior and leg injuries of lactating cows. Journal of Dairy Science, 90(8), 3647–3651. https://doi.org/10.3168/jds.2006-463

Rutherford KMD, Langford FM, Jack MC, Sherwood L, Lawrence AB and Haskell MJ, 2009. Lameness prevalence and risk factors in organic and non-organic dairy herds in the United Kingdom. The Veterinary Journal, 180, 95–105. https://doi.org/10.1016/j.tvjl.2008.03.015

Ruud LE, Bøe KE and Østerås O, 2010. Risk factors for dirty dairy cows in Norwegian freestall systems. Journal of Dairy Science, 93, 5216–5224. https://doi.org/10.3168/jds.2010-3321

Sambraus HH, Brummer H, Gv P, Schäfer M and Wennrich G, 1978. Nutztierethologie: Das Verhalten landwirtschaftlicher Nutztiere; eine angewandte Verhaltenskunde für die Praxis.

Santman-Berends IMGA, Olde Riekerink RGM, Sampimon OC, van Schaik G and Lam TJGM, 2012. Incidence of subclinical mastitis in Dutch dairy heifers in the first 100 days in lactation and associated risk factors. Journal of Dairy Science, 95, 2476–2484. https://doi.org/10.3168/jds.2011-4766

Santman-Berends IMGA, Swinkels JM, Lam TJGM, Keurentjes J and van Schaik G, 2016. Evaluation of udder health parameters and risk factors for clinical mastitis in Dutch dairy herds in the context of a restricted antimicrobial usage policy. Journal of Dairy Science, 99, 2930–2939. https://doi.org/10.3168/jds.2015-10398
Sarjokari K, Kaustell KO, Hurme T, Kivinen T, Peltoniemi OAT, Saloniemi H and Rajala-Schultz PJ, 2013. Prevalence and risk factors for lameness in insulated free stall barns in Finland. Livestock Science, 156, 44–52. https://doi.org/10.1016/j.livsci.2013.06.010
Sato S, Tarumizu K and Hatae K, 1993. The influence of social factors on allogrooming in cows. Applied Animal Behaviour Science, 38, 235–244. https://doi.org/10.1016/0168-1591(93)90022-H
Schenkenfelder J and Winckler C, 2021. Animal welfare outcomes and associated risk indicators on Austrian dairy farms: a cross-sectional study. Journal of Dairy Science, 104, 11091–11107. https://doi.org/10.3168/jds.2020-20085
Schenkenfelder J and Winckler C, 2022. To meet or not to meet welfare outcome thresholds: a case-control study in dairy cow herds. Animal, 16, 100461. https://doi.org/10.1016/j.animal.2022.100461
Schneider C, 2010. Dimensionierung und Gestaltung von Laufställen für behornte Milchkühe unter Berücksichtigung des Herdenmanagements. Place.
Schneider C, 2011. Laufställe für horntragende Milchkühe. 2nd edn. Frick, Switzerland, Forschungsinstitut für biologischen Landbau (FiBL).
Schulz KL, Anderson DE, Coetzee JF, White BJ and Miesner MD, 2011. Effect of flunixin meglumine on the amelioration of lameness in dairy steers with amphotericin B-induced transient synovitis-arthritis. American Journal of Veterinary Research, 72(11), 1431–1438. https://doi.org/10.2460/ajvr.72.11.1431
Schütz KE, Rogers AR, Poulouin YA, Cox NR and Tucker CB, 2010. The amount of shade influences the behavior and physiology of dairy cattle. Journal of Dairy Science, 93, 125–133. https://doi.org/10.3168/jds.2009-2416
Shane EM, Endres MI, Johnson DG and Reneau JK, 2010. Bedding options for an alternative housing system for dairy cows: a descriptive study. Applied Engineering in Agriculture, 26, 659–666.
Shepley E and Vasseur E, 2021. The effect of housing tiestall dairy cows in deep-bedded pens during an 8-week dry period on gait and step activity. JDS Communications, 2, 266–270. https://doi.org/10.3168/jdsc.2021-0091
Shepley E, Bergeron R and Vasseur E, 2017. Daytime summer access to pasture vs. free-stall barn in dairy cows with year-long outdoor experience: a case study. Applied Animal Behaviour Science, 192, 10–14. https://doi.org/10.1016/j.applanim.2016.11.003
Shepley E, Obinu G, Bruneau T and Vasseur E, 2019. Housing tiestall dairy cows in deep-bedded pens during an 8-week dry period: effects on lying time, lying postures, and rising and lying-down behaviors. Journal of Dairy Science, 102, 6508–6517. https://doi.org/10.3168/jds.2018-15859
Shepley E, Lensink J, Leruste H and Vasseur E, 2020a. The effect of free-stall versus strawyard housing and access to pasture on dairy cow locomotor activity and time budget. Applied Animal Behaviour Science, 224, 104928. https://doi.org/10.1016/j.applanim.2019.104928
Shepley E, Lensink J and Vasseur E, 2020b. Cow in motion: a review of the impact of housing systems on movement opportunity of dairy cows and implications on locomotor activity. Applied Animal Behaviour Science, 230, 105026. https://doi.org/10.1016/j.applanim.2020.105026
Siivonen J, Taponen S, Hovinen M, Pastell M, Lensink BJ, Pyörälä S and Hänninen L, 2011. Impact of acute clinical mastitis on cow behaviour. Applied Animal Behaviour Science, 132, 101–106. https://doi.org/10.1016/j.applanim.2011.04.005
Simensen E, Østerås O, Bøe KE, Kielland C, Ruud LE and Næss G, 2010. Housing system and herd size interactions in Norwegian dairy herds; associations with performance and disease incidence. Acta Veterinaria Scandinavica, 52, 14. https://doi.org/10.1186/1751-0147-52-14
Singh SS, Ward WR, Lautenbach K, Hughes JW and Murray RD, 1993. Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions. The veterinary record, 133, 469–474.
Sjöström K, Fall N, Blanco-Penedo I, Duval JE, Krieger M and Emanuelson U, 2018. Lameness prevalence and risk factors in organic dairy herds in four European countries. Livestock Science, 208, 44–50. https://doi.org/10.1016/j.livsci.2017.12.009
Smid A-MC, Weary DM, Costa JHC and von Keyserlingk MAG, 2018. Dairy cow preference for different types of outdoor access. Journal of Dairy Science, 101, 1448–1455. https://doi.org/10.3168/jds.2017-13294
Smid A-MC, Weary DM and von Keyserlingk MAG, 2020. The influence of different types of outdoor access on dairy cattle behavior. Frontiers in Veterinary Science, 7, 257. https://doi.org/10.3389/fvets.2020.00257
Solano L, Barkema HW, Pajor EA, Mason S, LeBlanc SJ, Nash CGR, Haley DB, Pellerin D, Rushen J, de Passillé AM, Vasseur E and Orsel K, 2016. Associations between lying behavior and lameness in Canadian Holstein-Friesian cows housed in freestall barns. Journal of Dairy Science, 99, 2086–2101. https://doi.org/10.3168/jds.2015-10336
Somers J and O'Grady L, 2015. Foot lesions in lame cows on 10 dairy farms in Ireland. Irish Veterinary Journal, 68, 10. https://doi.org/10.1186/s13620-015-0039-0
Somers J, Frankena K, Noordhuizen-Stassen EN and Metz JHM, 2003. Prevalence of claw disorders in dutch dairy cows exposed to several floor systems. Journal of Dairy Science, 86, 2082–2093. https://doi.org/10.3168/jds.S0022-0302(03)73797-7
Somers J, Schouten WGP, Frankena K, Noordhuizen-Stassen EN and Metz JHM, 2005a. Development of claw traits and claw lesions in dairy cows kept on different floor systems. Journal of Dairy Science, 88, 110–120. https://doi.org/10.3168/jds.S0022-0302(05)72668-0

Somers J, Frankena K, Noordhuizen-Stassen EN and Metz JHM, 2005b. Risk factors for interdigital dermatitis and heel erosion in dairy cows kept in cubicle houses in The Netherlands. Preventive Veterinary Medicine, 71, 23–34. https://doi.org/10.1016/j.prevetmed.2005.05.001
Sova AD, LeBlanc SJ, McBride BW and DeVries TJ, 2013. Associations between herd-level feeding management practices, feed sorting, and milk production in freestall dairy farms. Journal of Dairy Science, 96, 4759–4770.
Sprecher DJ, Hostetler DE and Kaneene JB, 1997. A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance. Theriogenology, 47, 1179–1187. https://doi.org/10.1016/S0093-691X(97)00098-8
Spruijt BM, Van Hooff JA and Gispen WH, 1992. Ethology and neurobiology of grooming behavior. Physiological Reviews, 72, 825–852.
Statista, 2021. Available online: https://de.statista.com/ [Accessed: 1 June 2023].
Statistics Denmark, 2021a. Number of dairy cows in Denmark 4th quarter of 2020 from Statistikbanken. Available online: www.statistikbanken.dk/KVAEG5 [Accessed: 3 December 2022].
Statistics Denmark, 2021b. Næsten halvdelen af Danmarks kvægbestand kommer på græs en del af året (Nearly half of the Danish cattle herd is on pasture part of the year). Available online: https://www.dst.dk/da/Statistik/nyheder-analyser-publ/bagtal/2021/2021-07-20-Naesten-halvdelen-af-danmarks-kvaegbestand-kommer-paa-graes [Accessed: 3 December 2022].
Statistik Austria, 2020. Available online: https://www.statistik.at/ [Accessed: 1 June 2023].
Statistisches Bundesamt, 2021a. Destatis https://www.destatis.de/ Accessed: 1 June 2023.
Statistisches Bundesamt, 2021b. Land- und Forstwirtschaft, Fischerei – Stallhaltung, Weidehaltung – Landwirtschaftszählung, Fachserie 3 [Agriculture, forestry and fisheries - housing, grazing - agricultural census, series 3], Wiesbaden, Germany Available online: https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Produktionsmethoden/Publikationen/Downloads-Produktionsmethoden/stallhaltung-weidehaltung-tb-5411404209004.pdf?__blob=publicationFile
Stengärde L, Hultgren J, Tråvén M, Holtenius K and Emanuelson U, 2012. Risk factors for displaced abomasum or ketosis in Swedish dairy herds. Preventive Veterinary Medicine, 103, 280–286. https://doi.org/10.1016/j.prevetmed.2011.09.005
Stoye S, Porter MA and Stamp Dawkins M, 2012. Synchronized lying in cattle in relation to time of day. Livestock Science, 149, 70–73. https://doi.org/10.1016/j.livsci.2012.06.028
Svennesen L, Enevoldsen C, Bjerg B and Klaas I, 2014. Udder health in a Danish compost bedded pack barn. Proceedings of the Abstract presented at NMC Regional Meeting. Ghent, Belgium.
Sverige V, 2021. Husdjursstatistik - Cattle statistics, 2021. Available online: https://www.vxa.se/globalassets/dokument/statistik/husdjursstatistik-2021.pdf [Accessed: 1 June 2023].
Talebi A, von Keyserlingk MAG, Telezhenko E and Weary DM, 2014. Reduced stocking density mitigates the negative effects of regrouping in dairy cattle. Journal of Dairy Science, 97, 1358–1363. https://doi.org/10.3168/jds.2013-6921
Taponen S, Liski E, Heikkila AM and Pyorala S, 2017. Factors associated with intramammary infection in dairy cows caused by coagulase-negative staphylococci, Staphylococcus aureus, Streptococcus uberis, Streptococcus dysgalactiae, Corynebacterium bovis, or Escherichia coli. Journal of Dairy Science, 100, 493–503.
Tarantola M, Valle E, De Marco M, Bergagna S, Dezzutto D, Silvia Gennero M, Bergero D, Schiavone A and Prola L, 2016. Effects of abrupt housing changes on the welfare of Piedmontese cows. Italian Journal of Animal Science, 15, 103–109. https://doi.org/10.1080/1828051X.2015.1128691
Teagasc, 2018. National Farm Survey Dairy Enterprise Factsheet 2018. Message.
Telezhenko E and Bergsten C, 2005. Influence of floor type on the locomotion of dairy cows. Applied Animal Behaviour Science, 93, 183–197. https://doi.org/10.1016/j.applanim.2004.11.021
Telezhenko E, Bergsten C, Magnusson M and Nilsson C, 2009. Effect of different flooring systems on claw conformation of dairy cows. Journal of Dairy Science, 92, 2625–2633. https://doi.org/10.3168/jds.2008-1798
Telezhenko E, von Keyserlingk MAG, Talebi A and Weary DM, 2012. Effect of pen size, group size, and stocking density on activity in freestall-housed dairy cows. Journal of Dairy Science, 95, 3064–3069. https://doi.org/10.3168/jds.2011-4953
Thompson JS, Huxley JN, Hudson CD, Kaler J, Gibbons J and Green MJ, 2020. Field survey to evaluate space allowances for dairy cows in Great Britain. Journal of Dairy Science, 103, 3745–3759. https://doi.org/10.3168/jds.2019-17004
Thompson JS, Hudson CD, Huxley JN, Kaler J, Robinson RS, Woad KJ, Bollard N, Gibbons J and Green MJ, 2022. A randomised controlled trial to evaluate the impact of indoor living space on dairy cow production, reproduction and behaviour. Scientific Reports, 12, 3849. https://doi.org/10.1038/s41598-022-07826-9
Thomsen PT and Houe H, 2018. Cow mortality as an indicator of animal welfare in dairy herds. Research in Veterinary Science, 119, 239–243. https://doi.org/10.1016/j.rvsc.2018.06.021
Toaff-Rosenstein RL, Velez M and Tucker CB, 2017. Technical note: Use of an automated grooming brush by heifers and potential for radiofrequency identification-based measurements of this behavior. Journal of Dairy Science, 100, 8430–8437. https://doi.org/10.3168/jds.2017-12984
top agrar, 2019. Der Kompostierungsstall für Milchkühe – gut für die Kühe, aber aufwändig. Available online: https://www.topagrar.com/heftplus/der-kompostierungsstall-fuer-milchkuehe-gut-fuer-die-kuehe-aber-aufwaendig-11534523.html [Accessed: 1 June 2023].

Tresoldi G, Weary D, Filho PML and von Keyserlingk M, 2015. Social Licking in Pregnant Dairy Heifers. Animals, 5, 1169–1179. https://doi.org/10.3390/ani5040404

Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, Moher D, Peters MDJ, Horsley T, Weeks L, Hempel S, Akl EA, Chang C, McGowan J, Stewart L, Hartling L, Aldcroft A, Wilson MG, Garritty C, Lewin S, Godfrey CM, Macdonald MT, Langlois EV, Soares-Weiser K, Moriarty J, Clifford T, Tunçalp Ö and Straus SE, 2018. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Annals of Internal Medicine, 169, 467–473. https://doi.org/10.7326/M18-0850

Tucker CB, Weary DM and Fraser D, 2003. Effects of three types of free-stall surfaces on preferences and stall usage by dairy cows. Journal of Dairy Science, 86, 521–529. https://doi.org/10.3168/jds.S0022-0302(03)73630-3

Tucker CB, Rogers AR, Verkerk GA, Kendall PE, Webster JR and Matthews LR, 2007. Effects of shelter and body condition on the behaviour and physiology of dairy cattle in winter. Applied Animal Behaviour Science, 105, 1–13. https://doi.org/10.1016/j.applanim.2006.06.009

Tucker CB, Jensen MB, de Passillé AM, Hänninen L and Rushen J, 2021. Invited review: Lying time and the welfare of dairy cows. Journal of Dairy Science, 104, 20–46. https://doi.org/10.3168/jds.2019-18074

USDA, 2018. USDA Gain Report, Poland, 2018 dairy and products report. Available online: https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=2018 Dairy and Products Report_Warsaw_Poland_11-5-2018.pdf

USDA, 2021. Dairy: World Markets and Trade, Washington DC, USA. Available online: https://apps.fas.usda.gov/psdonline/circulars/dairy.pdf

Väärikkälä S, Hänninen L and Nevas M, 2019. Assessment of welfare problems in finnish cattle and pig farms based on official inspection reports. Animals, 9, 263. https://doi.org/10.3390/ani9050263

Valde JP, Osteras O and Simensen E, 2005. Description of herd level criteria for good and poor udder health in Norwegian dairy cows. Journal of Dairy Science, 88, 86–92.

Val-Laillet D, Passillé AM, Rushen J and von Keyserlingk MAG, 2008a. The concept of social dominance and the social distribution of feeding-related displacements between cows. Applied Animal Behaviour Science, 111, 158–172. https://doi.org/10.1016/j.applanim.2007.06.001

Val-Laillet D, Veira DM and von Keyserlingk MAG, 2008b. Short communication: dominance in free-stall—housed dairy cattle is dependent upon resource. Journal of Dairy Science, 91, 3922–3926. https://doi.org/10.3168/jds.2008-1332

Val-Laillet D, Guesdon V, von Keyserlingk MAG, de Passillé AM and Rushen J, 2009. Allogrooming in cattle: relationships between social preferences, feeding displacements and social dominance. Applied Animal Behaviour Science, 116, 141–149. https://doi.org/10.1016/j.applanim.2008.08.005

van Amstel SR, Shearer JK and Palin FL, 2004. Moisture content, thickness, and lesions of sole horn associated with thin soles in dairy cattle. Journal of Dairy Science, 87, 757–763. https://doi.org/10.3168/jds.S0022-0302(04)73219-1

Van de Ven AH and Delbecq AL, 1972. The nominal group as a research instrument for exploratory health studies. American Journal of Public Health, 62, 337–342.

van den Pol-van DA, Hennessy D and Isselstein J, 2020. Grazing of dairy cows in europe—an in-depth analysis based on the perception of grassland experts. Sustainability, 12, 1098. https://doi.org/10.3390/su12031098

van der Peet G, Leenstra F, Vermeij I, Bondt N, Puister L and van Os J, 2018. Feiten en cijfers over de Nederlandse veehouderijsectoren 2018. Wageningen, Netherlands.

van Erp-van der Kooij E, Almalik O, Cavestany D, Roelofs J and van Eerdenburg F, 2019. Lying postures of dairy cows in cubicles and on pasture. Animals, 9, 183. https://doi.org/10.3390/ani9040183

van Gastelen S, Westerlaan B, Houwers DJ and van Eerdenburg FJCM, 2011. A study on cow comfort and risk for lameness and mastitis in relation to different types of bedding materials. Journal of Dairy Science, 94, 4878–4888. https://doi.org/10.3168/jds.2010-4019

Van Hertem T, Maltz E, Antler A, Romanini CE, Viazzi S, Bahr C, Schlageter-Tello A, Lokhorst C, Berckmans D and Halachmi I, 2013. Lameness detection based on multivariate continuous sensing of milk yield, rumination, and neck activity. Journal of Dairy Science, 96(7), 4286–4298. https://doi.org/10.3168/jds.2012-6188

Vanholder T, Papen J, Bemers R, Vertenten G and Berge ACB, 2015. Risk factors for subclinical and clinical ketosis and association with production parameters in dairy cows in The Netherlands. Journal of Dairy Science, 98, 880–888. https://doi.org/10.3168/jds.2014-8362

Veissier I, Andanson S, Dubroeucq H and Pomiès D, 2008. The motivation of cows to walk as thwarted by tethering. Journal of Animal Science, 86, 2723–2729. https://doi.org/10.2527/jas.2008-1020

VIT (Vereinigte Informationssysteme Tierhaltung), 2021. Trends, Fakten, Zahlen 2020. Verden, Germany. Available online: https://www.vit.de/fileadmin/Wir-sind-vit/Jahresberichte/vit-JB2020-gesamt.pdf

von Keyserlingk MAG and Weary DM, 2010. Review: feeding behaviour of dairy cattle: meaures and applications. Canadian Journal of Animal Science, 90, 303–309. https://doi.org/10.4141/CJAS09127

von Keyserlingk MAG, Olenick D and Weary DM, 2008. Acute behavioral effects of regrouping dairy cows. Journal of Dairy Science, 91, 1011–1016. https://doi.org/10.3168/jds.2007-0532

von Keyserlingk MAG, Barrientos A, Ito K, Galo E and Weary DM, 2012. Benchmarking cow comfort on North American freestall dairies: Lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. Journal of Dairy Science, 95, 7399–7408. https://doi.org/10.3168/jds.2012-5807 von Keyserlingk MAG, Amorim Cestari A, Franks B, Fregonesi JA and Weary DM, 2017. Dairy cows value access to pasture as highly as fresh feed. Scientific Reports, 7, 44953. https://doi.org/10.1038/srep44953

Wagner K, Barth K, Palme R, Futschik A and Waiblinger S, 2012. Integration into the dairy cow herd: long-term effects of mother contact during the first twelve weeks of life. Applied Animal Behaviour Science, 141, 117–129. https://doi.org/10.1016/j.applanim.2012.08.011

Wagner K, Brinkmann J, March S, Hinterstoißer P, Warnecke S, Schüler M and Paulsen H, 2017. Impact of daily grazing time on dairy cow welfare – results of the Welfare Quality® protocol. Animals, 8, 1. https://doi.org/10.3390/ani8010001

Wagner K, Brinkmann J, Bergschmidt A, Renziehausen C and March S, 2021. The effects of farming systems (organic vs. conventional) on dairy cow welfare, based on the Welfare Quality® protocol. Animal, 15, 100301. https://doi.org/10.1016/j.animal.2021.100301

Washburn SP, White SL, Green JT and Benson GA, 2002. Reproduction, mastitis, and body condition of seasonally calved Holstein and Jersey cows in confinement or pasture systems. Journal of Dairy Science, 85, 105–111. https://doi.org/10.3168/jds.S0022-0302(02)74058-7

Watters ME, Meijer KM, Barkema HW, Leslie KE, von Keyserlingk MA and Devries TJ, 2013. Associations of herd- and cow-level factors, cow lying behavior, and risk of elevated somatic cell count in free-stall housed lactating dairy cows. Preventive Veterinary Medicine, 111, 245–255.

Watters MEA, Barkema HW, Leslie KE, von Keyserlingk MAG and DeVries TJ, 2014. Relationship between postmilking standing duration and risk of intramammary infection in freestall-housed dairy cows milked 3 times per day. Journal of Dairy Science, 97, 3456–3471. https://doi.org/10.3168/jds.2013-7381

Weary DM and Taszkun I, 2000. Hock lesions and free-stall design. Journal of Dairy Science, 83, 697–702. https://doi.org/10.3168/jds.S0022-0302(00)74931-9

Wechsler B, Schaub J, Friedli K and Hauser R, 2000. Behaviour and leg injuries in dairy cows kept in cubicle systems with straw bedding or soft lying mats. Applied Animal Behaviour Science, 69, 189–197. https://doi.org/10.1016/S0168-1591(00)00134-9

Weigele HC, Gygax L, Steiner A, Wechsler B and Burla JB, 2018. Moderate lameness leads to marked behavioral changes in dairy cows. Journal of Dairy Science, 101, 2370–2382. https://doi.org/10.3168/jds.2017-13120

Welfare Quality®, 2009. Welfare Quality® assessment protocol for cattle. Welfare Quality® Consortium, Lelystad, Netherlands.

Westin R, Vaughan A, de Passillé AM, DeVries TJ, Pajor EA, Pellerin D, Siegford JM, Vasseur E and Rushen J, 2016a. Lying times of lactating cows on dairy farms with automatic milking systems and the relation to lameness, leg lesions, and body condition score. Journal of Dairy Science, 99, 551–561. https://doi.org/10.3168/jds.2015-9737

Westin R, Vaughan A, de Passillé AM, DeVries TJ, Pajor EA, Pellerin D, Siegford JM, Witaifi A, Vasseur E and Rushen J, 2016b. Cow- and farm-level risk factors for lameness on dairy farms with automated milking systems. Journal of Dairy Science, 99, 3732–3743. https://doi.org/10.3168/jds.2015-10414

Whay HR and Shearer JK, 2017. The Impact of Lameness on Welfare of the Dairy Cow. Veterinary Clinics of North America: Food Animal Practice, 33, 153–164. https://doi.org/10.1016/j.cvfa.2017.02.008

Whay HR, Waterman AE, Webster AJF and O'Brien JK, 1998. The influence of lesion type on the duration of hyperalgesia associated with hindlimb lameness in dairy cattle. The Veterinary Journal, 156, 23–29. https://doi.org/10.1016/S1090-0233(98)80058-0

White SL, Benson GA, Washburn SP and Green JT, 2002. Milk production and economic measures in confinement or pasture systems using seasonally calved Holstein and Jersey Cows. Journal of Dairy Science, 85, 95–104. https://doi.org/10.3168/jds.S0022-0302(02)74057-5

Wiggans GR and Shook GE, 1987. A lactation measure of somatic-cell count. Journal of Dairy Science, 70, 2666–2672.

Wilson-Welder J, Alt D and Nally J, 2015. Digital dermatitis in cattle: current bacterial and immunological findings. Animals, 5, 1114–1135. https://doi.org/10.3390/ani5040400

Winckler C and Willen S, 2001. The reliability and repeatability of a lameness scoring system for use as an indicator of welfare in dairy cattle. Acta Agriculturae Scandinavica, Section A — Animal Science, 51, 103–107. https://doi.org/10.1080/090647001316923162

Winckler C, Tucker CB and Weary DM, 2015. Effects of under-and overstocking freestalls on dairy cattle behaviour. Applied Animal Behaviour Science, 170, 14–19. https://doi.org/10.1016/j.applanim.2015.06.003

Winnicki S and Jugowar JL, 2011. The structure of cattle raising systems in Wielkopolska province. Problemy Inzynierii Rolniczej, 19, 83–90.

Yang DA, Laven RA and Chesterton RN, 2019a. Effects of climate and farm management practices on bovine digital dermatitis in spring-calving pasture-based dairy farms in Taranaki, New Zealand. The Veterinary Journal, 247, 75–80. https://doi.org/10.1016/j.tvjl.2019.03.004

Yang DA, Gates MC, Müller KR and Laven RA, 2019b. Bayesian analysis of herd-level risk factors for bovine digital dermatitis in New Zealand dairy herds. BMC Veterinary Research, 15, 125. https://doi.org/10.1186/s12917-019-1871-3

Zaalmink W, Bergevoet R, Daatselaar C and Smit B, 2020. Opportunities for improving the dairy sector in Romania. Wageningen, Netherlands, Wageningen Economic Research.

Zanon T, De Monte E and Gauly M, 2021. Effects of cattle breed and production system on veterinary diagnoses and administrated veterinary medicine in alpine dairy farms. Italian Journal of Animal Science, 20, 1126–1134.

Zuliani A, Mair M, Kraševec M, Lora I, Brscic M, Cozzi G, Leeb C, Zupan M, Winckler C and Bovolenta S, 2018. A survey of selected animal-based measures of dairy cattle welfare in the Eastern Alps: toward context-based thresholds. Journal of Dairy Science, 101, 1428–1436. https://doi.org/10.3168/jds.2017-13257

Abbreviations

a.p.	ante partum
ABM	Animal-based measures
acid-c	clinical acidosis
AMS	automatic milking system
AT	Austria
BCS	body condition score
BE	Belgium
BHB	beta hydroxybutyrate
CBS	Statistics Netherlands
CH	Switzerland
cub.	cubicles
d	days
DE	Germany
DIM	days in milk
DK	Denmark
ES	Spain
EST	Estonia
estim.	estimate
FI	Finland
FPR	fat protein ratio
FR	France
HU	Hungary
hypocal-c	clinical milk fever
ICAR	International Committee for Animal Recording
IRL	Ireland
ISR	Israel
IT	Italy
JPN	Japan
keto-c	clinical ketosis
keto-sc	subclinical ketosis
LDA	displaced abomasum
loose-h	loose housing
LSmeans	least square mean
LT	Lithuania
MA	multivariable analysis
MRD	milk recording data (≡ DHI, Dairy Health Improvement data)
na	not available
NEB	negative energy balance
NEFA	non-esterified fatty acid
NL	The Netherlands
NO	Norway
ns	not significant
NZ	New Zealand
OR	odds ratio
p.p.	post-partum
PL	Poland
PMR	partial mixed ration
pos	positive
preval.	prevalence
PT	Portugal
RO	Romania

SARA	subacuteruminal acidosis
SCC	Somatic Cell Count
SE	Sweden
SI	Slovenia
SRB	Serbia
tie-st	tie-stall
TMR	total mixed ration
TR	Türkiye
TS	Topic Search
UA	univariable analysis
UK	United Kingdom
USA	United States of America
USA(CA)	United States of America (California State)
USA(NE)	United States of America (Nebraska State)
USDA	United States Department of Agriculture

Appendix A – Statistical offices/databases of the EU-MS countries

Table A.1: Statistical offices/databases of the EU-MS countries

Country	Institution	Database	Link
EU	European Statistical Office	Eurostat	https://ec.europa.eu/eurostat/
Austria	Statistik Austria		https://www.statistik.at/
Belgium	StatBel		https://statbel.fgov.be/
Bulgaria	National Statistical Institute		https://www.nsi.bg/
Croatia	Croatian Bureau of Statistics	CBS	https://www.dzs.hr/
Cyprus	Statistical Service of Cyprus		https://www.cystat.gov.cy/
Czechia	Czech Statistical Office		https://www.czso.cz/
Denmark	Danmarks Statistic		https://www.statbank.dk/
Estonia	Statistics Estonia		https://www.stat.ee/
Finland	Statistics Finland		https://www.stat.fi/
Finland	Natural Resources Institute Finland	Luke	https://stat.luke.fi/
France	Institut national de la statistique et des études économiques	INSEE	https://www.insee.fr/
Germany	Statistisches Bundesamt	destatis	https://www.destatis.de/
Germany	Statista		https://de.statista.com/
Greece	Hellenic Statistical Authority		https://www.statistics.gr/
Hungary	Hungarian Central Statistical Office	KSH	https://www.ksh.hu/
Ireland	Central Statistics Office CSO		https://www.cso.ie/
Ireland	Central Statistics Office CSO	Open data portal	https://data.gov.ie/
Italy	Istituto Nazionale di Statistica	ISTAT	https://www.istat.it/
Latvia	Central Statistical Bureau of Latvia		https://www.csp.gov.lv/
Lithuania	Statistics Lithuania		https://www.stat.gov.lt/
Luxembourg	Service Central de la Statistique et des Etudes Economiques		https://statistiques.public.lu/
Malta	National Statistics Office	NSO	https://nso.gov.mt/
Netherlands	Centraal Bureau voor de Statistiek CBS	Statline	https://opendata.cbs.nl/statline/
Netherlands	Centraal Bureau voor de Statistiek	CBS	https://www.cbs.nl/
Poland	Statistics Poland		https://stat.gov.pl/
Portugal	Instituto Nacional de Estatística		https://ine.pt/
Romania	Institutul National de Statistica	Insse	https://insse.ro/
Slovakia	Statistical Office of the Slovak Republic		https://slovak.statistics.sk/
Slovenia	Statistical Office of the Republic of Slovenia		https://www.stat.si/statweb
Spain	Instituto Nacional de Estadística	INE	https://www.ine.es/
Sweden	Statistics Sweden	SCB	https://www.scb.se/

Appendix B – Literature search strategies

The methodological approach of a rapid review was used to address the research questions. A rapid review is defined as a knowledge synthesis in which components of the systematic and scoping review process (Tricco et al., 2018) are simplified or omitted to produce information in a shorter period of time (Khangura et al., 2012). For this scientific opinion, a rapid review was conducted for six different topics: husbandry systems, mastitis, foot and leg disorders, restriction of movement, metabolic disorders, dairy husbandry systems in the main milk-producing EU countries.

General methodology of the literature search

For this scientific opinion, the search was limited to the scientific database 'Web of Science'. Literature search, selection and abstraction were done by one person.

For each topic, a 'topic search' strategy (searching in abstract, title, author keywords, keywords plus) by using a specific keyword combination was defined (see following sections).

Search results were scanned by title and abstract for relevance using the following **inclusion criteria**:

- At least one of the populations studied was dairy cows (any lactation status, any age except calves and youngstock, including heifers in the last third of gestation).

Articles were **excluded** according to criteria depending on the topic (see following sections).

For each topic, details have been presented in narrative texts and/or tables in this opinion.

B.1. Literature search on husbandry systems

Table B.1: Description of the literature search on husbandry systems

Keyword combination of the 'topic search'	TS = ((dairy) AND (cow* OR cattle) AND (housing OR husbandry OR "farm type") AND (Europe OR European OR EU))
Defined time period	2015–2022 in order to focus on present housing systems and practices
Exclusion criteria	– exclusion of complete conference proceedings, – exclusion of articles in a language other than English or German, – exclusion of articles on countries other than EU-MS countries, – exclusion when no (direct) reference to certain housing systems or husbandry practices, – exclusion of experimental studies on individual (research) farms, – exclusion of articles on systems prevalent before 2000, – exclusion of attitude or consumer studies, – exclusion of project description only, no results given.
Outcome	Of 112 search results, **14 articles** were identified as relevant. For the descriptions, partly also literature from non-EU countries (such as Switzerland) was used, which was identified as relevant via a snowball search (literature cited in the selected literature).

B.2. Literature search on locomotory disorders

Table B.2: Description of the literature search on locomotory disorders

Keyword combination of the 'topic search'	TS = (dairy AND cow* OR cattle) AND ("locomot* problem*" OR "locomot* disorder*" OR "claw disorder*" OR "hoof disorder*" OR lame* OR "hock lesion*" OR "joint lesion*") AND (housing OR pasture)
Defined time period	1 January 2010 to 8 February 2022 in order to focus on present housing systems and practices
Exclusion criteria	– exclusion of proceedings, book chapters and editorial material, – exclusion of articles in a language other than English or German, – exclusion of articles from tropical countries, – exclusion of articles published in categories other than agricultural animal sciences, veterinary sciences, behavioural sciences and multidisciplinary sciences, – investigation of indicators other than indicators directly referring to foot and leg disorders,

	– investigation of implications/consequences instead of effects on foot and leg disorders, – exclusion of articles on husbandry systems or practices other than identified under Tor1, – no investigation of risk factors relating to housing systems or practices, – opinion elicitations, attitude or consumer studies, – prevalence studies involving less than five farms.
Outcome	Of 222 search results, 60 articles were identified as relevant, thereof 12 review articles. Of the remaining articles, five were not accessible. All other 43 were research articles on experimental or epidemiological studies.

Due to time restrictions, no further databases or hand searching of journals was conducted. However, a total of further 15 research articles (date range: 1 January 2010 until current) cited in the selected literature or identified in the literature examined under the search reported in Table B.1 were included as a supplement (snowball search).

B.3 Literature search on mastitis

Table B.3: Description of the literature search on mastitis

Keyword combination of the 'topic search'	TS = ((dairy AND cow* OR cattle) AND (mastitis OR "somatic cell*" OR "udder health") AND (risk AND (barn OR pasture OR "hous*")) NOT (goats or sheep or "buffalo*"))" as well as TS = ((dairy AND cow* OR cattle) AND (mastitis OR "somatic cell*" OR "udder health") AND (management AND (barn OR pasture OR "hous*")) NOT (goats or sheep or "buffalo*"))
Defined time period	1 January 2010 to 8 February 2022 in order to focus on present housing systems and practices
Exclusion criteria	– exclusion of proceedings, book chapters and editorial material, – exclusion of articles in a language other than English, – exclusion of articles from other countries than Europe, United States and Canada, – exclusion of articles published in categories others than agricultural animal sciences, veterinary sciences, – exclusion of articles on husbandry systems or practices other than identified under Tor1, – exclusion of case studies of mastitis outbreaks, – exclusion of articles on other topics: breeding, feeding, fertility, udder cleanliness and other welfare indicators, milk production, mortality, description of management without associations to health, – exclusion of articles with other study design than observational/epidemiological studies and experimental studies: surveys of farmer's attitudes, economical calculations, intervention/ medical treatment studies, – exclusion of review articles.
Outcome	Of 214 search results of research articles, 39 research articles were identified as relevant. A total of further eight relevant research articles cited in the selected literature were included in the review (snowball search). In total, **47 research articles** were reviewed in detail.

B.4. Literature search on restriction of movement and resting problems

For restriction of movement, a first literature search was conducted on review articles and a second literature search was conducted on research articles in order to also cover the time range of the last few years, which was not or only partially covered in the review articles.

Table B.4: Description of the literature search on restriction of movement

Literature search on review articles	
Keyword combination of the 'topic search'	TS = (dairy AND cow* OR cattle) AND (confine* OR move* OR "locomotor activity" OR exercise OR "social behav*" OR "lying behav*" OR "normal behav*" OR "sterotyp*") AND (housing OR husbandry OR pasture OR grazing OR outdoor OR yard OR paddock).
Defined time period	1 January 2010 and 2022 (8.2.2022)
Exclusion criteria	– exclusion of non-review articles, – exclusion of articles in a language other than English or German, – exclusion of articles from tropical countries, – exclusion of articles published in categories others than agricultural animal sciences, veterinary sciences, behavioural sciences and multidisciplinary sciences, – exclusion of articles on husbandry systems or practices other than identified under Tor1, – exclusion of review of methods' quality aspects only (e.g. reliability aspects), – exclusion of indicators not (directly) relating to animal welfare (e.g. milk flavour) and/or not to restriction of movement (e.g. feeding during transition period), – exclusion of foot and leg disorders.
Outcome	Out of 57 search results, **11 review articles** were identified as relevant. Four further review articles cited in the selected literature were additionally identified (snowball search).
Literature search on research articles	
Keyword combination of the 'topic search'	TS = (dairy AND (cow* OR cattle)) AND TS = (lying OR cleanliness OR "social behav*" OR "locomot* activity" OR "locomotion behav*") AND TS = (housing OR husbandry OR pasture)
Defined time period	2018-01-01 to current (11.2.2022)
Exclusion criteria	– exclusion of non-research articles, – exclusion of articles in a language other than English, – exclusion of articles from countries other than European countries, USA and Canada, – exclusion of articles published in categories other than agricultural animal sciences, veterinary sciences and behavioural sciences, – exclusion of articles on husbandry systems or practices other than identified under Tor1, – exclusion of investigation of methods quality aspects only, – exclusion of indicators not (directly) relating to animal welfare, – exclusion of descriptive case studies.
Outcome	The search resulted in 164 hits (some of which were articles that had already been found via the snowball search) of which 13 articles were identified as relevant. In total, **56 research articles** were reviewed in detail.

B.5. Literature search on metabolic disorders

Table B.5: Description of the literature search of research articles on metabolic disorders

Keyword combination of the 'topic search'	TS = ((dairy AND cow* OR cattle) AND (ketosis OR acidosis OR metabolic OR abomasum OR FPR) AND (pasture OR "hous*") NOT (goats or sheep or "buffalo*")) "and "TS = ((dairy AND cow* OR cattle) AND (ketosis OR acidosis OR metabolic OR abomasum OR FPR OR hypocalcemia) AND (pasture OR "hous*" OR stall) NOT (goats or giraffe or sheep or "buffalo*" or beef or steer)
Defined time period	1 January 2010 and current (2022-05-10) in order to focus on present housing systems and practices
Exclusion criteria	– exclusion of proceedings, book chapters and editorial material exclusion of articles in a language other than English or German, – exclusion of articles from other countries than Europe, United States and Canada, – exclusion of articles on husbandry systems or practices other than identified under Tor1, – exclusion of articles published in categories other than agricultural animal sciences and veterinary sciences,

	– exclusion of other topics: other topics: breeding, feeding, fertility and other welfare indicators, milk production, mortality, description of management without associations to health, – exclusion of other study design than observational/epidemiological studies and experimental studies: surveys of farmer's attitudes, economical calculations, – exclusion of review articles.
Outcome	Out of 131 search results of articles, 7 research articles were identified as relevant. From citations in the selected literature and from additional searches with a subset of keywords given above, 8 additional papers were included. In summary, **15 research articles** were reviewed.

B.6 Literature search on inability to perform comfort behaviour

Table B.6: Description of the literature search on the inability to perform comfort behaviour

Keyword combination of the 'topic search'	(TS = (dairy AND cow* OR cattle)) AND TS = ("comfort behav*" OR "*groom*" OR "brush")
Defined time period	2000-1-1 to 2022-4-28 (due to a limited number of studies on comfort behaviour in dairy cows, the search was extended to a longer publication period compared to the other literature search)
Exclusion criteria	– exclusion of non-review and non-research articles, – exclusion of articles in a language other than English, – exclusion of articles from other countries than Europe, USA, Canada, Japan, Australia and New Zealand, – exclusion of articles on husbandry systems or practices other than identified under Tor1, – exclusion of articles published in categories other than agricultural animal sciences, veterinary sciences and behavioural sciences, – exclusion of review or investigation of indicators other than animal-related indicators to assess comfort behaviour of dairy cows (e.g. cow-calf behaviour), – exclusion of investigations that considered comfort behaviour exclusively in the context of specific disorders (e.g. difficult calving) or events (e.g. novel object), or exclusively in relation to social networks, – exclusion of review or investigation of method quality aspects only.
Outcome	The search resulted in 179 hits of which 31 research and 4 review articles were identified as relevant. A snowball search of the review articles and report on task 1 identified a further three relevant research articles. In summary, **34 research articles** were reviewed.

Appendix C – Dairy husbandry systems: distribution in the main milk producing EU countries

In the following section, a brief description of dairy cow husbandry in selected EU member states is given including the main milk producing countries (in terms of total milk quantity, Table 1) as well as other countries representing a range of different climatic regions. However, for other countries than the main producers, no specific selection criteria were applied, but inclusion depended on the availability of information. When little or no statistical data or national reports were available for the main producing countries, information from the scientific literature was used.

Germany

According to the agricultural census in 2019–2020 (Statistisches Bundesamt, 2021b), 32.1% of all dairy cow holdings (in some cases several holdings per farm) were tie-stalls, 55.1% loose housing systems with cubicles, 10.6% straw yards, and the remainder other housing systems. In terms of animal numbers in the different housing systems, the majority of dairy cows were kept in cubicle housing (83.1%); this system is particularly prevalent on farms with larger herd sizes. The number of cows in tie-stalls was 11.5%, in straw yard systems 3.8% and in other systems 1.6%. In total, 12% of all housings and 12.5% of all holdings (except for year-round grazing) included access to an outdoor loafing area (Statistisches Bundesamt, 2021b).

The proportion of farms with a straw yard system is likely to be higher on organic dairy farms, due to the obligation to use bedding for the lying areas.[20] In a study by Hörning et al. (2003) involving 226 organic dairy farms with loose housing, the proportion of farms with straw yards accounted for 23%. In a current study by Wagner et al. (2021) on 46 organic and 69 conventional dairy farms in Germany, the proportion of straw yard barns was 54% among organic farms compared to 22% among the conventional farms.

Regardless of the housing system, 43% of all dairy farms in Germany offered cows access to pasture in summer (on average 14 h per day). Within the farms with herd sizes of more than 200 cows, however, with 6.4% the proportion of grazing farms was significantly lower. In addition, there were marked differences between the federal states: in Bavaria (south-east) the proportion of grazing dairy farms was 24%, in Schleswig-Holstein (north) 77%. In terms of animals, 31% of all dairy cows (1,221,900 out of 3,964,400 cows) had access to pasture (Statistisches Bundesamt, 2021b).

In addition to higher proportions of grazing farms in regions with a high share of grassland and depending on herd sizes, the proportion is also higher within organic dairy farms, which are obliged under EU Regulation 2018/848 to provide cows with permanent access to outdoor areas and preferably to pasture. In the study by Wagner et al. (2021) involving a total of 115 dairy farms in two different federal states in the north of Germany, access to pasture was offered by 74% of the conventional farms and by 100% of the organic farms, however, with marked differences in terms of hours per day (4.0–24.0 h) and days per year (150–365) (Wagner et al., 2021).

To be defined as grazing-pasture the German Pasture Charta requires at least 0.2 ha grassland with 0.1 ha pasture per cow and year, and access to pasture for at least 6 hours on 120 days per year (Pro Weideland, 2018).

France

In France, the share of tie-stall systems has decreased for years in favour of loose housing system (de Boyer des Roches et al., 2014). In 2015, 10.6% of all dairy farms had tie-stalls, in which 5.5% of all dairy cows were kept. The share in mountain areas, though, was significantly higher (40%) than in the lowlands (3%). At national level, accordingly, almost 90% of all French dairy farms kept their animals in loose housing systems in 2015: 56.5% of all farms had open-bedded systems (52.2% of all dairy cows) and 32.9% had cubicle systems, in which 42.3% of all cows were kept (idele, 2021).

In a study by van de Pol-van Dasselaar (2020), in which results from the working group 'Grazing' of the European Grassland Federation from 2010 to 2019 were analysed, the proportion of grazing cows in France was estimated at 90% in 2019. However, no information was given on grazing duration per day or grazing days per year. In a stratified study by de Boyer des Roches et al. (2014) on 131 French dairy farms, however, cows had access to pasture on average for 16 h (ranging from 0–24 h) on 229 days (ranging from 0–365 days).

[20] EU Regulation 2018/848 EUR-Lex - 02018R0848-20220101 - EN - EUR-Lex (europa.eu).

Poland

With regard to dairy cow housing systems in Poland, data are only available from the Wielkopolska region from 2010 (Winnicki and Jugowar, 2011). Wielkopolska in the mid-west of Poland is one of the most important dairy regions in Poland, the structure of which, according to Tomasz Sakowski (Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences, personal communication, November 2021), is also transferable to the other Polish dairy regions. In 2010, 87.1% of all dairy cows (371,500 out of 426,500) in Wielkopolksa were kept in tie-stall systems, the majority of them (99%) provided with litter on the lying area. 12.9% of the dairy cows were kept in loose housing systems (cubicle systems) - also predominantly with litter - which, however, was not specified in more detail. 0.3% of all cows were kept in slatted floor systems (without litter). 10% of all cows were offered pasture grazing (daily grazing time and grazing days per year were not specified).

Within the group of farms with larger herd sizes of >100 cows, the proportion of farms with loose housing systems was considerably higher: 56.3% of all herds, and 63.4% of all dairy cows (Winnicki and Jugowar, 2011).

According to Tomasz Sakowski (personal communication, November 2021), all cows on farms with herd sizes <30 cows in Poland (48% according to current statistical data) are still usually kept in tie-stall systems (with litter) plus a comparable proportion on larger herd sizes as reported by Winnicki and Jugowar (2011).

Italy

No official national statistics or reports could be accessed on dairy cow husbandry in Italy. However, scientific literature illustrates that farm structure, housing systems, and the extent of access to pasture for dairy cows differ considerably between regions in Italy (Benvenuti et al., 2018; Lora et al., 2020; Peli et al., 2016; Pugliese et al., 2021; Tarantola et al., 2016).

In the Alpine region, including e.g. Mugello (Benvenuti et al., 2018) or Piedmont region (Tarantola et al., 2016), with a high percentage of small-scale farms, structural and economic constraints, tie-stalls are the most prevalent housing system. In 2005, tie-stall systems still represented more than 98% of the total barns in the Alpine region (ISTAT in: Corazzin et al., 2010). But also in more recent scientific literature, the proportion of loose housing in the Alpine region of Italy was still reported to be low (Lora et al., 2020; Tarantola et al., 2016).

In lowland regions, however, loose housing systems predominate. In an epidemiological study by Peli et al. (2016) on 943 dairy farms in central and southern Italy, including Sicily and Sardinia, 84% of the participating farms used loose housing systems.

At national level, the proportion of dairy cows grazing in Italy has been estimated at 10–30%, buth without defining grazing hours per day or grazing days per year (van den Pol-van Dasselaar et al., 2020). Moreover, Peli et al. (2016) and Pugliese et al. (2021) point to regional differences, with higher proportions of farms offering pasture in central Italy. In the region of Sicily, the traditional semi-intensive system is characterised by access to pasture grazing for the provision of forage, for a minimum of 6 hours during day times from April to October. Farms with larger herds, mainly of the Holstein-Friesian breed, keep the animals in intensive systems in all-year loose housing without access to pasture (Pugliese et al., 2021).

Netherlands

In the 2012 report of the Dutch Statistical Office (CBS) on livestock farming, it was stated that 95% of all dairy cows were kept in cubicle systems. The remaining cows were kept in tie-stalls (4%) and other housing systems (1%). Straw yards were not represented (CBS, 2012).

About 80% of Dutch farms practise some form of grazing during part of the year, often defined as at least 6 h of grazing per day for at least 120 days per year. The other 20% of farms keep the animals indoors all year round (van der Peet et al., 2018).

Ireland

According to Muireann Conneely (Teagasc, Agriculture and Food Security Authority, personal communication, November 2021), there is no data available on the distribution of housing systems for Ireland at a national level.

However, dairy cow husbandry in Ireland is dominated by spring-time calving pasture-based systems (Crossley et al., 2021; Olmos et al., 2009a) offering pasture on up to 24 h per day for an average of 229 days per year (Teagasc, 2018). The largest proportion of dairy farms in Ireland (73%)

are located in the south. The average herd size there is 79 cows kept on an average of 60.5 ha (Dillon et al., 2021). Recent dramatic expansion in dairy cow numbers after the abolition of the EU milk quota (2015) may alter these statistics currently and in the future.

Romania

According to the research report by Zaalmink et al. (2020), 84% of Romanian dairy cow holdings can be considered as backyard farms keeping only one or two cows. Approximately only 25% of the milk produced is delivered to processing industry; the remaining part is either used for on-farm consumption or direct sales (Zaalmink et al., 2020). In 2013, the prevalence of tie-stall systems was estimated to be 75% in the middle sized and large farms and 90% in the small-scale farms in Romania (Popescu et al., 2013).

Denmark

Within the EU-MS, Denmark has the highest herd sizes with an average of more than 180 dairy cows per farm and at the same time the highest average milk yields (9.509 kg/cow*year, figures from 2016) (Eurostat, 2021).

The fact that tie-stalls will be banned in Denmark from 2027 is already reflected in a high proportion of cows in loose housing: In 2020, 60.7% of all cows were kept in cubicle systems and 32.2% in straw yard systems. A share of 3.3% were still kept in tie stalls. The remaining cows were either kept in other types of housing or in pasture-based systems. The majority of dairy cows in Denmark (71.4%), however, had no access to pasture in 2020, 3.9% for a period of 1–3 months per year, 18.6% for 4–6 months, 5.5% for 7–9 months and 0.6% for up to 12 months (Statistics Denmark, 2021b).

Austria

According to a survey conducted on behalf of the Austrian Federal Ministry for Sustainability and Tourism (Pöllinger et al., 2018), 37% of all dairy cows were kept in tie-stalls in 2016/2017. The remaining 63% were kept in loose housing systems: 59% in cubicles, 2% in straw yards, and 1% each in sloped-floor ('Tretmist') or compost-bedded pack systems. The latter is considered to be less established because the system does not suit every management and does not work in all climatic regions of Austria. Compared to a previous survey in 2005, the ratio has more or less reversed: at that time, 68.1% of the dairy cows were kept in tethered systems.

With regard to the type of floor, the majority of the Austrian dairy cows (46%) were kept in barns with solid floors. 27% were kept in barns with slatted floors, 20% had a combination of solid and slatted floors, and the remaining 7% were kept in barns with slatted floors combined with rubber lips.

According to information obtained from the farmers, 50% of all dairy cows were kept in systems with an outdoor loafing area available (defined as outdoor areas of < $10m^2$/cow to avoid confusion with pasture). Of these cows, 46% had permanent access to the outdoor area, 42% only 2–4 h access and 12% had 5–12 h access. Grazing was reported for 71% of all dairy cows. However, this proportion included all grazing types and durations. 17% of the grazing cows had on average only 1–5 h of grazing per day, 16% had more than 20 h of grazing per day (Pöllinger et al., 2018).

Sweden

In 2004, 75% of all Swedish dairy herds were still tethered during the winter housing season (Loberg et al., 2004). In 2015, however, the share of farms with tie-stall systems was estimated at only 45.0% (Barkema et al., 2015) and the share of tethered dairy cows at 32% (Lundmark Hedman et al., 2018). The declining trend is also attributable to the fact that new buildings of tie-stall barns are not allowed in Sweden since August 2007. Accordingly, any such currently existing systems are relatively old (Lundmark Hedman et al., 2018).

For all dairy cows, regardless of the housing system, the Swedish animal welfare legislation requires to provide pasture for at least 2–4 months (depending on the region) during the summer (Loberg et al., 2004; Lundmark Hedman et al., 2018).

Estonia

According to the Estonian Agricultural and Information Agency (EAIA) fully insulated tie-stall housing with solid manure systems represent the most prevalent housing systems in Estonia, and together with naturally-ventilated loose housing with liquid manure system (cubicles). Official statistical data on the distribution of the different housing systems and on grazing are not available. With regard to the housing systems, however, the trend is to change from tie-stall to loose housing systems (Maasikmets et al., 2015). Reimus et al. (2020) found in an epidemiological study that 61% of farms keeping 20 or more cows applied loose housing system and 39% of farms kept animals only indoors (no grazing) during the study period (2015–2017).

Finland

In Finland, tie-stalls are the most common housing system for dairy cows. However, according to a 2014 report by the Finnish Animal Welfare Centre (University of Helsinki), tie-stall housing is permitted in Finland, provided that the cows have access to exercise on a paddock or pasture for at least 60 days per year. Overall, 70% of all Finnish dairy farms, mostly small-scale farms with low animal numbers, kept the animals in tie-stalls in 2014. The average herd size over all farms in 2014 was 34 cows. A conversion from small herd size to viable loose housing size is considered economically not feasible for the majority of Finish cattle farms, which is why building costs for new tie-stall barns are also subsidised by the state. However, in the years before 2014, only 3–6 new tie-stalls were built annually compared to 60–86 new loose houses (Animal Welfare Centre, 2014).

In a study by Väärikkäla et al. (2019) of data collected during official national animal welfare inspections in 2010–2015 on 939 dairy farms, 88.7% of farms kept the cows tethered, and of these, 4.4% kept cows tethered without access to outdoor to a paddock during winter and 6.9% without access to an outdoor loafing area or pasture grazing in summer.

Azores Islands (Portugal)

Dairy farming on the Azores archipelago (autonomous region of the Azores) represents about 30% of the overall Portuguese dairy production and is the region's most important sector with a total annual milk production of 629,000 t in 2015 (ø milk yield per cow*year: 6,216 kg) (from Instituto Nacional de Estatística in de Almeida et al., 2021).

In 2018, a total of 91,250 dairy cows were kept in the Azores. Herd sizes ranged predominantly between 20 and 100 cows (de Almeida et al., 2021). Due to the mild temperate climate dairy cows are predominantly kept in pasture-based systems offering up to 100% pasture throughout the year (de Almeida et al., 2021). About 40% of the land occupation was classified as pasture land in 2017 (COS.A, 2018 in de Almeida et al., 2021).

Appendix D – Locomotory disorders: prevalence in different housing systems and effect of outdoor access

Table D.1: Lameness prevalence or mean locomotion scores reported for tie-stall systems

Country	n[(a)]	ø Herd size (range)	Scale	Level	Variable	Measure	Prevalence	Reference
AT, IT	93	14	0/1	herd	% lame	Mean	7.9	Katzenberger et al. (2020)
CAN	100	> 40	0/1	cow	% lame		25.0	Bouffard et al. (2017)
DE	56	26 (4–61)	0/1	herd	% lame	Mean	23.3	Oehm et al. (2020)
RO	30	70	0/1	herd	% lame	Mean	20.7	Popescu et al. (2014)
RO	80	69 (30–113)	0/1	herd	% lame	Range	8.6–30.0	Popescu et al. (2013)
Algeria	9	Small scale	1–3	Herd	% score ≥ 2	Mean	17.6	Dendani-Chadi et al. (2020)
PL	na	na	1–3	Cow	% score ≥ 2		42.2	Olechnowicz et al. (2010)
SRB	3	na	0–2	Herd	% score 1	Mean ± SD	54.2 ± 13.5	Ostojić Andrić et al. (2011)
					% score 2	Mean ± SD	16.3 ± 10.0	
Türkiye	15	na	0–3	Cow	Mean score		1.8	Kara et al. (2011)

(a): Number of farms, na – data not available.

Table D.2: Lameness prevalence or mean locomotion scores reported for cubicle systems

Country	n[(a)]	ø Herd size (range)	Scale	Level	Variable	Measure	Prevalence	Reference
DE	na	na	0–2	Cow	% score ≥ 1		26	Sjöström et al. (2018)
ES	na	na	0–2	Cow	% score ≥ 1		9	Sjöström et al. (2018)
FR	na	na	0–2	Cow	% score ≥ 1		26	Sjöström et al. (2018)
SI	na	na	0–2	Cow	% score ≥ 1		7	Sjöström et al. (2018)
ES	1	na	0–2	Herd	% score 1	LSmean	15.4	Fernández et al. (2020)
					% score 2	LSmean	0.7	
FR	76	51.2 [± 1.51]	0–2	Herd	% score 1	Median (1st–3rd quartiles)	9.2 [3.4–17.1]	De Boyer des Roches et al. (2014)
					% score 2		0.0 [0.0–3.6)	
DE	64	374 (47–1,609)	0–2	Herd	% score 2	Mean ± SD	15.7 ± 10.2	Gieseke et al. (2020)
Algeria	5	Small-scale	1–3	Herd	% score ≥ 2	Mean	6.1	Dendani-Chadi et al. (2020)
PL	na	na	1–3	Cow	% score ≥ 2		44.0	Olechnowic z et al. (2010)
UK	169	na	0–3	Herd	% score ≥ 2	Mean	38.8	Barker et al. (2010)
NL	179	(22–211)	1–5	Herd	% score > 2	Mean (range)	32.3 (0–97.7)	de Vries et al. (2015)
FI	87	49 (40–105)	1–5	Herd	% score > 2	Median (range)	21.0 (2.0–62.0)	Sarjokari et al. (2013)
AT	5	30 (20–39)	1–5	Herd	% score ≥ 2	Mean ± SD	14.9 ± 13.4	Burgstaller et al. (2016)

Country	n(a)	ø Herd size (range)	Scale	Level	Variable	Measure	Prevalence	Reference
USA	40	na	1–5	Herd	% score ≥ 3	Mean	55.0	Chapinal et al. (2013)
	39	na					31.0	
USA	66	851 (203–2966)	1–5	Herd	% score ≥ 3	Mean ± SD	13.2 ± 7.3	Cook et al. (2016)
					% score ≥ 4	Mean ± SD	2.5 ± 2.7	
CAN, USA	36	125	1–5	Herd	% score ≥ 4	Mean (range)	15 (2.5–46)	Westin et al. (2016)
					% score 5	Mean	4	
USA	7	na	1–5	Herd	Mean score	LSmean	2.27	Eckelkamp et al. (2016)
Türkiye	22	na	0–4	Cow	Mean score		1.53	Kara et al. (2011)

(a): Number of farms, na – data not available, LSmean – least squares mean.

Table D.3: Lameness prevalence reported for straw yard systems

Country	n(a)	Herd size	Scale	Level	Variable	Measure	Prevalence	Reference
SRB	3	na	0–2	Herd	% score 1	Mean ± SD	15.2 ± 10.3	Ostojić Andrić et al. (2011)
					% score 2	Mean ± SD	3.8 ± 2.5	
FR	na	na	0–2	Cow	% score ≥ 1		21	Sjöström et al. (2018)
DE	na	na	0–2	Cow	% score ≥ 1		12	Sjöström et al. (2018)
ES	na	na	0–2	Cow	% score ≥ 1		6	Sjöström et al. (2018)
UK	36	na	0–3	Herd	% score ≥ 2	Mean	27.1	Barker et al. (2010)

(a): Number of farms, na – data not available.

Table D.4: Lameness prevalence or mean locomotion scores reported for compost-bedded pack systems

Country	n(a)	ø Herd size (range)	Scale	Level	Variable	Measure	Prevalence	Reference
ES	1	na	0–2	Cow	% score 1	LSmean	13.2	Fernández et al. (2020)
					% score 2	LSmean	4.2	
AT	5	28 (20–41)	1–5	Herd	% score ≥ 2	Mean ± SD	18.7 ± 11.8	Burgstaller et al. (2016)
USA	6	121 (75–214)	1–5	Group	% score ≥ 3	LSmean	4.4	Lobeck et al. (2011)
	18				% score ≥ 4	LSmean	0.8	
AT	5	(18–35)	1–5	Cow	% score ≥ 3		25.4	Ofner-Schröck et al. (2015)
					% score ≥ 4		8.7	
USA	8	na	1–5	Herd	Mean score	LSmean	2.2	Eckelkamp et al. (2016)
IT	1	na	0–4	Herd	Mean score	Mean ± SD	1.0 ± 0.0	Biasato et al. (2019)

(a): Number of farms, experimental study in the case of n = 1, na – data not available.

Table D.5: Lameness prevalence reported for dairy cows kept in pasture-based systems

Country	n(a)	ø Herd size (range)	Scale	Level	Variable	Measure	Prevalence	Reference
IRL	82	125	0–3	Herd	% score ≥ 2	Mean	10.0 (summer)	Crossley et al. (2021)
IRL	10	(72–185)	1–5	Cow	% score ≥ 3		12.0 (summer)	Somers and O'Grady (2015)

(a): Number of farms.

Table D.6: Herd prevalence of claw disorders reported for tie-stall systems

Country	n(a)	ø Herd size	Level	Variable	Prevalence	Reference
PL	na	na	Claw	% claw diseases	38.8	Olechnowicz et al. (2010
FI	949	na	Cow	% infectious claw disease	1.7	Häggman and Juga (2015)
			Cow	% non-infectious claw disease	26.2	
AT, IT	93	14.4	Herd mean	% overgrown claws	44.4	Katzenberger et al. (2020)

(a): Number of farms, na – data not available.

Table D.7: Herd prevalence of claw disorders reported for cubicle systems

Country	n(a)	Herd size, ø (range)	Level	Variable	Measure	Prevalence	Reference
PL	na	na	Claw	% claw diseases		36.1	Olechnowicz et al. (2010)
AT	5	29.6 (20–39)	Cow	% concave dorsal wall		15.9	Burgstaller et al. (2016)
				% heel horn erosion		59.9	
				% interdigital dermatitis		3.1	
				% white line disease		46.6	
ES	1	na	Herd	% inflamed coronet	LSmeans	0.6	Fernández et al. (2020)
				% overgrown claws	LSmeans	15.2	
DK	41	164	Herd	% overgrown claws	Median	52.2(b)	Burow et al. (2013a)
AT, IT	111	23.7	Herd	% overgrown claws	Mean	31.8	Katzenberger et al. (2020)

(a): Number of farms, experimental study in the case of n = 1.
(b): Prevalence recorded during winter housing, but on farms offering summer pasture, na – data not available.

Table D.8: Herd prevalence of claw disorders reported for compost-bedded pack systems

Country	n(a)	Herd size, ø (range)	Level	Variable	Measure	Prevalence	Reference
IT	1	na	Herd	% claw diseases	Mean	0.0	Biasato et al. (2019)
	5	28.2 (20–41)	Cow	% concave dorsal wall		6.5	Burgstaller et al. (2016)
				% heel horn erosion		26.9	
				% interdigital dermatitis		0.2	
				% white line disease		20.4	
ES	1	na	Herd	% inflamed coronet	LSmeans	15.1	Fernández et al. (2020)
				% overgrown claws	LSmeans	19.1	

(a): Number of farms, experimental study in the case of n = 1, na – data not available.

Table D.9: Herd prevalence of claw disorders reported for pasture-based systems (100% all year)

Country	n(a)	ø Herd size	Level	Variable	Prevalence	Reference
NZ	57	na	Cow	% digital dermatitis	0.5–1.6 (5 farm visits)	Yang et al. (2019a)
NZ	127	840	Cow	% digital dermatitis	0.0–2.1 (4 regions)	Yang et al. (2019b)

(a): Number of farms, na – data not available.

Table D.10: Prevalence of integument alterations reported for tie-stall systems

Country	n(a)	Herd size, ø (range)	Level	Body region	Variable	Prevalence	Reference
AT, IT	93	14.4	Herd mean	Hock	% alteration(b)	70.3	Katzenberger et al. (2020)
CAN	100	> 40	Cow	Hock	% severe(c)	58.3	Bouffard et al. (2017)
CH	27	20 (15–49)	Cow	Hock	% mild(d)	62.2	Bernhard et al. (2020)
					% lesion	34.4	
					% swelling	24.0	
AT, IT	93	14.4	Herd mean	Knee	% alteration(b)	65.5	Katzenberger et al. (2020)
CAN	100	> 40	Cow	Knee	% severe(c)	43.8	Bouffard et al. (2017)
CH	27	20 (15–49)	Cow	Knee	% mild(d)	54.4	Bernhard et al. (2020)
					% lesion	7.7	
					% swelling	6.1	
CH	27	20 (15–49)	Cow	Stifle	% mild(d)	18.6	Bernhard et al. (2020)
					% lesion	8.9	
					% swelling	3.4	

(a): Number of farms.
(b): Hairless patches or lesion/swelling.
(c): Lesion/swelling.
(d): Hairless patches.

Table D.11: Prevalence of integument alterations reported for cubicle systems

Country	n(a)	ø Herd size	Level	Body region	Variable	Measure	Prevalence	Reference
AT, IT	111	23.7	Herd	Hock	% alteration(b)	Mean	26.1	Katzenberger et al. (2020)
DE, AT	105	58	Herd	Hock	% severe(c)	Mean (range)	50.0 (0–100)	Brenninkmeyer et al. (2013)
DK	41	164	Herd	Hock	% mild(d)	Median	24.5 (winter)	Burow et al. (2013a)
					% severe(c)	Median	21.7 (winter)	
SI	99	106	Herd	Hock	% mild(d)	Mean (range)	67 (23–100)	Ekman et al. (2018)
					% severe(c)	Mean (range)	6 (0–32)	
USA (CA)	38	na	Herd	Hock	% severe(c)	Mean ± SD	2 ± 3	Barrientos et al. (2013)
					% alteration(b)	Mean ± SD	57 ± 22	
USA (NE)	38	na	Herd	Hock	% alteration(b)	Mean ± SD	81 ± 22	Barrientos et al. (2013)
					% severe(c)	Mean ± SD	5 ± 6	
USA	66	851	Herd	Hock	% mild(d)	Mean ± SD	50.3 ± 28.3	Cook et al. (2016)
					% severe(c)	Mean ± SD	12.2 ± 15.3	

Country	n(a)	ø Herd size	Level	Body region	Variable	Measure	Prevalence	Reference
UK	63	162	Hock	Hock	% mild(e)		25.6	Potterton et al. (2011)
					% mild(f)		14.5	
					% lesion		18.1	
					% swelling(g)		23.0	
					% swelling(h)		2.3	
ES	1	na	Herd	Tarsus	% mild(a)	LSmeans	62.0	Fernández et al. (2020)
					% severe(e)	LSmeans	3.7	
FR	76	2,404 cows in total	Cow	Tarsus	% cows with at least one integument alteration		41.2	De Boyer des Roches et al. (2019)
AT, IT	111	23.7	Herd	Knee	% alteration(b)	Mean	35.1	Katzenberger et al. (2020)
DK	41	164	Herd	Knee	% mild(a)	Median	1.6 (winter)	Burow et al. (2013a)
					% severe(e)	Median	0.0 (winter)	
USA	66	851	Herd	Knee	% mild(a)	Mean ± SD	53.0 ± 24.0	Cook et al. (2016)
					% severe(e)	Mean ± SD	6.2 ± 5.5	
ES	1	na	Herd	Carpus	% mild(d)	LSmeans	2.9	Fernández et al. (2020)
					% severe(c)	LSmeans	0.6	
FR	76	2,404 cows in total	Cow	Carpus	% cows with at least one integument alteration		21.2	De Boyer des Roches et al. (2019)
FR	76	2,404 cows in total	Cow	Neck, shoulder, back	% cows with at least one integument alteration		28.2	De Boyer des Roches et al. (2019)
FR	76	2,404 cows in total	Cow	Flank, side, udder	% cows with at least one integument alteration		11.6	De Boyer des Roches et al. (2019)
FR	76	2,404 cows in total	Cow	Hindquarters	% cows with at least one integument alteration		22.0	De Boyer des Roches et al. (2019)

(a): Number of farms, experimental study in the case of n = 1.
(b): Hairless patch or lesion/swelling, na – data not available.
(c): Lesion/swelling.
(d): Hairless patches.
(e): Moderate hair loss.
(f): Severe hair loss.
(g): Moderate swelling.
(h): Severe swelling.

Table D.12: Prevalence of integument alterations reported for compost-bedded pack systems

Country	n(a)	Herd size, ø (range)	Level	Body region	Variable	Measure	Prevalence	Reference
USA	6	121(75–214)	Group	Hock	% alteration(b)	LSmeans	3.8	Lobeck et al. (2011)
					% severe	LSmeans	1.0	
IT	1	na	Cow	Hock	% severe	LSmeans	0.0	Biasato et al. (2019)

Country	n(a)	Herd size, ø (range)	Level	Body region	Variable	Measure	Prevalence	Reference
ES	1	na	Cow	Tarsus	% mild	LSmeans	2.0	Fernández et al. (2020)
ES	1	na	Cow	Tarsus	% severe	LSmeans	8.8	Fernández et al. (2020)
ES	1	na	cow	Carpus	% mild(c)	LSmeans	0.3	Fernández et al. (2020)
ES	1	na	Cow	Carpus	% severe(d)	LSmeans	0.3	Fernández et al. (2020)
AT	5	(18–35)	Herd	Limbs	% mild	Mean (range)	2.2 (0.0–12.6)	Ofner-Schröck et al. (2015)
AT	5	(18–35)	Herd	Limbs	% lesion	Mean (range)	0.7 (0.0–4.0)	Ofner-Schröck et al. (2015)

(a): Number of farms investigated; experimental study in the case of n = 1.
(b): Hairless patches or lesion/swelling, na – data not available.
(c): Hairless patches.
(d): Lesion/swelling.

Table D.13: Effects of access to pasture (or outdoor loafing) on lameness prevalence or mean locomotion scores of dairy cows

Country	System(a)	Time(b)	Group comparisons	Variable	n (herds)	n (animals)	Analysis(c)	Effect	Reference
DE	Tie-stall	na	Outdoor access (vs. zero-grazing)	Lame (no/yes)	56	1,006	MA	ns	Oehm et al. (2020)
IT	Tie-stall	Spring – winter	Zero-grazing Before grazing During grazing After grazing	% lame	24	–	UA	↓(d)	Corazzin et al. (2010)
RO	Tie-stall	Winter	Outdoor access (vs. zero-grazing)	% lame	80	3,192	UA	↓	Popescu et al. (2013)
CAN	Cubicle	May–January	Zero-grazing Overnight pasture	Mean score	1	50	MA	ns	Chapinal et al. (2010)
DE	Cubicle	Winter, summer	Zero-grazing < 6 h grazing(e) 6–10 h grazing(e) > 10 h grazing(d)	% lame	61	3,128	MA	↓	Armbrecht et al. (2019)
DE	Cubicle	Winter	Zero-grazing Summer pasture(f)	% severe lame	64	–	MA	ns	Gieseke et al. (2020)
DK	Cubicle	Winter	Zero-grazing Summer grazing	% lame	37	2,593	MA	ns	Andreasen and Forkman (2012)
DK	Cubicle	Winter, summer	Winter housing Summer grazing	% lame	56	3,148	UA	ns	Burow et al. (2013a)
NL	Cubicle	Winter	Zero-grazing Summer grazing	% lame	179	–	MA	↓	de Vries et al. (2015)

Country	System(a)	Time(b)	Group comparisons	Variable	n (herds)	n (animals)	Analysis(c)	Effect	Reference
USA	Cubicle	Summer	Zero-grazing Dry cows grazing	% lame	1	40	MA	↓	Chapinal et al. (2013)
Algeria	Various	Winter	Zero-grazing Summer-grazing All-year grazing	% lame	14	349	UA	↓	Dendani-Chadi et al. (2020)
AT, IT	Various	Summer	Zero-grazing Summer pasture	% lame	204	1,891	MA	↓	Katzenberger et al. (2020)
DE	Various	Summer	Zero-grazing Medium grazing High grazing	% lame	201	8,109	MA	↓	Sjöström et al. (2018)
DE	Various	Winter, summer	< 6 h grazing < 12 h grazing ≥ 12 h grazing	% lame	32	–	MA	↓	Wagner et al. (2017)
IRL	Pasture-based	Winter, summer	Winter housing Summer grazing(g)	% lame	64	–	UA	ns	Crossley et al. (2021)

↓ = significantly less lameness during grazing or with increased time spent on pasture ($p < 0.05$), ns = no significant ($p \geq 0.05$) or marginal ($p \geq 0.1$) effect.
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Period of data collection.
(c): Statistical analysis: MA = multivariable analysis (in the case of univariable preselection of factors only effects of the final models were considered), UA = univariable analysis.
(d): Significant differences were only found between prevalence before (12.4%) and during grazing (5.2%).
(e): Access to pasture at ≥ 120 days/year.
(f): Access to pasture for < 6 h/day.
(g): Access to pasture at > 200 days/year.

Table D.14: Effects of access to pasture or outdoor loafing area on prevalence of claw disorders

Country	System(a)	Time(b)	Group comparisons	n herds	n animals	Variable	Analysis(c)	Effect	Reference
IT	Tie-stall	Spring – winter	All-year tethering before pasture during pasture after pasture	24	–	Claw condition	UA	↓(d)	Corazzin et al. (2010)
FI	Tie-stall	Spring–winter	Pasture + winter exercise(e) Pasture + winter indoors Exercise(e) All-year indoors	949	28,645	Infectious claw diseases	MA	↑	Häggman and Juga (2015)
						Non-infectious claw diseases	MA	↓(f)	
AT, IT	Cubicle, tie-stall	Summer	Zero-grazing Summer pasture	204	1,891	Claw diseases	MA	↓	Katzenberger et al. (2020)
						Overgrown claws	MA	ns	

Country	System(a)	Time(b)	Group comparisons	n herds	n animals	Variable	Analysis(c)	Effect	Reference
CH	Cubicle	Spring–winter	Zero-grazing Summer pasture	35	339	Slight white line fissures	MA	↓	Haufe et al. (2012)
						Deep white line fissures	MA	ns	
						Digital dermatitis	MA	↓(g)	
						Heel horn erosion	MA	ns	
						Haemorrhage	MA	ns	
						Sole ulcer	MA	ns	
						Subclinical claw diseases	MA	↓(h)	
DE	Cubicle	Winter, summer	Zero-grazing < 6 h grazing(i) 6–10 h grazing(i) > 10 h grazing(e),(i)	20	240	Digital dermatitis	MA	ns	Armbrecht et al. (2018)
						Double sole	MA	ns	
						Heel horn erosion	MA	↓(j)	
						Horn fissure	MA	ns	
						Interdigital dermatitis	MA	ns	
						Interdigital hyperplasia	MA	ns	
						Interdigital phlegmon	MA	ns	
						Haemorrhage	MA	ns	
						Sole ulcer	MA	ns	
						White line disease	MA	ns	
DK	Cubicle	Winter, summer	Winter housing Summer grazing	56	3,148	Overgrown claws	UA	↓	Burow et al. (2013a)
IT	Cubicle, straw yard		Zero-grazing Summer pasture	18	2821	Claw disorders	UA	ns	Pugliese et al. (2021)
FI	Cubicle, straw yard	Spring–winter	Pasture + winter exercise(e) Pasture + winter indoors Exercise(e) All-year indoors	262	10,495	Infectious claw diseases	MA	ns	Häggman and Juga (2015)
						Non-infectious claw diseases	MA	ns	

↓ = significantly fewer disorders during outdoor access or with increased time spent in the outdoor loafing area ($p < 0.05$), ↑ = significantly more disorders ($p < 0.05$), ns = not significant ($p \geq 0.05$).
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Period of data collection.
(c): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
(d): After pasture vs. before pasture and all-year tethering; potential confounder by claw trimming before pasture.
(e): Access to outdoor loafing area.
(f): Summer pasture + winter exercise vs. all-year indoors.
(g): Effect of floor type*pasture.
(h): Effect of grazing*season (lowest risk at the end of summer on grazing farms).
(i): > 120 days/year.
(j): Effect of grazing*season.

Table D.15: Effect of access to pasture or outdoor loafing area on prevalence of integument alterations on the limbs

Country	System[(a)]	Time[(b)]	Group comparisons	N herds	N animals	Variable	Analysis[(c)]	Effect	Reference
CH	Tie-stall	Winter	< 13 days outdoor[(d)] 13 days outdoor[(d)] 14–15 days outdoor[(d)] > 15 days outdoor[(d)]	27	607	Carpal mild[(e)]	MA	↓[g]	Bernhard et al. (2020)
						Carpal severe[(f)] Severe[(g)]	MA	↓	
						Hock mild[(e)]	MA	↓	
						Hock severe[(f)] severe[(f)]	MA	ns	
						Stifle alterations	UA	ns	
IT	Tie-stall	Spring, summer, winter	All-year tethering Before pasture During pasture After pasture	24	–	Integument lesions	UA	↓[(o)]	Corazzin et al. (2010)
						Integument mild[f]	UA	ns	
RO	Tie-stall	Winter	All-year tethering Outdoor access	80	3,192	Integument severe[(g)]	UA	↓	Popescu et al. (2013)
AT, IT	Cubicle Tie-stall	Summer	Zero-grazing Summer pasture	204	1,891	Hock alterations	UA	↓	Katzenberger et al. (2020)
DE, AT	Cubicle	Winter	Days at pasture	105	3,691	Hock alterations	MA	ns	Brenninkmeyer et al. (2013)
			Outdoor loafing (no/yes)				MA	ns	
DE	Cubicle	Winter, summer	Zero-grazing < 6 h grazing[(l)] 6–10 h grazing[(l)] > 10 h grazing[(l)]	20	240	Integument mild[(g)]	MA	↓	Armbrecht et al. (2019)
						Integument severe[(f)]	MA	↓	
DE	Cubicle	Winter	Zero-grazing Summer pasture[m]	64	–	Integument severe[(f)]	MA	ns	Gieseke et al. (2020)
DK	Cubicle	na	Zero-grazing 3–9 h grazing 9–21 h grazing	56	3,148	Hock alterations	MA	↓[(d)]	Burow et al. (2013b)
						Hock severe[(j)]	MA	↓[(h)]	
DK	Cubicle	Winter, summer	Winter housing Summer grazing	56	3,148	Carpal index	UA	(↓)	Burow et al. (2013a)
						Hock index	UA	↓	
DK	Cubicle	Winter	Zero-grazing Summer pasture	37	2,593	Hock alterations	MA	ns	Andreasen and Forkman (2012)
NL	Cubicle	Winter	Zero-grazing Summer grazing	179	–	Integument severe[(j)]	MA	↓	de Vries et al. (2015)

Country	System(a)	Time(b)	Group comparisons	N herds	N animals	Variable	Analysis(c)	Effect	Reference
UK	Cubicle	Winter	2–40 days housing 41–76 days housing 77–11 days housing > 112 days housing	76	–	Hock lesions	MA	↓(i)*	Potterton et al. (2011)
						Hock mild(e)	MA	↓*	
						Hock swelling	MA	ns	
USA (NE)	Cubicle	Summer	Zero-grazing Dry cows grazing	38	1,450	Hock alterations	MA	↓	Barrientos et al. (2013)
						Hock severe(f)	MA	↓	
DE	Various	Winter, summer	< 6 h grazing < 12 h grazing ≥ 12 h grazing	32	–	Integument mild(f)	MA	↓	Wagner et al. (2017)
						Integument severe(g)	MA	ns	
IRL	Pasture-based	Winter, summer	Winter housing Summer grazing(n)	82	–	Carpal alterations	UA	↓	Crossley et al. (2021)
						Tarsus alterations	UA	↓	
						Hock severe(g)	MA	↓	

↓ = significantly fewer alterations during outdoor access or increased time spent outdoor ($p < 0.05$), (↓) = by tendency less alterations ($p < 0.1$), ns = not significant ($p \geq 0.05$).
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Period of data collection.
(c): Statistical analysis: MA = multivariable analysis (in the case of univariable preselection of factors only effects of the final models were considered), UA = univariable analysis.
(d): Outdoor exercise during winter.
(e): Hairless patches.
(f): Lesion/swelling.
(g): Only 14–15 days compared to < 13 days.
(h): 9–21 h compared to zero-grazing.
(i): Only 77–111 days compared to 2–14 days.
(j): Lesion/swelling.
(k): 9–21 h compared to zero-grazing.
(l): ≥ 120 days/year.
(m): < 6 h/days.
(n): > 200 days/year.
(o): Only after pasture vs. during pasture, and after pasture vs. zero-pasture.
*: Less integument alterations in lower number of winter housing days.

Appendix E – Mastitis: prevalence in different housing systems and management-related hazards

Table E.1: Bacteriological finding, clinical mastitis or somatic cell counts reported for tie-stall systems

Country	n[(a)]	ø herd size (range)	Variable	Level	Measure	Mean/ prevalence	Reference
Bacteriological findings (BACT)							
CAN	372	84	S. aur. in BM[(e),(b)]	Herd	Prev.	61%	Bauman et al. (2018)
Clinical mastitis (CM)							
CAN	35	65	CM/100 cow-yrs at risk	Herd	Prev.	23.7%	Levison et al. (2016)
NO	812	27 (15–55)	CM/cow	Herd	Prev.	0.21	Simensen et al. (2010)
CAN	180	(33–345)	CM incidence	Lactation	Incidence	8.8%	Elghafghuf et al. (2014)
Somatic cell count (SCC)							
USA	56	na	BMSCC	Herd	Mean	260	Eckelkamp et al. (2016)
NO	812	27 (15–55)	BMSCC	Herd	Mean	125; 145[(b),(c)]	Simensen et al. (2010)
CAN	11,019	na	gBMSCC	Herd	Mean	212	Bauman et al. (2018)
CAN	35	65	gBMSCC	Herd	Mean	241	Levison et al. (2016)
FI	na[(c),(d)]	na	CSCC	Cow	Mean	179.1	Hiitio et al. (2017)
	na[(c),(d)]	na	SCC ≥ 200 in ≥ 1 of 4 test days	Cow	Prev.	18.7%	
	na[(c),(d)]	na	SCC ≥ 200 in ≥ 13 of 4 test days	Cow	Prev.	14.8%	
USA	201	na	SCS	Herd	Mean	2.7; 3.0; 2.9[(d),(e)]	Dechow et al. (2011)

(a): Number of farms.
(b): *Staphylococcus aureus* in bulk tank milk.
(c): Small (20 cows); large herds (> 50 cows), both provided only graphically.
(d): 18.7% of 273,012 cows.
(e): Confined; with outdoor access and TMR; with outdoor access and component feeding.

Table E.2: Bacteriological finding, clinical mastitis or somatic cell counts reported for farms with cubicles only

Country	n[(a)]	ø herd size (range)	Variable	Level	Measure	Mean/ prevalence	Reference
Clinical mastitis (CM)							
CAN	77	(33–345)	CM	Lactation	Incidence	5.0%	Elghafghuf et al. (2014)
NO	363	26.5	CM/lactation	Lactation	Incidence	13.6%	Ruud et al. (2010)
NO	812	27 (15–55)	CM/cow	Herd	Incidence	0.23; 0.16[(b)]	Simensen et al. (2010)
USA	34	130–3,700	CM/100 cow-years at risk	Herd	Incidence	66.3%, 49%[(c)]	Husfeldt and Endres (2012)
USA	1	109	CM/1,000 quarter days at risk	Quarter	Prev.	0.26	Rowbotham and Ruegg (2016)

Country	n[(a)]	ø herd size (range)	Variable	Level	Measure	Mean/ prevalence	Reference
USA	7[(d)]	84	CM/weak	Herd	Incidence	1.2%	Eckelkamp et al. (2016a,b)
Somatic cell count (SCC)							
AT, DE, IT, NL, SI, SE	16	(14–175)	$\log_{10}$SCC	Herd	Marginal mean	67.7	Emanuelson et al. (2022)
			highSCC[(h)]	Herd	prev.	12.9%	
			New highSCC[(h)]	Herd	prev.	8.2%	
CAN	22	162	LN SCC	Herd	Mean	225	Sova et al. (2013)
CAN	18	22	SCC from < 100 to > 200	Herd	Incidence	0.45 /cow-year at risk	Robles et al. (2021)
DE	64	374 (47–1,609)	SCC > 400	Herd	prev.	20.2%	Gieseke et al. (2020)
DE, NL, IT, AT, SI, SE	20	116 (30–270)	SCC	Herd	Median	64	Blanco-Penedo et al. (2020)
FI	na[(e)]	na	CSCC	Cow	Mean	200.2; 238.7[(f)]	Hiitio et al. (2017)
			SCC ≥ 200 in ≥ 1 of 4 test days	Cow	Prev.	20.9%; 22.6%[(f)]	
			SCC ≥ 200 in ≥ 3 of 4 test days	Cow	Prev.	16.6%; 21.3%[(f)]	
NO	812	27 (15–55)	BMSCC	Herd	Mean	120; 140[(b)]	Simensen et al. (2010)
USA	92	na	BMSCC	Herd	Mean	259	Eckelkamp et al. (2016a,b)
USA	7[(d)]	84	BMSCC	Herd	Mean	205	Eckelkamp et al. (2016a,b)
			Theoretical BMSCC	Herd	Mean	229	
			SCC ≥ 200	Herd	Prev.	19.4%	
USA	34	130–3,700	BMSCC	Herd	Mean	268, 282[(b)]	Husfeldt and Endres (2012)
USA	113	na	SCS	Herd	Mean	2.92; 3.02[(g)]	Dechow et al. (2011)
USA	1	109	SCC > 200	Quarter	Incidence	1.36/1,000 quar. days at risk	Rowbotham and Ruegg (2016)

(a): Number of farms.
(b): Small (20 cows); large herds (50 cows), both provided only graphically.
(c): All farms with cubicles with recycled manure solids: with deep-bedding; with mattress.
(d): Only sand bedded cubicles.
(e): n: 20.9% (with parlour), 22.6% (with AMS) of 273,012 cows.
(f): With parlour, with AMS.
(g): Confined; with outdoor access.
(h): HighSCC: > 150 in primiparous cows, > 200 in multiparous cows.

Table E.3: Bacteriological finding, clinical mastitis or somatic cell counts reported for loose housing systems with mainly cubicle systems

Country	n(a)	ø herd size (range)	Variable	Level	Measure	Mean/ prevalence	Reference
Bacteriological findings (BACT)							
CAN	372	84	S. aur. in BM	Herd	Prev.	35%	Bauman et al. (2018)
CH	46	27 (10–48)	Quarter bact pos. & SCC > 100	Herd	Prev.	16.9%	Ivemeyer et al. (2011)
DE, DK	30	85 (29–215)	Quarter bact pos. & SCC > 100	Herd	Prev.	12.3%	Ivemeyer et al. (2018)
Clinical mastitis (CM)							
CAN	24	65	CM/100 cow-years at risk	Herd	Prev.	16.8%	Levison et al. (2016)
Somatic cell count (SCC)							
CAN	11,019	na	gBMSCC	Herd	Mean	199	Bauman et al. (2018)
CAN	24	65	gBMSCC	Herd	Mean	232	Levison et al. (2016)
CH	46	27 (10–48)	SCS over 1 year	Herd	Mean	2.85	Ivemeyer et al. (2011)
			SCC > 100 quarters	Herd	Prev.	29.6%	
			newinf (from 100 to > 200)	Herd	Incidence	8.9%	
DE, DK	30	85 (29–215)	SCS over 1 year	Herd	Mean	3.22	Ivemeyer et al. (2018)
NL	173	79	SCC > 150	Herd	Prev.	25.5%	Santman-Berends et al. (2012)

(a): Number of farms.

Table E.4: Bacteriological finding, clinical mastitis or somatic cell counts reported for straw yard systems

Country	n(a)	ø Herd size (range)	Variable	Level	Measure	Mean/ prevalence	Reference
Clinical mastitis (CM)							
CAN	8	(33–345)	CM	Lactation	Incidence	0.4%	Elghafghuf et al. (2014)
ES	1	242	CM(b)	Cow	Incidence	35%; 11.7%	Astiz et al. (2014)
USA(c)	1	269	CM	Cow	Prev.	15.1%	Sjostrom et al. (2019)
Somatic cell counts (SCC)							
DE, NL, IT, AT, SI, SE	21	117 (16–720)	SCC	Herd	Median	79	Blanco-Penedo et al. (2020)
ES	1	181	SCC	Cow	Mean	139.5	Astiz et al. (2014)
USA	6	na	BMSCC	Herd	Mean	301	Eckelkamp et al. (2016a,b)
USA(c)	1	268	SCS	Cow	LSmean	2.57	Heins et al. (2019)

(a): Number of farms.
(b): CM in 150 DIM: first and second mastitis-case incidence.
(c): Straw yard outside.

Table E.5: Prevalence of mastitis reported for compost-bedded pack systems

Country	n(a)	ø herd size (range)	Variable	Level	Measure	Mean/ prevalence	Reference
Clinical mastitis (CM)							
ES	1	242	CM(b)	Cow	Incidence	22.1%; 5.1%	Astiz et al. (2014)
USA	8	178	CM/weak	Herd	Incidence	1.2%	Eckelkamp et al. (2016a,b)
USA	1	269	CM	Cow	Prev.	27.1%	Sjostrom et al. (2019)
Somatic cell count (SCC)							
AT, DE, IT, NL, SI, SE	16	(14–175)	log_{10}SCC	Herd	Marginal mean	86.9	Emanuelson et al. (2022)
			highSCC(c)	Herd	prev.	18.9%	
			new highSCC(c)	Herd	Incidence	12.2%	
ES	1	242	SCC	Cow	Mean	96.1	Astiz et al. (2014)
IT	1	22	CSCC	Cow	Mean	51.5	Biasato et al. (2019)
USA	36	na	BMSCC	Herd	Mean	259	Eckelkamp et al. (2016)
USA	8	178	Theoretical BMSCC	Herd	Mean	241	Eckelkamp et al. (2016)
			SCC ≥ 200	Herd	Prev.	21.8%	
USA	1	268	SCS	Cow	LSmean	2.57	Heins et al. (2019)

(a): Number of farms.
(b): CM within 150 DIM: first and second mastitis-case incidence.
(c): HighSCC: > 150 in primiparous cows, > 200 in multiparous cows.

Table E.6: Housing- and management-related hazards affecting different variables for mastitis **in cubicle systems**

Housing- and management-related hazards	Variable	Effect	Analysis(a)	Reference
Cubicle dimension				
cubicle length > 1.9 m	BACT: S. aur. IMI	↓	MA	Dufour et al. (2012)
	BACT: CNS IMI	ns	MA	Watters et al. (2014)
	CM: CM/100 cow-years at risk	ns	MA	Husfeldt and Endres (2012)
cub. width > 121.7 cm	SCC: from SCC < 100 to SCC > 200	(↓)	UA/MA	Watters et al. (2013)
	SCC: SCC > 400	ns	MA	Gieseke et al. (2020)
Cubicle surface bedding material				
Shallow (vs. deep-bedded cub.)	BACT: bact pos. & SCC > 100	↑	MA	Ivemeyer et al. (2018)
	BACT: CNS IMI	ns	MA	Watters et al. (2014)
Sand or concrete cubicle base (vs. rubber mattress or mats (especially in parity > 1))	BACT: S. aur. IMI	↓	MA	Dufour et al. (2012)
Bedding > 2 cm	BACT: S. aur. IMI	↓		
Rubber surface (vs. non-rubber surface)	BACT: S. aur. in BM	↑	MA	Olde Riekerink et al. (2010), Bauman et al. (2018)
	CM(b)	ns	MA	Rowbotham and Ruegg (2016)
Soft mats, concrete (vs. rubber, multi-layer, mattresses)	CM: CM/lactation(c)	↑	MA	Ruud et al. (2010)
Concrete (vs. mattresses)	CM: second CM/ lactation(c)	↑	MA	Ruud et al. (2010)

Housing- and management-related hazards	Variable	Effect	Analysis[a]	Reference
Organic manure solids bedding (vs. sand)	CM: CM incidence/year	↑	MA	Esser et al. (2019)
Deep bedded vs. mattress[e]	CM: CM/100 cow-years at risk	ns	MA	Husfeldt and Endres (2012)
Organic manure solids bedding (vs. sand)	SCC: %SCC > 200	ns	MA	Esser et al. (2019)
Inorganic bedding (sand)	SCC: BMSCC	(↓)	MA	Matson et al. (2022)
Shallow (vs. deep-bedded cub.)	SCC: cure during lactation	↑	MA	Ivemeyer et al. (2018)
	SCC: SCS	↑	MA	
Deep-bedded (vs. mattress)	SCC: from SCC < 100 to > 200	ns	na[d]	Robles et al. (2021)
	SCC: from SCC < 100 to SCC > 200	ns	UA/MA	Watters et al. (2013)
	SCC: gBMSCC	ns	UA	Bauman et al. (2018)
Heifers kept on organic bedding material	SCC: SCC > 100[b]	↑	MA	Kromker et al. (2012)
	SCC: SCC > 150	ns	MA	Santman-Berends et al. (2012)
	SCC: SCC > 200[b]	ns	MA	Rowbotham and Ruegg (2016)
	SCC: SCS[b]	ns	MA	
	SCC: SCC > 400	ns	MA	Gieseke et al. (2020)
Organic manure solids bedding (vs. sand)	SCC: SCS	ns	MA	Esser et al. (2019)
Further housing factors				
Parlour milking (vs. AMS)	BACT: bact pos. & SCC > 100	↓	MA	Ivemeyer et al. (2018)
	BACT: CNS IMI	ns	MA	Watters et al. (2014)
Parlour (vs. AMS)	SCC: BMSCC	↓	MA	Nielsen and Emanuelson (2013)
Parlour milking (vs. AMS)	SCC: gBMSCC	↓	UA	Bauman et al. (2018)
Parlour (vs. AMS)	SCC: SCC ≥ 200 in ≥ 1 of 4 test days	↓	MA	Hiitio et al. (2017)
Parlour (vs. AMS)	SCC: SCC > 150	↓	MA	Santman-Berends et al. (2012)
Headlock (vs. 'post & rail' feeder)	SCC: LN SCC	↓	MA	Sova et al. (2013)
↗ Bunk space (m/cow)	SCC: LN SCC	↓		
	SCC: CSCC	ns	MA	Hiitio et al. (2017)
	SCC: from SCC < 100 to SCC > 200	ns	UA/MA	Watters et al. (2013)
Management and further factors				
Farmers perceive contact to cows as pleasant	BACT: bact pos. & SCC > 100	↓	MA	Ivemeyer et al. (2018)
Quantity of herd observation beside routine work	BACT: bact pos. & SCC > 100	(↓)		
90–120 min post-milking-standing	BACT: CNS IMI	↓	MA	Watters et al. (2014)
Milkers wear gloves Preteat disinfection Number of calving pens Adequate teat condition score	BACT: S. aur. IMI	↓	MA	Dufour et al. (2012)

Housing- and management-related hazards	Variable	Effect	Analysis[a]	Reference
Milking equipment checked by an independent technician < once yearly	BACT: S. aur. in BM	↓	MA	Olde Riekerink et al. (2010)
Chronically infected cows are tagged fore-stripping	BACT: S.aur. in BM	↓	MA	Bauman et al. (2018)
Lame cows Overconditioned cows	SCC: BMSCC	↑	MA	Matson et al. (2022)
Organic (vs. conventional)	SCC: CSCC	↑	MA	Hiitio et al. (2017)
Holstein breed (vs. Ayrshire and others)	SCC: CSCC	↑	MA	
	SCC: SCC ≥ 200 in ≥ 1 of 4 test days	↑	MA	
Longer contact of stockpersons and cows during routine work	SCC: cure during lactation	(↓)	MA	Ivemeyer et al. (2018)
% farmer's positive interaction with cows during milking	SCC: cure during lactation	↓	MA	Ivemeyer et al. (2018)
	SCC: SCS		MA	
Farmer's agreement with patience when moving cows	SCC: SCS	↓	MA	Ivemeyer et al. (2018)
Fresh cleaning material per cow	SCC: SCS	(↓)		
> 90 min post-milk-standing; encourage of post-milk-standing (feed)	SCC: from SCC < 100 to SCC > 200	↓	UA/MA	Watters et al. (2013)
Juvenile cross-sucking	SCC: SCC > 100[b]	↑	MA	Kromker et al. (2012)
Removing supernumery teats heifers close to calving housed together with lactating cows	SCC: SCC > 150	↓	MA	Santman-Berends et al. (2012)

↑/↓ = significantly higher/lower ($p < 0.05$); (↑)/(↓) = by tendency higher/lower ($p < 0.1$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red).
(a): Statistical analysis: MA = multivariable analysis; UA = univariable analysis.
(b): Primiparous cows.
(c): All systems without or with very low amounts of bedding material.
(d): Only abstract available.
(e): All farms with cubicles with recycled manure solids.

Appendix F – Restriction of movement and resting problems: effect of outdoor access

Table F.1: Effects of access to pasture or outdoor loafing area (OLA) on lying down and rising up movement, collisions, lying outside lying areas, and lying postures, +/– = significantly higher/lower ($p < 0.05$)

Country	System[(a)]	Time[(b)]	Group comparison	Variable	Analysis[(c)]	Effect	Reference
IT	Tie-stall	Spring–winter (before, during and after grazing)	Summer pasture (vs. zero-grazing)	Lying down movement (s)	UA	ns	Corazzin et al. (2010)
				Rising up movement (s)	UA	↓[(e),(d)]	
				Abnormal lying down movement (%)	UA	ns	
				Abnormal rising up movement (%)	UA	(↑)[(f),(e)]	
				Rising up attempts	UA	ns	
RO	Tie-stall	Winter	Outdoor access (vs. all-year tethered)	Lying down movement (s)	UA	↓	Popescu et al. (2013)
				Lying outside stall (%)	UA	↓	
				Collisions while lying down (%)	UA	↓	
DE	Cubicle	Winter	Summer pasture[(d),(f)] (vs. zero-grazing)	Lying down movement (s)	MA	ns	Gieseke et al. (2020)
				Lying outside cubicle (%)	MA	ns	
				Collisions while lying down (%)	MA	ns	
NL	Cubicle	September to February	Summer pasture (vs. winter barn)	Short lying position (%)	MA	↓	van Erp-van der Kooij et al. (2019)
				Wide lying position (%)	MA	↑	
				Long lying position (%)	MA	ns	
				Narrow lying position (%)	MA	ns	
AT	Various	Winter	Access to OLA (d/wk)	Break/resting on carpus while rising up (%)	MA	ns	Schenkenfelder and Winckler (2021)
				Abnormal rising/ severe difficulty (%)	MA	ns	
			Access to summer pasture (d/yr)	Break/resting on carpus while rising up (%)	MA	ns	
				Abnormal rising/ severe difficulty (%)	MA	ns	

(↑)/(↓) = by tendency higher/lower ($p < 0.1$); ns = not significant.
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Period of data collection.
(c): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.

(d): Rising up movement was shorter after pasture and by tendency during pasture compared to before pasture.
(e): h/day and days/year.
(f): By tendency less abnormal rising up in zero-grazing herds, which might be explained by improved stall characteristics on these farms.

Table F.2: Effects of access to pasture or outdoor loafing area (OLA) on social behaviour

Country	System[(a)]	Time[(b)]	Group comparison	Variable	Analysis[(c)]	Effect	Reference
RO	Tie-stall	Winter	Outdoor access (vs. all-year tethered)	Displacements (number/cow*h)	UA	↓	Popescu et al. (2013)
				Head butts (number/cow*h)	UA	↑	
IRL	Cubicle	Summer	Overnight pasture (vs. Zero-grazing)	Lying synchrony (k_f)	MA	↑	Crump et al. (2019)
USA	Cubicle	August–november	All-day pasture (vs. Zero-grazing)	Displacements at feed place (number/cow*2 h)	MA	↓	Black and Krawczel (2016)
FR	Cubicle	Winter, summer	Summer pasture (vs. Winter barn)	Social interactions[(d)] (% time)	MA	ns	Shepley et al. (2020a)
	Straw yard				MA	↓	

↑/↓ = significantly higher/lower ($p < 0.05$), ns = not significant ($p \geq 0.05$).
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Period of data collection.
(c): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
(d): Affiliative and agonistic interactions.

Appendix G – Inability to perform comfort behaviour: associated factors, brush use and management-related hazards

Table G.1: Animal-related factors associated with self-grooming, brush use, and allo-grooming reported for dairy cows in different housing systems

Animal-related factors	System	Variable	Effect	Analysis[a]	Reference
Animal related factors affecting self-grooming					
***E. coli* infection (day of infection vs. before and after infection)**	Tie-stall	Self-licking, scratching with claws, rubbing on objects (events/h)	↓	UA	Fogsgaard et al. (2012)
Lameness (lame vs. non-lame)	Cubicle	Self-licking and rubbing on objects (min/96 min)	↑	UA	Almeida et al. (2008)
Mastitis (SCC > 200,000 vs. SCC < 100,000)	Cubicle	Self-licking, scratching and rubbing on objects (s/h), over 24 h	ns	UA	Caplen and Held (2021)
		Self-licking, scratching and rubbing on objects (s/h), over 60 min. following morning milking	(↑)	UA	
Animal-related factors affecting brush use					
Lameness (moderately lame vs. non-lame)	Cubicle	Brush use (number/d)	↓	MA	Weigele et al. (2018)
Lameness (lame and severely lame vs. non-lame and mild lame) with brush located away from feed bunk (16 m)	Open-bedded	Brush use (s/d)	↓	MA	Mandel et al. (2018)
		Brush use (% cows /d)	↓	MA	
Lameness (lame and severely lame vs. non-lame and mild lame) with brush located near the feed bunk (3 m)	Open-bedded	Brush use (s/d)	ns	MA	
		Brush use (% cows /d)	ns	MA	
Mastitis (SCC > 200,000 vs. SCC < 100,000)	Cubicle	Brush use (s/h)	ns	UA	Caplen and Held (2021)
Metritis (cows with metritis vs. control group)	Open-bedded	Brush use (s/d)	↓	MA	Mandel et al. (2017)
		Brush use (% cows/d)	↓	MA	
Metritis (cows with metritis vs. control group) with brush located away from feed bunk (16 m)	Open-bedded	Brush use (s/d)	↓	MA	Mandel et al. (2017)
		Brush use (% cows/d)	↓	MA	
Metritis (cows with metritis vs. control group) with brush located near the feed bunk (3 m)	Open-bedded	Brush use (s/d)	ns	MA	Mandel et al. (2017)
		Brush use (% cows/d)	ns	MA	
Animal-related factors affecting allo-grooming					
Lameness (lame vs. non-lame)	Cubicle	Received social licking (number/h)	↑	UA	Galindo and Broom (2002)
		Initiated social licking (number/h)	ns	UA	
		Social licking and rubbing (number/h)	ns	UA	
Lameness (lame vs. non-lame)	Cubicle	Social licking and rubbing (min/96 min)	ns	UA	Almeida et al. (2008)
Mastitis (SCC > 200,000 vs. SCC < 100,000)	Cubicle	Given social licking (s/h)	↓	UA	Caplen and Held (2021)
		Received social licking (s/h), over 24 h	ns	UA	
		Received social licking (s/h), during 60 min. following morning milking	↓	UA	

1: UA = univariable, MA = multivariable.

Table G.2: Different measures of brush use reported for cows housed in cubicle systems

Country	n farms	Herd size	Level	Variable	Mean/ prevalence	Reference
CAN	1	72	Cow	Brush use (min/day)	6.76	DeVries et al. (2007)
			Cow	Brush use (visits/day)	7.71	
			Cow	Displacements from brush (number/day)	0.12 ± 0.39	
CAN	1	72	Cow	Brush use, time at brush (min/day)	0.12 ± 0.01	Val-Laillet et al. (2008b)
			Cow	Displacements at the brush (number/h spent at the brush)	20.1 ± 10.0	
CAN	1	16	cow	Pre-partum (72–48 h before calving) brush use (min/day)	31.5 ± 17.7	Newby et al. (2013)

Table G.3: Management-related hazards associated with different variables of self-grooming

Hazards	Variable	Effect	Analysis(a)	Reference
Herd size	Self-licking and scratching (events/33 h), after integration into dairy herd	ns	MA	Wagner et al. (2012)
	Self-licking and scratching (% time), after integration into dairy herd	ns		
Permanent mother/herd contact (vs. no herd contact)	Self-licking and scratching (events/33 h), after integration into dairy herd	↑	MA	Wagner et al. (2012)
Mother contact (permanent or 2-times/d)(b) (vs. feeding automat, 2 or 6-times/d)(b)	Self-licking and scratching (% time), after integration into dairy herd	ns		
Mother contact 2-times/day (vs. feeding automat, 2 and 6 times/day)(b)	Self-licking and scratching (events/33 h), after integration into dairy herd	(↑)		
After calving with calf (open-bedded) (vs. before calving (cubicle))	Self-licking (min/h)	ns	MA	Newby et al. (2013)
	Scratching and rubbing on objects (min/h)	↓		
After removal of calf (open-bedded) (vs. before calving (cubicle))	Self-licking (min/h)	↑		
	Scratching and rubbing on objects (min/h)	↓		
Regrouped individually (vs. regrouped as a pair)	Self-licking (min/h), immediately after integration into lactating herd[3]	ns	MA	Mazer et al. (2020)
Integration time into lactating group	Self-licking and rubbing on objects (s/h)	ns	MA	Fukasawa and Tsukada (2010)
Floor cleaning	Self-licking and rubbing on objects (s/h)	ns	MA	Fukasawa and Tsukada (2010)
Fresh food every 2 days (vs. daily feeding)	Self-licking and rubbing on objects (events/days)	↑	UA	Phillips and Rind (2001a)
4 feedings/days and 1 feeding/days, housed together (vs. 1 feeding/days, housed apart from cows fed 4 times/days)	Self-licking and rubbing on objects (events/d)	↓	UA	

↑/↓ = significant increase/decrease ($p < 0.05$); (↑)/(↓) = by tendency higher/lower ($p < 0.1$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.
(a): UA = univariable, MA = multivariable.
(b): Systems the test animals had been reared in during the first twelve weeks of life.

Table G.4: Management-related hazards associated with different variables of allo-grooming

Hazards	Variable	Effect	Analysis[(a)]	Reference
Stocking density	Social licking (min/1 h after regrouping)	ns	MA	Mazer et al. (2020)
Mother contact (permanent or 2-times/day)[(b)] (vs. feeding automat, 2 or 6-times/days)[(b)]	Received social licking (number/33 h), after integration into dairy herd	ns	MA	Wagner et al. (2012)
	Initiated social licking (number/33 h), after integration into dairy herd	ns		
Regrouping (3 days after vs. 3 days before regrouping)	Initiated allo-grooming (number/days)	↓	UA	von Keyserlingk et al. (2008)
	Received allo-grooming (number/days)	↓		
Regrouping (pre regrouping vs. directly post regrouping vs.1 week after regrouping)	Initiated social licking among familiar cows (number/48 h)	ns	UA	Foris et al. (2021)
Regrouped individually (vs. regrouped as a pair)	Social licking (min/1 h after regrouping)	ns	MA	Mazer et al. (2020)
Integration time into lactating group	Social licking (s/h)	ns	MA	Fukasawa and Tsukada (2010)
Floor cleaning	Social licking (s/h)	ns	MA	Fukasawa and Tsukada (2010)
Fresh food every 2 days (vs. daily feeding)	Social licking (number/days)	ns	UA	Phillips and Rind (2001a)
4 feedings/days and 1 feeding/days, housed together (vs. 1 feeding/ days, housed apart from cows fed 4 times/days)	Social licking (number/days)	ns	UA	

↑/↓ = significant increase/decrease ($p < 0.05$); ns = not significant. The colour of the sign (red or green) indicates whether the effect is considered positive from an animal welfare perspective (green) or negative (red). Arrows in black reflect an unclear interpretation of the effect from a welfare perspective.
(a): UA = univariable, MA = multivariable.
(b): Systems the test cows had been reared in during their first 12 weeks of life.

Appendix H – Metabolic disorders: prevalence in different housing systems and effect of outdoor access

Table H.1: Prevalence of metabolic disorders reported in different housing systems

Group	Country	n[(a)]	Mean herd size (range)	Variable	Level	Measure	Mean/ prevalence	Reference
Metabolic disorders reported for tie-stall systems								
ACID-sc	AT	264	15 (IQR: 7)	FPR < 1	Herd	Median	8%	Schenkenfelder and Winckler (2022)
ACID-sc	USA	201	na	FPR < 1.0	Herd	Prevalence	11.9, 13.1, 8.6%[(b)]	Dechow et al. (2011)
KETO-c	NO	812	27 (15–55)	inci. rate/100 cow years	Herd	Incidence	3.39%	Simensen et al. (2010)
KETO-sc	AT	264	15 (IQR: 7)	FPR > 1.5	Herd	Median	12%	Schenkenfelder and Winckler (2022)
KETO-sc	USA	201	na	fat Δ 1st to nadir	Herd	Prevalence	1.24, 1.32, 1,27%[(b)]	Dechow et al. (2011)
Metabolic disorders reported for loose housing systems with mainly cubicle systems								
ACID-sc	AT	392	29 (IQR: 22)	FPR < 1	Herd	Median	9%	Schenkenfelder and Winckler (2022)
ACID-sc	USA	113	na	FPR < 1.0	Herd	Prevalence	14.1%, 15.1%[(b)]	Dechow et al. (2011)
KETO-c	DE, FR, IT, NL, UK	131	294 (± 28)	Diagnoses	Herd	Prevalence	1.6%	Berge and Vertenten (2014)
KETO-c	NO	812	27 (15–55)	Inci rate/100 cow years	Herd	Incidence	1.3%	Simensen et al. (2010)
KETO-sc	AT	392	29 (IQR: 22)	FPR >1.5	Herd	Median	11%	Schenkenfelder and Winckler (2022)
KETO-sc	AT, DE, IT, NL, SI, SE	16	(14–175)	FPR > 1.4	Herd	Prevalence	10.3%	Emanuelson et al. (2022)
KETO-sc	DE	51	111.8 (20–420)	BHB ≥1.2 mmol/L	Herd	Prevalence	13.7%, 33.3%[(c)]	Oetting-Neumann et al. (2018)
KETO-sc	DE	51	111.8 (20–420)	Elevated NEFA	Herd	Prevalence	51%, 47.1%[(c)]	Oetting-Neumann et al. (2018)
KETO-sc	DE, FR, IT, NL, UK	107	na	BHB ≥ 100 μmol/L	Herd	Prevalence	39%	Berge and Vertenten (2014)
KETO-sc	USA	113	na	fat Δ 1st to nadir	Herd	Prevalence	1.39%, 1.29%[(b)]	Dechow et al. (2011)
Metabolic disorders reported for straw yard systems and compost bedded pack systems								
KETO-sc	DE, FR, IT, NL, UK	14	na	BHB ≥ 100 μmol/L	Herd	Prevalence	54%	Berge and Vertenten (2014)
KETO-sc	AT, DE, IT, NL, SI, SE	16	(14–175)	FPR > 1.4	Herd	Prevalence	9.8%	Emanuelson et al. (2022)

(a): Number of farms.
(b): Confined, with outdoor access and TMR, with outdoor access and component feeding.
(c): Primiparous, multiparous cows.

Table H.2: Effects of access to pasture (or outdoor loafing) on metabolic disorders prevalence

Country	System[(a)]	n[(b)]	Group comparisons	Indicator group	Variable	Effect	Reference
CH	Cubicles	1	Pasture vs. same fresh grass indoor (with outdoor yard)	KETO-sc	Acetone	ns	Dohme-Meier et al. (2014)
					BHB	↑, but below threshold	
					NEFA	ns	
CH	Cubicles	1	Pasture vs. same fresh grass indoor	KETO-sc	BHB	↑, but below threshold	Kaufmann et al. (2012)
					NEFA	ns in summer and autumn, ↓ in spring	
CH	Cubicles	1	Full-pasture access during vegetation period vs. indoor + PMR + 3 h pasture access	KETO-sc	BHB	ns	Frey et al. (2018)
					NEFA	ns (p.p); ↑ (a.p.), but below threshold	
DE	Loose housing	51	Pasture vs. confined	KETO-sc	NEFA	ns (cows), ↓ (heifers)	Oetting-Neumann et al. (2018)
					BHB	(↑) (cows), ns (heifers)	
DE, FR, IT, NL, UK	Various	131	Pasture and outdoor yard vs. confined	KETO-sc	BHB	ns	Berge and Vertenten (2014)
IT	na	18	Pasture (7 months) vs. zero-grazing	DISABO-c	Cases	ns	Pugliese et al. (2021)
				HYPOCAL-c	Cases	ns	
				KETO-c or ACID-c	Cases in 90DIM	ns	
IRL	Cubicles	1	Pasture vs. confined; (peripartum)	KETO-sc	BHB	↑ BHB p.p. (15 DIM); (↓) a.p. (−15 d); ns at calving; all below threshold	Olmos et al. (2009a)
					NEFA	↑ NEFA p.p. (15 DIM); ns a.p. (−15 d) and at calving	
PT	na	105	≥ 8 h/days grazing with mobile milking vs. confined		DISA estimated score (1–5)	ns	Medeiros et al. (2021)
USA	Tie-stall	314	Outdoor access (yard or pasture) vs. confined	ACID-sc	FPR < 1.0	ns (with TMR), ↓ (tie-stall with component feed)	Dechow et al. (2011)
	Cubicles	314		KETO-sc	fat Δ 1st to nadir	ns	
USA	Various	177	Grazing vs. non-grazing	KETO-c	cases	Ns (organic grazing vs. conventional non-grazing); (↓) (within conventional)	Richert et al. (2013)

↓ = significantly less metabolic disorders during (increased) grazing ($p < 0.05$), ns = not significant ($p \geq 0.05$) or () significant ($p \leq 0.1$) effect.
(a): Housing systems or husbandry practices used on the investigated farms.
(b): Number of farms.

Appendix I – Variables collected at national levels and their association with welfare

Table I.1: Number of holdings keeping dairy cows, total number of dairy cows, average herd sizes, annual raw milk production and average milk yield per cow in the EU-MS Member States in 2016; average herd size and average milk yield based on calculations (source of data: Eurostat, 2021)

Country	No. ofdairy cows	No. of dairy farms	ø Herd size	Raw milk from farm (1,000 t)	ø Milk yield per cow
EU-MS	21,928,780	1,190,950	18		
Germany	4,274,480	69,190	62	32,672.34	7,644
France	3,678,420	64,420	57	25,138.93	6,834
Poland	2,183,470	243,560	9	13,244.00	6,066
Italy	2,010,090	53,380	38	11,886.04	5,913
Netherlands	1,744,830	17,910	97	14,531.00	8,328
Ireland	1,398,060	18,320	76	6,871.94	4,915
Romania	1,137,890	472,780	2	3,934.00	3,457
Spain	905,850	19,820	46	7,123.77	7,864
Denmark	571,640	3,170	180	5,435.70	9,509
Austria	562,430	31,980	18	3,627.61	6,450
Belgium	531,010	11,770	45	3,933.25	7,407
Czechia	369,110	2,870	129	3,064.73	8,303
Sweden	330,830	3,870	86	2,862.23	8,652
Lithuania	302,280	55,430	6	1,623.87	5,372
Bulgaria	285,350	39,850	7	1,019.00	3,571
Finland	282,440	8,070	35	2,429.60	8,602
Portugal	277,610	8,100	34	1,922.97	6,927
Hungary	246,460	7,730	32	1,918.23	7,783
Latvia	160,650	18,420	9	983.50	6,122
Croatia	148,280	18,830	8	671.00	4,525
Slovakia	127,670	4,130	31	905.26	7,091
Greece	124,040	5,030	25	702.56	5,664
Slovenia	111,110	9,570	12	649.68	5,847
Estonia	85,220	1,740	49	782.70	9,184
Luxembourg	51,030	700	73	376.22	7,373
Cyprus	22,030	190	116	186.02	8,444
Malta	6,490	100	65	43.13	6,646

Table I.2: Most recent national data on average herd sizes (number of dairy cows per farm) available for individual EU Member States

Country	Year[(a)]	Reference	ø Herd size
Germany	2020	Statistisches Bundesamt (2021a)	70
Netherlands	2020	CBS (2021)	101
Ireland	2020	Dillon et al. (2021)	82
Spain	2018	Ministerio de Agricultura Pesca y Alimentacíon (2020)	89
Austria	2020	Statistik Austria (2020)	20
Finland	2019	European Dairy Association (2021)	37
Denmark	2020	Statistics Denmark (2021)	229

(a): Year of recording.

Table I.3: Most recent national data on milk yield (average milk kg per cow and year) available for individual EU Member States

Country	Year[(a)]	Reference	ø Milk yield
Germany	2020	Statista (2021)	8,457
Germany	2020	BRS (2021)	9,154[(b)]
Poland	2017	USDA (2018)	6,235
Italy	2020	CLAL (2021)	7,732
Netherlands	2020	CBS (2021)	8,897
Ireland	2020	Dillon et al. (2021)	5,643
Spain	2020	Conafe (2021)	12,529[(b)]
Austria	2020	Statistik Austria (2020)	7,286
Sweden	2020	Sverige (2021)	10,679[(b)]
Finland	2019	European Dairy Association (2021)	9,000
Portugal	2020	Instituto Nacional de Estatística (2021)	7,244
Denmark	2020	Statistics Denmark (2021)	10,000

(a): Year of recording.
(b): Farms participating in the official milk recording schemes.

Table I.4: Association between milk yield and lameness

Country	System	n[(a)]	ø Milk yield	Variable	Analysis[(b)]	Effect	Reference
DE	Tie-stall	56	22.9[(c)]	Lameness	MA	↓	Oehm et al. (2020)
FI	Cubicle	87	8,984[(d)]	Lameness	MA	ns	Sarjokari et al. (2013)
ES	Cubicle Straw yard	23	9,524[(d)]	Lameness	MA	ns	Pérez-Cabal and Alenda (2014)
IRL	Pasture-based	68	na	Lameness	MA	↑	O'Connor et al. (2020)
				Severe lameness	MA	ns	

↓ = significantly less lameness at higher milk yield ($p < 0.05$), ↑ = significantly more lameness at higher milk yield ($p < 0.05$), ns = not significant.
(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
(c): Mean per cow*day.
(d): Mean per cow*year, na – data not available.

Table I.5: Association between milk yield and claw disorders; ns = not significant ($p > 0.05$)

Country	System	n[(a)]	ø Milk yield	Variable	Analysis[(b)]	Effect	Reference
CAN	Cubicle	62	10,345[(c)]	Digital dermatitis	MA	ns	de Jong et al. (2021)
FI	Cubicle	149	8,394[(c)]	White line disease	MA	ns	Kujala et al. (2010)
				Sole haemorrhage	MA	ns	
FI	Tie-stall	553	8,670[(c)]	White line disease	MA	ns	Kujala et al. (2010)
				Sole haemorrhage	MA	ns	

(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
(c): Mean per cow*year, na – data not available.

Table I.6: Associations between milk yield and hock alterations

Country	System	n(a)	ø Milk yield	Variable	Analysis(b)	Effect	Reference
UK	Cubicle	63	26.9(c)	Hock mild(d)	MA	↑	Potterton et al. (2011)
				Hock lesion	MA	↑	
				Hock swelling	MA	↑	
SI	Cubicle	99	9,914(e)	Hock mild(d)	MA	ns	Ekman et al. (2018)
				Hock severe	MA	↑	
USA	Cubicle, compost-bedded pack	18	34.7–37.5(f)	Hock alterations(g)	MA	ns	Lobeck et al. (2011)

↑ = significantly more alterations at higher milk yield ($p < 0.05$), ns = not significant ($p > 0.05$).
(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of final models were considered), UA = univariable analysis.
(c): Mean per cow at last milk recording.
(d): Hair loss.
(e): ECM/cow*year.
(f): FCM/cow*day.
(g): Hair loss, lesion and/or swelling.

Table I.7: Associations between herd size and lameness

Country	System	n(a)	Herd size, ø (range)	Variable	Analysis(b)	Effect	Reference
DE	Tie-stall	56	25.6 (4–61)	Lameness	MA	↑	Oehm et al. (2020)
DK	Cubicle	36	na	Lameness	MA	ns	Burow et al. (2014)
USA (NE)	Cubicle	40	na	Lameness	MA	↓	Chapinal et al. (2013)
USA (CA)	Cubicle	39	na	Lameness	MA	↓	Chapinal et al. (2013)
				Severe lameness	MA	ns	
NL	Cubicle	179	(22–211)	Lameness	MA	ns	de Vries et al. (2015)
UK	Cubicle Straw yard	205	163 (37–642)	Lameness	MA	ns	Barker et al. (2010)
FR, DE, SI	Cubicle Straw yard	201	9–360	Lameness	MA	↑	Sjöström et al. (2018)
ES	Cubicle Straw yard	201	9–360	Lameness	MA	↑/↓(c)	Sjöström et al. (2018)
Algeria	Tie-stall, cubicle Pasture-based	14	Small scale(d)	Lameness	UA	↑	Dendani-Chadi et al. (2020)

↓ = significantly less lameness in larger herds ($p < 0.05$), ↑ = significantly more lameness in larger herds ($p < 0.05$), ns = not significant ($p > 0.05$).
(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of final models were considered), UA = univariable analysis.
(c): Effect of herd size was non-linear, with highest risk for medium herd sizes.
(d): Herd size categories: ≤ 10, 11–30, > 30 cows, na – data not available.

Table I.8: Associations between herd size and claw diseases

Country	System	n(a)	Herd size, ø (range)	Variable	Analysis(b)	Effect	Reference
FI	Tie-stall	553	27 (5–85)	White line disease	MA	ns	Kujala et al. (2010)
				Sole haemorrhage	MA	ns	
FI	Cubicle	149	50 (13–180)	White line disease	MA	ns	Kujala et al. (2010)
				Sole haemorrhage	MA	ns	
CAN	Cubicle	62	183 (74–517)	Digital dermatitis	MA	↑	de Jong et al. (2021)

↑ = significantly higher prevalence in larger herds ($p < 0.05$), ns = not significant ($p > 0.05$).
(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.

Table I.9: Associations between herd size and integument alterations

Country	System	n(a)	Herd size, ø (range)	Variable	Analysis(b)	Effect	Reference
SI	Cubicle	99	106 (49–223)	Hock alteration	MA	ns	Ekman et al. (2018)
USA (NE)	Cubicle	38	na	Hock alteration	MA	ns	Barrientos et al. (2013)
USA (CA)	Cubicle	38	na	Hock alteration	MA	ns	Barrientos et al. (2013)
UK	Cubicle	63	162 (46–394)	Hock mild(c)	MA	↓	Potterton et al. (2011)
				Hock lesion	MA	↑	
				Hock swelling	MA	ns	
NL	Cubicle	179	(22–211)	Integument severe(d)	MA	ns	de Vries et al. (2015)

↓ = significantly less alterations in larger herds ($p < 0.05$), ↑ = significantly more alterations in larger herds ($p < 0.05$), ns = not significant ($p > 0.05$).
(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
(c): Hair loss.
(d): Lesion/swelling.

Table I.10: Association between milk yield and mastitis; + = positive association: significantly more mastitis in herds with more milk yield ($p < 0.05$), – = negative association: significantly more mastitis in herds with lower milk yield ($p < 0.05$), ns = not significant

Country	System	n1	ø Milk yield	Variable	Analysis2	Association	Reference
FI	Tie-stall, cubicles	4,173	Median, 2nd parity: 8,900 kg/cow & year	BACT: *C. bovis* IMI incidence	MA	ns	Taponen et al. (2017)
				BACT: CNS IMI incidence	MA	+	
				BACT: *E. coli* IMI incidence	MA	+	
				BACT: *S. aur.* IMI incidence	MA	+	
				BACT: *Strep. dysgal.* IMI incidence	MA	+	
				BACT: *Strep. uberis* IMI incidence	MA	+	
AT	Tie-stall, loose housing	1,221	Median: 5,617 kg/cow & year	CM: CM per cow & year	MA	+	Schenkenfelder and Winckler (2021)

Country	System	n[1]	ø Milk yield	Variable	Analysis[2]	Association	Reference
CAN	Cubicle, straw yard, tie-stall	59	26.8; 31.2 kg/cow & days[3]	CM: CM/100 cow years at risk	MA	ns	Levison et al. (2016)
CAN	Tie-stall, loose housing	11,636	701,000 kg/herd	SCC: gBMSCC	UA	ns	Bauman et al. (2018)
FI	tie-stall, Cubicles	7,640	Only give in categories	SCC: SCC	MA	+	Hiitio et al. (2017)
CH	Loose housing	47	21.0 kg/days	SCC: SCS (1 year)	MA	–	Ivemeyer et al. (2011)

1: Number of farms.
2: Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
3: Loose housing; tie stalls.

Table I.11: Associations between herd size and mastitis; + = positive association: significantly more mastitis in larger herds ($p < 0.05$), – = negative association: significantly more mastitis in smaller herds ($p < 0.05$), ns = not significant

Country	System	n[1]	Herd size, ø (range)	Variable	Analysis[2]	Association	Reference
USA	Tie-stall, loose housing	267	66	BACT: ≥ 50 cfu/mL Coliforms in BM	MA	ns	Cicconi-Hogan et al. (2013)
				BACT: *S. aur.* in BM	MA	ns	
CAN	Loose housing, tie-stall	372	84 (76–92)	BACT: *S.aur.* in BM	MA	ns	Bauman et al. (2018)
AT	Tie-stall, loose housing	208	26.9 (8–94)	CM: acute or chronic/cow & year	MA	ns	Firth et al. (2019)
USA	Cubicle, straw yard, pasture or dry lot, tie-stall	292	Only give in categories	CM: CM per 305 cow-days	MA	ns	Richert et al. (2013)
CAN	Cubicle, straw yard, tie-stall	59	65 (18–220)	CM: CM/100 cow years at risk	MA	ns	Levison et al. (2016)
IT	Tie-stall, cubicle	41	12	CM: medical dry-off	MA	ns	Zanon et al. (2021)
				CM: medical treated CM	MA	+	
CH	Loose housing	46	27 (10–48)	SCC: % from < 100 to > 200	UA/MA	+/ns	Ivemeyer et al. (2011)
				SCC: %quarters SCC > 100	UA/MA	+/ns	
CAN	Loose housing, tie-stall	1,062	77 (72–82)	SCC: gBMSCC	UA	ns	Bauman et al. (2018)
NO	Cubicle, tie-stall	812	27	SCC: gBMSCC	MA	+	Simensen et al. (2010)
FI	Tie-stall, cubicle	7,640	only give in categories	SCC: mean herd SCC	MA	+	Hiitio et al. (2017)
				SCC: SCC ≥ 200 in ≥ 1 of 4 test days	MA	+	
				SCC: SCC ≥ 200 in ≥ 3 of 4 test days	MA	+	

1: Number of farms.
2: Statistical analysis: MA = multivariable analysis, UA = univariable analysis.

Table I.12: Association between milk yield and locomotion behaviour / activity, ns = not significant

Country	System	n[1]	ø Milk yield[2]	Variable	Analysis[3]	Effect	Reference
CAN	Cubicle (AMS[4])	13	35.1 ± 10.0	Post-milking standing (min)	MA	ns	Deming et al. (2013)
				Pre-milking standing (min)	MA	ns	
USA	Cubicle	16	42.0 ± 10.5	Standing/walking in alley (h/day)	MA	ns	Gomez and Cook (2010)
				Standing in cubicle (h/day)	MA	ns	

1: Number of farms.
2: Mean ± standard deviation per cow*day (kg).
3: Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).
4: Automatic milking system.

Table I.13: Association between milk yield and lying behaviour; ↑/↓ = higher/lower ($p < 0.05$), ns = not significant

Country	System	n[1]	ø Milk yield	Variable	Analysis[2]	Effect	Reference
CAN	Cubicle	44	34.0–37.0[4]	Lying time (h/day)	MA	ns	Morabito et al. (2017)
CAN	Cubicle (AMS[3])	13	35.1 ± 10.0[4]	Lying time (h/day)	MA	↓	Deming et al. (2013)
				Lying bout duration	MA	↓	
CAN	Cubicle	41	33.7 ± 2.8[4]	Lying time (h/day)	MA	ns	King et al. (2016)
				Lying bout duration	MA	ns	
CAN	Cubicle	141	≥ 7,000[5]	Lying time (h/day)	MA	↓	Solano et al. (2016)
				Lying bout duration	MA	ns	
				Number of lying bouts/day	MA	ns	
USA (CA)	Cubicle	39	na	Lying bout duration	MA	ns	Ito et al. (2014)
USA	Cubicle	16	42.0 ± 10.5[4]	Lying time (h/d)	MA	ns	Gomez and Cook (2010)
				Lying bout duration	MA	ns	
				Number of lying bouts/day	MA	ns	
AT	Various	246	5,700 ± 1425[6]	Abnormal rising up/severe difficulty (%)	MA	↓	Schenkenfelder and Winckler (2021)
				Resting on carpus while rising up (%)	MA	↑	

1: Number of farms.
2: Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).
3: Automatic milking system.
4: Mean ± standard deviation per cow*day (kg).
5: Mean per cow*year (kg).
6: Mean ± standard deviation of milk delivered per cow*year, calculated based on an extended sample within the study.

Table I.14: Association between milk yield and prevalence of soiled cows; – = negative ($p < 0.05$), ns = not significant

Country	System	n[1]	ø Milk yield[2]	Variable	Analysis[3]	Effect	Reference
NO	Cubicle	232	7,062 ± 945	Dirty hindquarter	MA	ns	Ruud et al. (2010)
FR	Cubicle	76	na	Dirty hindquarter	MA	–	Lardy et al. (2021)
				Dirty lower hind legs	MA	–	
				Dirty udder	MA	–[5]	
AT	Various	1,221	5,700 ± 1,425[4]	Dirty hindquarter	MA	–	Schenkenfelder and Winckler (2021)
				Dirty lower hind legs	MA	–	
				Dirty udder	MA	ns	

1: Number of farms.
2: Mean ± standard deviation per cow*year (kg).
3: Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).
4: Milk delivered per cow*year.
5: Risk decreased with ø daily milk yield > 35 L and increased with < 25 L compared to 25–35 L.

Table I.15: Association between herd size and lying behaviour; – = negative ($p < 0.05$), ns = not significant

Country	System	n[(a)]	Herd size, ø (range)	Variable	Analysis[(b)]	Effect	Reference
CAN	Cubicle	44	158	Lying time (h/day)	MA	ns	Morabito et al. (2017)
CAN	Cubicle	41	105 (37–365)	Lying time (h/day)	MA	ns	King et al. (2016)
				Lying bout duration	MA	ns	
USA (NE)	Cubicle	40	na	Lying time (h/d)	MA	ns	Ito et al. (2014)
				Lying bout duration	MA	ns	
				Number of lying bouts/day	MA	ns	
USA (CA)	Cubicle	39	na	Lying time (h/day)	MA	ns	Ito et al. (2014)
				Lying bout duration	MA	ns	
				Number of lying bouts/day	MA	ns	
DE	Cubicle	80	383 (45–1,629)	Time needed to lie down (s)	MA	–	Gieseke et al. (2018)
				Lying outside lying area (%)	MA	ns	
				Collision with equipment during lying down (%)	MA	ns	

(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).

Table I.16: Association between herd size and cow cleanliness; ↑/↓ = higher/lower (p < 0.05), ns = not significant

Country	System	n[(a)]	Herd size, ø (range)	Variable	Analysis[(b)]	Effect	Reference
NO	Cubicle	232	38.6 (17.6–103.1)	Dirty hindquarter	MA	ns	Ruud et al. (2010)
DE	Cubicle	80	383 (45–1629)	Dirty hindquarter	MA	ns	Gieseke et al. (2018)
				Dirty lower hind legs	MA	↓	
DK	Cubicle	42	153 (49–453)	Dirty lower hind legs	MA	ns	Nielsen et al. (2011)

(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).

Table I.17: Association between herd size and social behaviour; + = positive (p < 0.05), – = negative (p < 0.05), ns = not significant

Country	System	n[(a)]	Herd size, ø (range)	Variable	Analysis[(b)]	Effect	Reference
NL	Cubicle	179	(22–211)	Displacements[(c)]	MA	–	de Vries et al. (2015)
DE	Cubicle	80	383 (45–1,629)	Displacements[(c)]	MA	–	Gieseke et al. (2018)
				Head butts[(c)]	MA	ns	

(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered).
(c): ø number per cow*h.

Table I.18: Association between milk yield and metabolic disorders

Country	System	n[(a)]	ø Milk yield	Variable	Analysis[(b)]	Association	Reference
SE	Tie-stalls, cubicles	40, 20[(c)]	9,818, 9,308 kg ECM/cow-year[3]	KETO-c or DISABO-c	UA	(+)	Stengärde et al. (2012)
SE	Tie-stalls, cubicles	40, 20[(c)]	55, 51 max. kg ECM/day (LN > 1)[3]	KETO-c or DISABO-c	MA	(+)	Stengärde et al. (2012)
SE	Tie-stalls, cubicles	40, 20[(c)]	41.6, 8.7 max. kg ECM/day (LN = 1)[3]	KETO-c or DISABO-c	UA	(+)	Stengärde et al. (2012)
NL	Cubicles	23	sc: 35.7 kg, c: 36.2 kg, no: 34.5 kg[4]	KETO-c, KETO-sc	MA	+	Vanholder et al. (2015)
DE, FR, IT, NL, UK	Cubicles, straw yard, tie-st	131	na	KETO-sc: BHB	MA	ns	Berge and Vertenten (2014)

+ = positive association: significantly more metabolic disorders in herds with more milk yield (p < 0.05), (+) marginal (p ≥ 0.1) effect, ns = not significant.
(a): Number of farms.
(b): MA = multivariable analysis (in the case of univariable pre-selection of factors only effects of the final models were considered), UA = univariable analysis.
(c): 40 high-incidence herds, 20 low incidence herds.
(d): sc = subclinical ketosis, c = clinical ketosis, no = no ketosis.

Table I.19: Associations between herd size and metabolic disorders

Country	System	n[(a)]	Herd size, ø (range)	Variable	Analysis[(b)]	Association	Effect	Reference
NO	Cubicle, tie-stall	812	27	HYPOCAL-c	MA	ns		Simensen et al. (2010)
USA	Cubicle, straw yard, pasture or dry lot, tie-stall	177	Only give in categories	KETO-c	MA	ns		Richert et al. (2013)
NO	Cubicle, tie-stall	812	27	KETO-c	MA	–	Estim. –0.019	Simensen et al. (2010)
DE	Tie-stalls, cubicles	60	77	KETO-c or DISABO-c, high-incidence	MA	(+)	OR 9.8	Stengärde et al. (2012)
DE, FR, IT, NL, UK	Cubicles, straw yard, tie-st	131	294	KETO-sc: BHB	MA	–	Estim. –0.001	Berge and Vertenten (2014)

+ = positive association: significantly more metabolic disorders in larger herds ($p < 0.05$), – = negative association: significantly more metabolic disorders in smaller herds ($p < 0.05$), ns = not significant.
(a): Number of farms.
(b): Statistical analysis: MA = multivariable analysis, UA = univariable analysis.

Table I.20: Data on the average age of dairy cows in individual EU-MS countries

Country	Level	Year[(a)]	Ø Age	Months	Years	Reference
Germany	National[(b)]	2020	In living animals	56.4	4.7	BRS (2021)
Germany	National[(b)]	2020	At slaughter	66.0	5.5	BRS (2021)
France	National[(c)]	2018	At slaughter[(d)]	55.2	4.6	Dallago et al. (2021)
Poland	National[(e)]	2019	At slaughter[(d)]	74.4	6.2	Dallago et al. (2021)
Italy	National[(b)]	2019	At slaughter[(d)]	68.4	5.7	Dallago et al. (2021)
Netherlands	National[(e)]	2019	At slaughter[(d)]	70.8	5.9	Dallago et al. (2021)
Ireland	National[(e)]	2020	At slaughter[(d)]	76.8	6.4	Dallago et al. (2021)
Spain	National	2018	Not specified	38.4	3.2	Ministerio de Agricultura Pesca y Alimentacíon (2020)
Spain	National[(e)]	2020	Not specified	44.0	3.7	Conafe (2021)
Sweden	National[(b)]	2020	At slaughter	61.2	5.1	Sverige, 2021

(a): Year of recording.
(b): Farms participating in the official milk recording schemes.
(c): farms registered at the French livestock institute Idele.
(d): Calculated from age at first calving plus length of productive lifetime.
(e): Farms registered in a breeding association.

Table I.21: Data on the productive lifespan of dairy cows in individual EU-MS countries

Country	Level	Year[(a)]	Ø Productive lifespan	Months	Years	Reference
Germany	Regional[(b)]	2020	In living animals	27.5	2.3	VIT (2021)
Germany	Regional[(b)]	2020	At slaughter	36.5	3.0	VIT (2021)
France	National	2000s	At slaughter	26.4	2.2	Dallago et al. (2021)
Poland	National	2010s	At slaughter	51.6	4.3	Dallago et al. (2021)
Italy	National	2010s	At slaughter	42.0	3.5	Dallago et al. (2021)
Netherlands	National	2010s	At slaughter	41.0	3.4	Dallago et al. (2021)
Ireland	National	2010s	At slaughter	41.0	3.4	Dallago et al. (2021)

(a): Year of recording.
(b): Data from farms participating in the official milk recording schemes in central and eastern federal states.

Table I.22: Culling rates reported for individual EU-MS countries in epidemiological studies or based on national statistical data

Country, Region	Level	Year[(a)]	Ø Culling[(b)]	Reference
Germany	National[(c)]	2020	31.9	BRS (2021)
Netherlands	Sample[(d)]	2007–2010	23.0–28.0	Nor et al. (2014)
Ireland	National	2003–2006	21.3	Maher et al. (2008)
Sweden	National[(c)]	2020	35.8	Sverige (2021)

(a): Year of recording.
(b): Percentage of cows in the herd (over 1 year) that were removed from the farm for slaughter.
(c): Farms participating in the official milk recording schemes.
(d): n = 1,903.

Table I.23: Mortality rates reported for individual EU-MS countries in epidemiological studies or based on national statistical data

Country, Region	Level	n Farms	Year[(a)]	Ø Mortality[(b)]	Reference
Germany, North	Sample	253	2016–2020	3.7	PraeRi (2020)[(c)]
Germany, East	Sample	252	2016–2020	4.2	PraeRi (2020)[(d)]
Germany, South	Sample	260	2016–2020	2.3	PraeRi (2020)[(e)]
France	National	–	2003–2009	3.5	Perrin et al. (2011)
France	National	–	2005–2006	3.7–3.8	Raboisson et al. (2011)
France	Sample	131	2010–2011	2.0[(f)] (0.0–17.0)	de Boyer des Roches et al. (2014)[(g)]
Ireland	National	–	2003–2006	3.2–4.1	Maher et al. (2008)
Denmark	Sample	73	2010–2011	3.1–3.7	Otten et al. (2014)[(h)]

(a): Years of recording.
(b): Mean percentage of dairy cows which died on the farm, were euthanised due to disease or accidents or were emergency slaughtered over 1 year.
(c): 3.6% tie-stall, 83.4% cubicle, 2.4% straw yard, 3.6% pasture-based, and 7.1% mixed systems.
(d): 1.2% tie-stall, 78.6% cubicle, 4.4% straw yard, 2.4% pasture-based, and 13.5% mixed systems.
(e): 29.6% tie-stall, 67.3% cubicle, 0.8% straw yard, 2.3% mixed systems.
(f): Non identified.
(g): Stratified sample, excluding tie-stall systems.
(h): Exclusively cubicle systems and herd sizes > 100 cows.

Table I.24: Udder health data reported for individual EU-MS countries in epidemiological studies or based on national statistical data

Country	Level	Year[(a)]	n Farms	Variable	Values	Reference
Germany	National[(b)]	2020		ø SCC[(c)]	231	BRS (2020)
Germany	National[(b)]	2020		% SCC ≤ 100,000	58.0	BRS (2020)
Germany	National[(b)]	2020		% SCC > 400,000	12.1	BRS (2020)
France	Sample	2010–2011	131	% SCC > 400,000	19.0	de Boyer des Roches et al. (2014)[(d)]
Denmark	Sample	2010–2011	73	ø SCC[(c)]	230–251	Otten et al. (2014)[(e)]
Sweden	National[(b)]	2019		ø SCC[(c)]	208	Sverige (2021)

(a): Year of recording.
(b): Farms participating in the official milk recording schemes (MR).
(c): SCC = somatic cell count in cells*1,000 mL^{-1}.
(d): Stratified sample, excluding tie-stall systems.
(e): Exclusively cubicle systems and herd sizes > 100 cows.

Appendix J – Additional technical information regarding the EKE

J.1. EKE Participants

Participants in the EKE are listed below. Throughout the following sections, they are referred to using initials as follows:

Eliana Lima – EL
Denise Candiani – DC
Mariana Aires – MA
Hans-Hermann Thulke – HT
Christoph Winckler – CW
Alice de Boyer des Roches – ABR
George Stilwell – GS
John Mee – JM
Søren Nielsen – SN
Marie Haskell – MH
Margit Bak Jensen – MJ
Martin Green – MG

The following personnel were involved in different aspects of the EKE:

Elicitation design group – MG, EL, HT, DC, CW
Elicitation steering and moderation group during the procedure – EL, HT, DC, MA
Data collation and analysis – EL, HT, MG, DC, MA
Report writing – MG, EL, DC, CW
Expert group – All WG members (CW, ABR, GS, SN, MJ, MH, JM, MG)
Report reviewing – All WG members (CW, ABR, GS, SN, MJ, MH, JM, MG).

J.2. Initiation of the EKE

The initial concept to use an EKE to develop a farm-level, risk-based approach to dairy cow welfare arose after the WG meeting on 25 and 26 April 2022. The concept was discussed further by EFSA scientific officers (EL and DC), and WG members (CW (Chair) and MG) and it was decided to construct an initial plan for further discussion. HT was co-opted as an EKE expert to help design and conduct the EKE.

An outline concept was developed by EL, MG, HT and DC and presented to the full WG on 7th June 2022. Following feedback and further development, the concept was discussed with the European Commission on 5 and 19 July 2022 and it was decided the approach was appropriate and worthwhile. The EKE protocols and procedures were designed in full in July and August 2022 by MG, EL, HT and DC and the procedure commenced in September 2022.

J.3. Selection of experts

Experts were selected on the basis of their expertise to cover the welfare consequences and housing systems specified in the mandate, while ensuring different geographical areas in Europe were covered as follows:

- GS: southern EU
- JM: north-western EU
- CW: central and Eastern Europe with focus on Alpine region
- MG: north-western countries
- MJ: Scandinavian countries
- MH: north-western countries
- AB: central Europe
- SN: Scandinavian countries.

J4. ecisions on the elicitation method

Given the subject matter of the elicitation, it was decided to use formal, consensus-based methods to achieve the best outcome. Both ranking and quantitative scoring methods were needed for different aspects of the elicitation. Ranking-based elicitations are of value to derive a consensus around the order of importance of a list of choices whereas quantitative scoring methods provide a consensus value (or distribution) for a specific parameter; both approaches were used and are described in detail in Sections 5.8.2.

It was decided to conduct the elicitation procedure in two main phases, firstly to define farm characteristics associated with a farm being deemed at high risk of poor welfare and secondly, to define the welfare consequences (and related animal-based measures) that would be used to evaluate the 'at-risk' farms.

J.5. Background material and training given to the expert group

Having been provided with an overview of the proposed elicitation (7 June 2022), on 19 September 2022, the expert group were provided with a detailed written document that outlined the background, rationale and aims of the elicitation. This document also detailed the first elicitation task to be undertaken by expert members, the individual selection of candidate farm characteristics (further details below in section B6 below). An on-line meeting was conducted with the expert group on 30 September 2022 to discuss the elicitation and clarify any uncertainties. An overview of the phases of the elicitation was provided as was an outline of the methods to be used. Most group members had participated in a previous EKE and additional brief training was provided at the start of the main elicitation meeting (25–26th October). This latter training comprised detailed introduction into the elicitation process and training on the use of the electronic tool for completing ranking-based judgements.

J.6. Document sent to the expert group outlining background, rationale and aims of the EKE

The following text was sent to the expert group as background information:

'The purpose of this document is to provide the necessary information for scientific experts to participate in an elicitation exercise on dairy cow welfare. The document provides background information, an outline of the elicitation procedure and the initial steps required from all participants prior to a face-to-face meeting in October 22, at which the elicitation will be completed.

Background and aims of the elicitation

As a part of a request to EFSA to provide a Scientific Opinion on adult dairy cow welfare, the European Commission included a desire for a *risk-based approach* to the welfare assessment of dairy herds. The concept of a risk-based approach is to evaluate and categorise farms using relatively simple measures, such that farms at high risk of poor welfare can be identified for further action. While it was initially hoped that farms at high risk of poor welfare could be identified using basic farm data such as herd size or milk yield, scientific literature indicated this was not possible. Therefore, an alternative approach is proposed to achieve this outcome. The aim of this elicitation is to develop a practical framework, based on a relatively small number of farm factors, for a simple risk-based assessment of dairy cow welfare that could be applied to categorise farms throughout Europe based on being at high risk of poor welfare.

It is important to note, the final risk-based system is not intended to provide the whole solution to dairy cow welfare in Europe. Rather it should be viewed as one component of a toolkit that could be used to identify farms and practices that place cows at high risk of poor welfare. The risk-based approach would be used in addition to the major recommendations arising from the full Scientific Opinion on dairy cow welfare and can be thought of as a way to extend the reach of the Opinion to include a wider range of factors that have an important impact on cow welfare.

Our end goal is that the risk-based approach will define a small set of farm characteristics (e.g. 3–6) that are associated with a farm being at high risk of having poor cow welfare. These risk characteristics do not necessarily mean a farm has poor welfare, but it is at increased risk compared to those without the characteristic.

Overview of the process of elicitation

The working group (WG) members appointed to compile the scientific opinion on dairy cow welfare have agreed to participate in the elicitation process. The process can be thought of as a way of reaching an inclusive consensus – *it is important the outcome is a true team-based decision*.

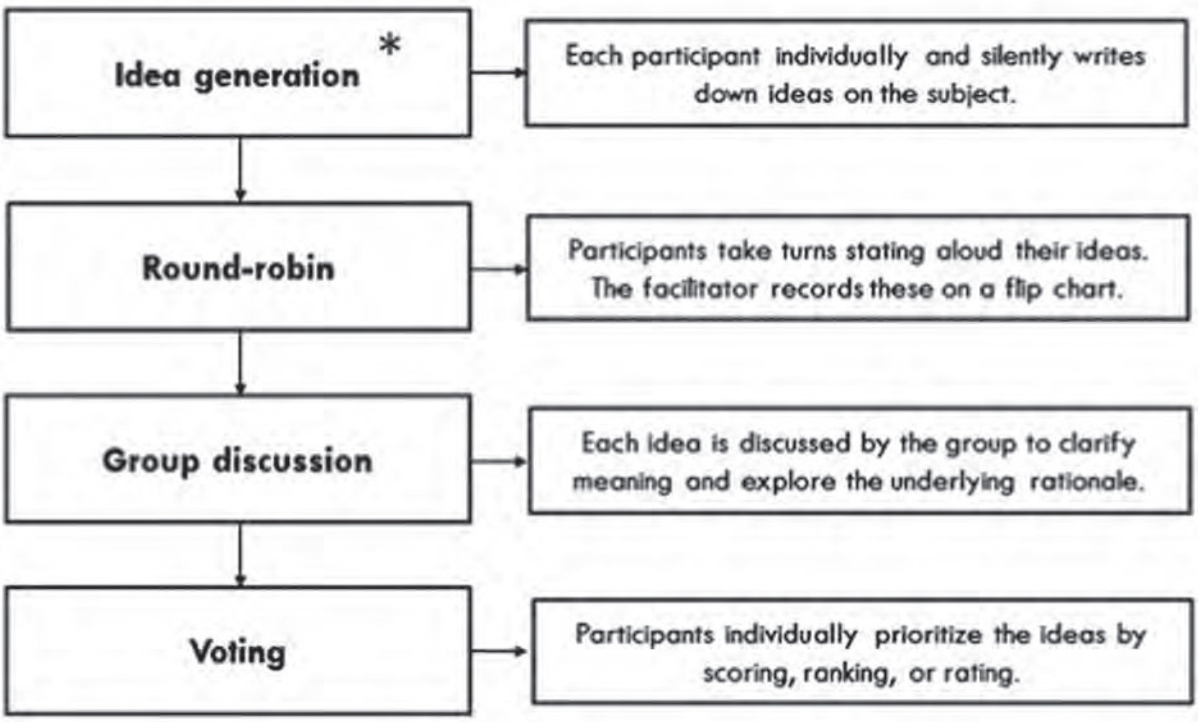
To achieve the aim of developing a framework for a risk-based assessment of dairy cow welfare, a series of steps will be undertaken as follows:

1) Elicitation group members (EGM) will be asked to read this background information before the working group meeting on 30th September and seek any clarifications at that meeting.

efsa JOURNAL

2) After the September meeting and by 10th October, EGM will be asked to undertake the first elicitation task ('Task 1')) individually. This task will involve identifying farm characteristics deemed most likely to be indicative of, or associated with, poor dairy cow welfare; the task is described in detail later in this document.
3) At the face-to-face meeting on 25–26 October, further steps in the procedure will be:
   a) Continuation of discussions around the most effective farm characteristics indicative of poor dairy cow welfare, to synthesise ideas proposed by EGM prior to the meeting, and reach consensus.
   b) A group elicitation to reach consensus on animal- or herd-based welfare outcomes that can be used to assess cow welfare on farms that have a characteristic identified in a.
   c) A group elicitation to reach consensus on thresholds for welfare outcomes identified in b. to determine whether the farm requires corrective action.

Each step of the elicitation will comprise an adapted Nominal Group Technique (NGT) (Van de Ven and Delbecq, 1972; Durkin et al., 2019), a structured approach that facilitates idea generation and exploration, and leads to group consensus. The steps of a conventional NGT are outlined in Figure I.1. In the first stage, participants are introduced to the topic and invited to engage in an individual 'generation of ideas' phase. In the second stage, each participant is invited in-turn to share ideas with the rest of the group in a 'Round Robin' format. There may be clarification of ideas at this stage but no discussion. Each idea is recorded by a facilitator until all ideas have been listed. In the third stage ideas are discussed, duplicates removed and clarifications provided such that all participants fully understand and explore the underlying rationale for each of the proposed ideas. An extensive discussion is allowed such that participants can consider and decide on the relative merits of different ideas. It is important for participants to remain open minded and free to alter and adapt opinions during this stage; group sharing and discussion should help to arrive at the most appropriate list of ideas. The fourth and final stage involves participants individually prioritising ideas by rating or ranking the ideas listed by the group. Ranks are combined to arrive at a final consensus (Dening et al., 2013).



*For this elicitation, Stage 1 (individual idea generation) will be conducted remotely prior to the meeting in Parma.

Figure I.1: An outline of the steps in consensus elicitation using a conventional Nominal Group Technique

Outcome of the Elicitation

Having conducted the whole procedure, including all the elicitation steps at the Parma meeting, the aim is to arrive, by consensus, at a framework for a risk-based approach as outlined, for example, in Figure I.2. The concept of the framework is to identify farms at increased risk of poor welfare, based on a small number of farm characteristics, so that such farms can be assessed and further action taken if necessary. The intention is that the final framework would involve specification of a small set (3–6) of what are agreed to be the farm characteristics ('Specific Relevant Hazards') most likely to increase the risk of poor cow welfare on dairy farms. Therefore, in practice, when these Specific Relevant Hazards are present on-farm, a sequence of events would be instigated to make an assessment of cow welfare on that farm. The actual measures required to make this welfare assessment (as well as a judgement of minimum acceptable levels for each measure) will also be agreed during the elicitation process. The aim is to design a practical, effective solution that could be adopted by legislators in the future.

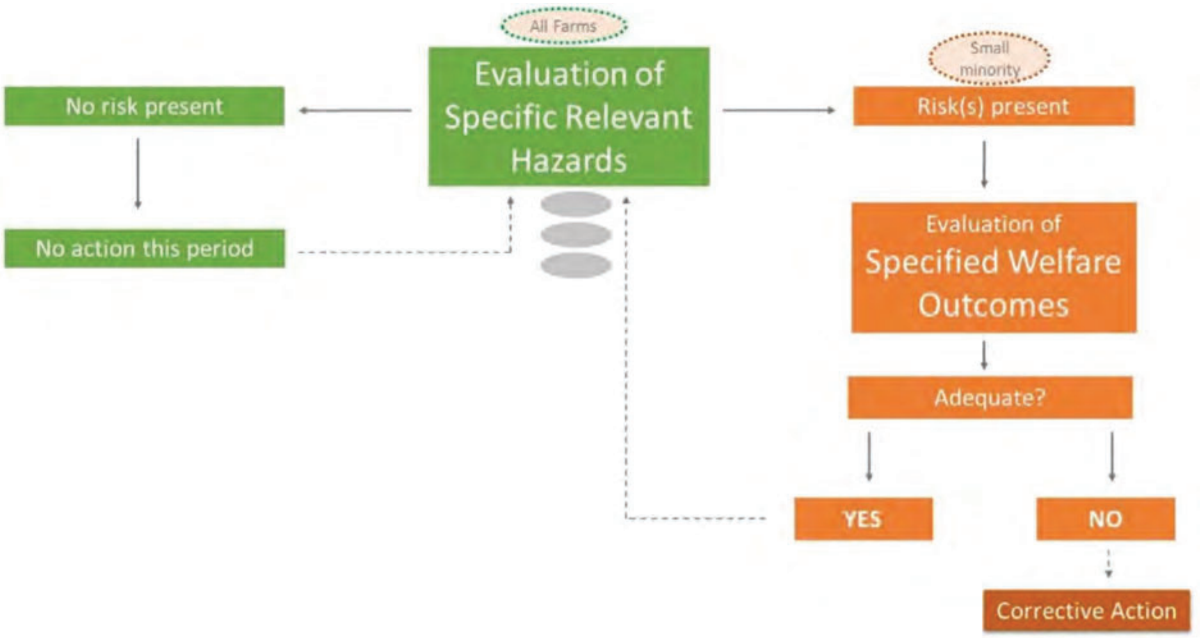


Figure I.2: Diagrammatic representation of a risk-based approach to welfare assessment on dairy farms

Again to stress, the final risk-based system is not intended to provide the whole solution to dairy cow welfare in Europe. Rather it should be viewed as one component of a toolkit that could be used to identify farms and practices that place cows at high risk of poor welfare. Even if only relatively few important aspects of dairy cow welfare are addressed and corrected using the method, cow welfare across Europe would improve and it would be a success. The challenge is to design a system to have the largest possible impact, within the limitations that exist in such an approach.

Timelines for the First Elicitation Task

Before the working group meeting on 30th September we request that you read Task 1 below such that any clarifications can be requested at the September meeting. *After the September meeting we would like you to complete Task 1 before 10th October so that results can be collated prior to the meeting in Parma on* 25th–26th October. We ask you to set aside *at least 1 h* to complete Task 1 such that considerable thought and imagination can be applied. We would like you to think clearly and carefully when making the initial identification of the specific relevant farm hazards.

Task 1: Identification of Specific Relevant Hazards: Farm characteristics associated with poor cow welfare

The aim of this task is for you to list the three to five farm characteristics that you believe will identify, across European dairy farms, those at highest risk of having poor cow welfare. Please complete this task by 10th October – your input will be used for subsequent steps in the elicitation at the meeting in Parma on 25th–26th October.

Remember, there are not 'right' or 'wrong' answers here, we are conducting the elicitation to understand your beliefs as experts and reach a team decision. Your three to five farm characteristics are not expected to solve all dairy cow welfare problems – but we would like you to identify the characteristics that you feel would have the largest, most widespread impact on welfare in European dairy farms.

Please note, we are excluding tie stall systems from this risk-based approach, so please do not specify farm characteristics related solely to tie stall systems. This is because the WG have currently proposed to recommend the phasing out of tie stall in the main Scientific Opinion.

We would like you to consider the possibilities very carefully since it is hoped that the final consensus of ideas will be used in a wide-ranging risk-based scheme for dairy cow welfare assessment across Europe.

Before considering farm characteristics, we would like you to contemplate what 'poor' cow welfare means in this context:

1) Please consider what you believe poor cow welfare to be and therefore which herds should be identified in our risk-based approach.

We would like you to carefully consider dairy cow welfare in terms of what you feel would be 'unacceptably poor' and try to define this in your mind. To help develop a clear picture of what you deem to be poor welfare, it may help to think of herds with poor welfare in different ways as follows:

- 'Herds in which most reasonable, informed, knowledgeable people would consider welfare is inadequate'.
- 'Herds in which many cows are likely to experience physiological or behavioural welfare issues'.
- 'Herds that require immediate support, action or resource to make improvements in welfare'.
- 'Herds in which some or all cows are regularly below what you consider a minimum acceptable level of welfare (i.e. poor welfare is not confined to only a small portion of the herd or to short time periods)'.
- 'Herds in which the negative impacts on cow welfare occur on a day-to-day or week-to-week basis'.
- 'Herds in which there is a high risk that poor welfare will continue (or get worse) if no corrective measures are implemented'.

Farm Characteristics

We would now like you to identify the *top farm characteristics* that you believe are associated with a substantial deleterious impact on adult cow welfare across most dairy herds in the EU. *Please list at least 3 and no more than 5 farm* characteristics; they do not need to be ranked. That is, we are asking you to list the three to five most important farm characteristics that are associated with the standard of poor welfare you have mentally developed in point 1 above.

To confirm, we are excluding tie stall systems from the risk-based approach, so please do not specify farm characteristics that solely relate to tie stall systems.

You do not need to specify these farm characteristics in a quantitative way, although it would be preferable if you can. To provide an unlikely example, if you felt that the length of farm driveway was an important farm characteristic leading to poor welfare, you can either specify your farm characteristic as 'a farm driveway that is too long' (i.e. with an indicator of the direction of the effect) or, preferably, 'a farm driveway longer than [for example] 2 km' (i.e. with an exact threshold). The latter would be more informative for later discussions, but the former is acceptable if you do not have a clear quantitative value in mind. Final quantification of such detail will be discussed and agreed later in the elicitation, after consensus has been reached on the farm characteristics most urgent to address.

A single farm characteristic can, if you feel appropriate, be specified as an aggregate of several factors, which are all required together, to have the deleterious impact on welfare. For example, if an important characteristic only exists in your view at a certain time of year or in a specific system, this should be specified so that the characteristic can be defined as clearly and accurately as possible. For example, if you believed the length of farm drive was only important in winter and in herds with the Highland breed of cow, these would be specified together to represent one single farm risk; 'a farm driveway longer than 2km, in winter, in dairy herds with highland cattle'.

You may like to think of your farm characteristics as those areas that you would most like to see changed across European dairy farms – If you could ensure just three (up to five) farm characteristics were in place on all dairy farms, what would these be?

You may also like to imagine a typical dairy farm with what you consider to be poor cow welfare. Try to visualise the farm now. Such a farm would benefit from immediate corrective action. If you carefully picture this farm and the cows, what are the key characteristics of the farm associated with poor welfare? What exactly is affecting the cows throughout their day-to-day and week-to-week lives? Can you be as specific as possible about which elements of the farm are most impacting on welfare in these particularly poor farms? Are these elements present within all dairy farming systems and at all times of year or, if not, can you be specific about exactly when they are present?

Having considered a farm with poor welfare, can you now picture a farm with what you consider to be 'good welfare'. Does it help to consider the key differences between this and the farm you visualised with poor welfare? In terms of farm characteristics and hazards, what are the main differences between farms you visualised with poor as opposed to good welfare?

While you are visualising farms with poor welfare, we encourage you to think widely, through as many aspects of dairy farm facilities and management practices as possible, to ensure everything is considered. Please consider all aspects of dairy farm facilities for all systems and at all times of the year, including spring, summer autumn and winter and for tie stalls, cubicles, open yards, pasture and hybrids (mixed systems). To facilitate this, you may like to consider all aspects of a dairy cow's day-to-day life; all activities and events that occur in each of the systems at all times of year. While going through these events and activities, which three to five farm characteristics do you believe are best to distinguish farms at high risk of having poor cow welfare?

Having visualised dairy farms with poor welfare and considered farm characteristics responsible for the poor welfare, please can you decide on the three to five most important characteristics that you feel increase the risk of poor welfare on European dairy farms. Please write down each of your farm characteristics in one simple, short sentence or bullet point. For example 'Farm driveway longer than 2km' or 'Farm driveway longer than 2km, in winter, in herds with highland cows'. You will have time to further describe, explain and clarify each of your farm characteristics at the meeting in Parma on the 25th-26th October.

Please can you email the three to five sentences describing your farm characteristics to Eliana Lima (eliana.lima@efsa.europa.eu) and Hans-Herman Thulke (hans.thulke@ufz.de) by 10th October 2022.

Appendix K – Intermediate outcomes of the EKE

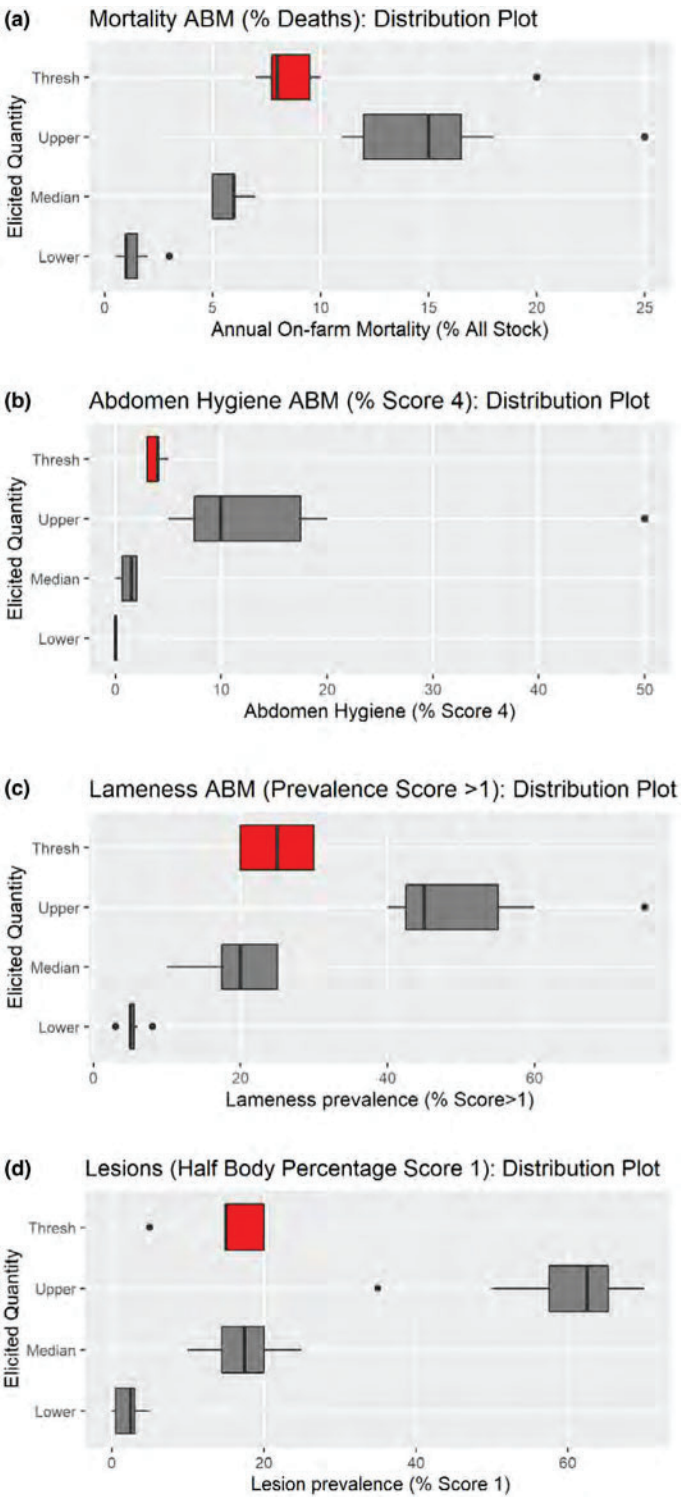
Table K.1: List of welfare consequences and animal-based measures (ABM) supplied to the expert group during the elicitation

Welfare consequence	POSSIBLE ABMs			
Thermoregulatory Stress	Incidence rates of accurately recorded disease events (seasonal)	Lying times score (automated or observed)	Observational scoring of social or exploratory behaviours	Score of % lying in passageways
Group, handling sensory stress	Observational scoring of social or exploratory behaviours	Flight distance score	Lying times score (automated or observed)	
Gastro-enteric	Incidence rates of accurately recorded disease events	Faecal pat scoring	Score of rumen fill	Body condition score
Respiratory disorders	Incidence rates of accurately recorded disease events	Body condition score		
Reproduction-related stress	Calving to conception interval, FTC, Conception rate			
Inability to perform feed- and exploration-related behaviours	Observational scoring of social or exploratory behaviours	Flight distance score		
Inability to perform play behaviour	Observational scoring of social or exploratory behaviours			
Inability to perform comfort behaviour	Observational scoring of social or exploratory behaviours	Cleanliness scoring		
Locomotory disorders	Lameness - gait score (and lesion score)	Body condition score		
Mastitis	Incidence rate clinical cases, Bulk milk SCC	Teat score		
Metabolic disorders	Metabolic profile sampling	Body condition score		
Prolonged hunger or thirst	Body condition score	Score of rumen fill	Incidence rates of accurately recorded disease events	Water usage/cow/day
Restriction of movement	Observational scoring of social or exploratory behaviours	Score of lying, rising and lying down behaviours	Cleanliness scoring	Lameness - gait score (and lesion score)
Resting problems	Leg lesion/injury/integument score	Cow posture scoring	Score of % lying in passageways	Score of lying, rising and lying down behaviours
Skin or soft tissue damage	Leg lesion/injury/integument score	Lameness - gait score (and lesion score)		
Musculoskeletal disorders	Leg lesion/injury/integument score	Lameness - gait score (and lesion score)		

Table K.2: Farm characteristics initially proposed by members of the expert group, deemed most likely to be indicative of, or associated with, poor dairy cow welfare on European dairy farms

Expert 1	Expert 2	Expert 3	Expert 4
Zero-grazing for at least 60 days/year	Continuous (or all-year round) housing without access to pasture	Prolonged housing; > 4 months/year	Freedom of the dairy cow to choose where she wants to be (freedom to choose if she will be on pasture, in a shed, in the stable, in the milking robot and so forth)
Overstocking at the cubicles (> 1.1 cows/cubicle)	A cow to cubicle ratio of less than 1:1 (might even be 1:1 or higher)	Non-recommended cubicle dimensions; incorrect length	Basic training in animal welfare of staff (Lack of attention from the primary caretaker(s). When the caretaker is not/no longer capable of observing that something is wrong)
Uncomfortable cubicle base	Cubicles with no forward lunging space	Low staff to cow ratio	Mortality, including also proportion of euthanised cows (as an indicator of timely dealing with the cow before it is dying)
Space allowance per cow (including cubicles/lying area)	Low staff to cow ratio	Infrequent cow roadway maintenance; every 2–3 years	Inter-quartile range of body condition scores among milking cows – as an indicator of hunger or obesity and the interaction between feeding, milk yield and lameness
Share of employed workers	High calf mortality		Lameness frequency or frequency of claw and leg disorders (that are not managed)
Expert 5	**Expert 6**	**Expert 7**	**Expert 8**
Access to an outside space ($\geq$ 1 m^2/cow in size) for all milking cows when housed in cubicles or yards, at all times of year	The number of cubicles is too low (less than 1.2 cubicle per cow) to ensure sufficient assess to lie down during the main resting periods	Attitudes of the farmer towards the cows' behaviour and welfare criteria	A farm where functional hoof trimming is not done at least once per lactation in all cows (e.g. at drying off)
Cubicle availability per cow when housed in cubicle facilities at all times of year; $\geq$ 5% more cubicles than cows (i.e. 100 cows would require $\geq$ 105 cubicles)	Cubicles are too small (dimensions depending on breed) to support comfortable resting behaviour as well as lying down and getting up movements.	Pain management practices for routine painful procedures performed by the farmer, the technician and the vet	A farm where on farm mortality, including rearing animals > 1 day old, is above 5%
Bedding depth when housed in cubicles or yards at all times of year; $\geq$ 15 cm depth	Cubicles are too hard (less than 10 cm bedding or deformable surface) to support comfortable resting behaviour as well as lying down and getting up movements.	Ratio no of workers / No of cows, heifers and calves on the farm	A farm where bulk tank SCC is over 300.000 cell/mL at least 6 months per year and more than 10% of the animals are above 400.000 cells/mL at least 6 months a year.

Expert 1	Expert 2	Expert 3	Expert 4
Total space requirement for milking and dry cows when housed in cubicles or yards at all times of year; ≥ 7 m^2 per cow	The total area too small (less than 8–10 m^2 depending on breed) and limits cow's access to resources such as feeding and resting places	Housing system (the ones that we defined in the main document)	A farm where calving interval is for more than two consecutive years, above 400 days.
Involuntary culling – Losses (death or culling) of adult cows in the first 100 days of lactation; ≤ 4% per annum (% of all cows calving)	The number of feeding spaces per cow (one pace is 65–70 cm per cow depending on breed) is too low to ensure ad libitum access to fed during activity periods	Ratio profits/No of cows, heifers and calves on the farm	A farm with constant high use of antimicrobials or over 17 mg/PCU (where PCU is a standardised population-corrected unit)


(a)
Mortality ABM (% Deaths): Distribution Plot
Elicited Quantity
Thresh
Upper
Median
Lower
0
5
10
15
20
25
Annual On-farm Mortality (% All Stock)
(b)
Abdomen Hygiene ABM (% Score 4): Distribution Plot
Elicited Quantity
Thresh
Upper
Median
Lower
0
10
20
30
40
50
Abdomen Hygiene (% Score 4)
(c)
Lameness ABM (Prevalence Score >1): Distribution Plot
Elicited Quantity
Thresh
Upper
Median
Lower
0
20
40
60
Lameness prevalence (% Score>1)
(d)
Lesions (Half Body Percentage Score 1): Distribution Plot
Elicited Quantity
Thresh
Upper
Median
Lower
0
20
40
60
Lesion prevalence (% Score 1)

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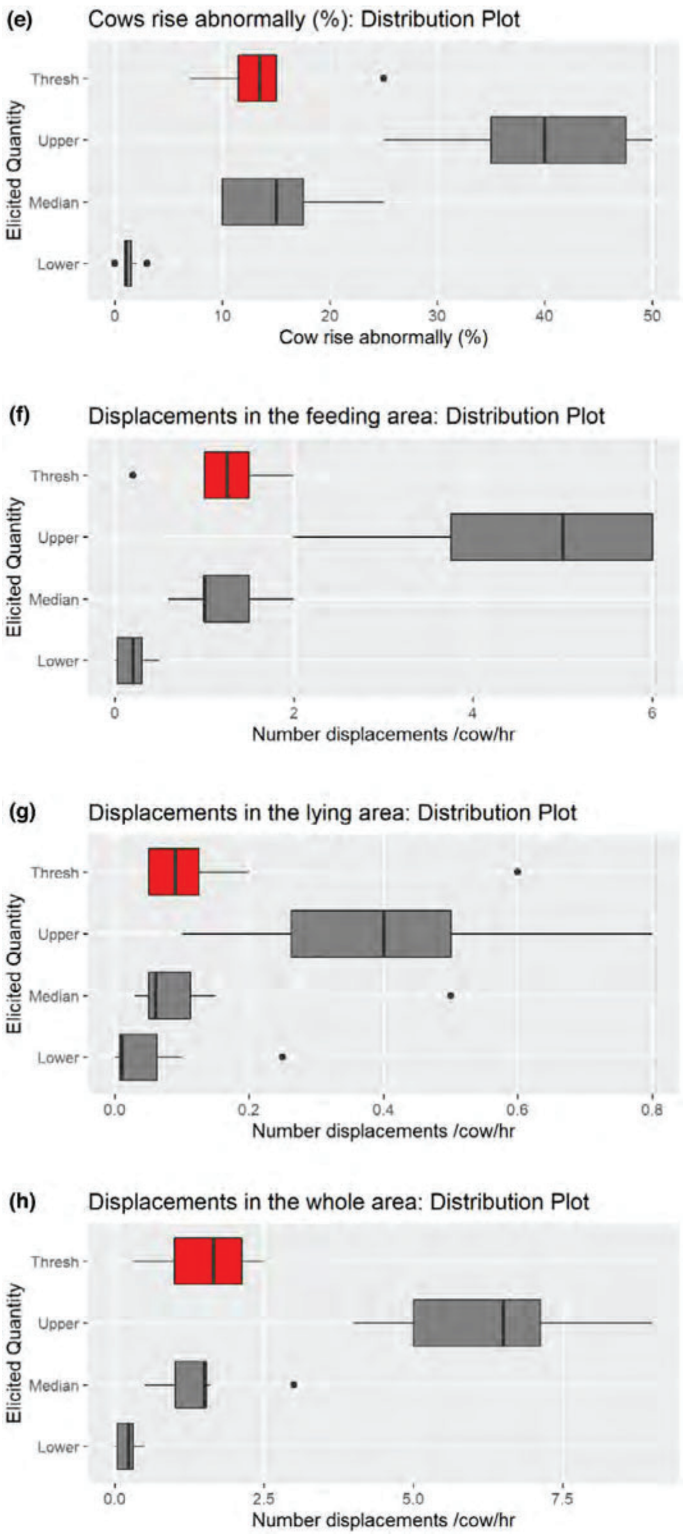

Figure K.1: (a)–(g). Boxplots to illustrate the distribution across expert group members of elicited quantities for each farm-based measure. 'Lower' represents dairy farms considered to implement best welfare practices, 'Upper' represents farms considered to have the poorest welfare and 'Median' represents farms considered to have the most widespread or average practices in dairy farming. 'Thresh' represents the threshold at which the group expert deemed corrective action should be taken. The distributions of Lower, Upper and Median summarise the values of individual experts (not revealing individual's uncertainty) and comprise the outcome of the consensus discussion between the experts. Lower, Upper and Median were elicited independent of the value of Thresh. The former refers to the dairy farm population in EU, while the latter is about a farm with specified farm characteristic