Comparison of stable environment in prior approved and non-prior approved horse stables

Jämförelse av stallmiljö i förprövade och ej förprövade häststallar

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I denna serie publiceras olika typer av studentarbeten, bl.a. examensarbeten, vanligtvis omfattande 7,5-30 hp. Studentarbeten ingår som en obligatorisk del i olika program och syftar till att under handledning ge den studerande träning i att självständigt och på ett vetenskapligt sätt lösa en uppgift. Arbetenas innehåll, resultat och slutsatser bör således bedömas mot denna bakgrund.

SUMMARY

To establish good horse welfare there are several factors that need to be considered. One important factor is the environment in which the horses are kept. In Sweden horses are stabled during long periods of time in the cold season and consequently the stable environment is even more important. The most essential environmental factors in a horse stable are ambient temperature, relative humidity (RH) and concentrations of contaminants in the stable air. The air in a horse stable contains dust, noxious gases, moulds and microorganisms which all can contribute to developing respiratory diseases in horses. In Sweden it is legislated that when a livestock building is erected, altered or extended it needs a prior approval from the County Administrative Board. The aim with the legislation is to approve the building from an animal welfare and animal health perspective and to prevent welfare issues.

The aim of this study was to compare stable environment in stables with prior approval with stables without in order to investigate whether the prior approval process has a positive effect on stable environment in horse stables. Temperature, RH, carbon dioxide (CO_2) and ammonia (NH_3) were measured in four horse stables; two with prior approval and two without. The measurements were conducted in the morning at feeding in the stable and outside at three consecutive days. In addition, data loggers were placed in the stables and outside for continuous measurements of temperature and RH during the same three consecutive days.

The results from the study show that the prior approved stables have higher values of CO_2 and NH_3. However, those values were far below the legislated maximum limits in Sweden. From the collected data from the data loggers there were many values of RH that had to be removed because they were not reliable. Overall high values of RH could be seen in all four stables and no major differences between stables could be seen. On the basis of these results, the conclusion of this study is that the prior approval process is no guarantee for a good stable climate and air quality. However, it is not possible to determine whether prior approved stables have better stable environment than non-prior approved stables in general because of the differences in ventilation system, stable size, bedding material and feed in the studied stables as well as the small number of stables studied. The results of this study give an indication that this issue is of importance and needs to be researched further to achieve adequate long term horse welfare in Sweden.

SAMMANFATTNING

För att uppnå god hästvälfärd finns det flera faktorer som måste beaktas. En viktig faktor är den miljö där hästarna hålls. I Sverige hålls hästar uppstallade i långa perioder under den kalla årstiden vilket resulterar i att stallklimatet har stor betydelse för hästens välfärd. De mest väsentliga faktorerna när det gäller stallmiljön är omgivningens temperatur, relativ fuktighet (RF) och koncentrationer av föroreningar i stalluften. Luften i ett stall innehåller damm, skadliga gaser, mögel och mikroorganismer vilka kan bidra till utvecklingen av luftvägssjukdomar hos hästar. I Sverige är det lagstiftat att när en djurbyggnad uppförs, ändras eller byggs ut behövs ett förhandsgodkännande från Länsstyrelsen, det vill säga förprövning. Syftet med förprövningen är att godkänna byggnaden från ett djurskydds- och djurhälsoperspektiv och för att förhindra välfärdsproblem.

Syftet med studien var att jämföra stallmiljön i förprövade stall med stall som inte var förprövade för att undersöka om förprövningsprocessen har en positiv effekt på stallklimatet. Temperatur, RF, koldioxid (CO_2) och ammoniak (NH_3) mättes manuellt i fyra stall, två förprövade och två ej förprövade stall. Mätningarna utfördes på morgonen vid utfodring i stallet och utomhus tre dagar i följd. Dessutom placerades dataloggrar i stallet och utanför för kontinuerliga mätningar av temperatur och RF under samma mätdagar.

Resultatet från studien visar att de förprövade stallen har högre värden av CO_2 och NH_3. Dock var dessa värden långt under de lagstiftade gränsvärdena i Sverige. Från de insamlade data från dataloggrarna var det många värden av RF som tvingades tas bort då de inte tillförlitliga. Generellt höga värden av RF kunde ses i alla fyra stall och inga större skillnader mellan stall kunde ses. Utifrån resultatet av denna studie är slutsatsen att förprövning inte är en garanti för en bra stallmiljö. Det är dock inte möjligt att generellt avgöra om de förprövade stallen har bättre stallmiljö än de stall som inte är förprövade på grund av skillnaderna i ventilationssystem, strömedel och foder i de studerande stallen samt fåtalet studerade stall. Resultatet av denna studie ger dock en indikation på att denna fråga är viktig och måste utredas vidare för att uppnå långsiktigt bra hästvälfärd i Sverige.

GLOSSARY

Absolute humidity

Absolute humidity (AH) is mass of water vapour per volume of air and is expressed as g/m^3 (Ahrens et al., 2012), i.e. the actual amount of moisture in the air. AH is not dependent on air temperature.

Air quality

Air quality refers to concentrations of contaminants and gases in the stable air.

Evaporative heat loss

Heat loss by evaporation of water from skin and airways of the animal. Evaporation has a cooling effect and occurs in the animal by sweating and panting (Sjaastad et al., 2003).

Heat loss

Heat is transported from the animal’s body to its surroundings through radiation, conduction, convection and evaporation and condensation of water (Sjaastad et al., 2003).

Non-evaporative heat loss

Heat loss through radiation, conduction and convection. Transportation of non-evaporative heat loss always goes from a warmer to colder region and increases as the difference between the skin surface and the surroundings is increasing (Sjaastad et al., 2003).

Relative humidity

Relative humidity (RH) is the ratio of the air’s water content to its water capacity, i.e. how close the air is of being saturated. RH is presented in percentage and 100 % means that the air is saturated with water vapour. RH is the most common used moisture measurement in animal stables (Ahrens et al., 2012). The total amount of water vapour that air can hold is to a great extent dependent on temperature; warmer air can contain more water vapour than cold air (Lstiburek & Carmody, 1994).

Stable climate

Stable climate refers to thermal factors in the stable, such as temperature and RH.

Stable environment

In this report stable environment refers to both stable climate and air quality parameters in a horse stable.

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1 INTRODUCTION

Good horse welfare is multi-dimensional and includes aspects of health, behaviour, housing management and feeding. The factor that is highlighted in this paper is welfare aspects regarding the effects of stable environment on the horse. This is an important issue since stable owners in Sweden generally do not have much knowledge about the climate tolerance of the horse, resulting in poor ventilated stables (Michanek, 2008). In addition, modern housing mainly focuses on human's need instead of the horse's which does not contribute to good horse welfare (Mills & Clarke, 2002).

Good management of the housing environment is essential for horse welfare since the keeping in a 'closed' environment inevitably exposes the integumentary and respiratory system of the horse to different substances in the aerial environment (Hartung, 1994; Mills & Clarke, 2002). Consequently, the respiratory health, performance and longevity of the horse are negatively affected (Curtis et al., 1996; Mills & Clarke, 2002). It is difficult to say how much time a horse needs to spend in a stable in order to get affected by poor air quality and there is a great deal of individual variation with regard to stabling time (Casey, 2002). According to Casey (2002) leisure riding horses generally spend much time outside grazing while racing horses spend most of their life stabled. Svala (2008) did a survey with horse owners in Sweden regarding management systems. Among 47 horse facilities 29 had their horses at pasture day and night for five months or more during a year. Interestingly, six of the stables did not have their horses at pasture at all and the majority of them were dressage or racing horses. According to A-C. Bengtsson at Swedish Equestrian Federation (pers. comm., 4th of September 2012) the average grazing time at riding schools in Sweden is five to six hours per day. Together with approximately two hours at riding lessons, this means that horses are stabled for 16-17 hours a day. However, the majority of horses are privately owned and, to our knowledge, there is no information available about their daily time in the field or otherwise outside the stable.

In Sweden horses generally spend more time stabled during autumn and winter due to low outside temperatures and this is proven to cause more respiratory signs in horses, such as coughing and increased respiratory effort (Couëtil & Ward, 2003; Hotchkiss et al., 2007). Time spend in a closed environment is also strongly associated with locomotor stereotypic behaviors (McGreevy et al., 1995), such as box-walking and weaving due to lack of exercise (Cooper & Mason, 1998). In a study made by McGreevy et al. (1995) they found that stabling more than 20 hours per day is often associated with the occurrence of stereotypic behaviours.

The importance of the horse stable's design and function are great and since 1973 Swedish legislation requires a pre-approval for erection, alteration and extensions of livestock buildings and horse stables. This is legislated in the Animal Welfare Act (SFS 1988:534), the Animal Welfare Ordinance (SFS 1988:539) and *Statens Jordbruksverks föreskrifter och allmänna råd (SJVFS 2012:12) om förprövning av djurstallar*. The prior approval process is considered important to prevent inadequate animal welfare and animal health issues in stables in an early stage. It is the County Administrative Board (CAB) that examines and approves the building and this applies when the number of horses is five or more. If a livestock building requires a prior approval an application has to be filled in together with a building plan and a site plan including all the details regarding the building and its surroundings. When the application and the building plan are approved the erection, alteration or extension of the building needs to be carried out within three years. After completion, CAB carries out an inspection to make sure that the building is in accordance with the approved application. If alterations are made without an approval CAB can impose a special charge and decide that the building is prohibited for animal housing. Stables can also be approved in retrospect if it fulfils the legislation.

This area is an important issue in terms of horse welfare and much work have been done regarding stable environment and its effect on stabled horses. However, no studies have been found regarding prior approval and its function related to stable environment, and hence horse welfare.

1.1 Objectives

The aim of this study is to analyse and compare stable environment in two prior approved horse stables with two stables that have no approval. The results from this study form the basis for further discussion of how the prior approval process affects the horse welfare in terms of stable environment.

1.2 Hypotheses

- The stables with prior approval have better stable environment in terms of ambient temperature and RH as well as concentrations of CO_2 and NH_3.
- The results from this study give an indication that the prior approval process is an important step in achieving good horse welfare in terms of stable environment.

2 LITERATURE REVIEW

2.1 Environmental factors in a horse stable

Environmental factors in the stable influence the horse in terms of behaviour and health and is associated with the prevalence of respiratory diseases (Sainsbury, 1984). There are three main environmental factors affecting the horse: ambient temperature, relative humidity (RH), and concentrations of contaminants in stable air (Sainsbury, 1984; Clarke, 1987b).

2.1.1 Ambient temperature

The horse is able to acclimatize to climate differences (Webster, 1994) since it is evolved as a free-ranging herd-living animal in vast areas (Clarke, 1994; Ventorp & Michanek, 2001). The horse is a homeothermic animal which means that it can increase or decrease the blood circulation in the superficial blood vessels to adapt to quick changes of temperature and thereby support the maintenance of its body-core temperature (McCutcheon & Geor, 2008). In addition, the horse has a very effective insulation in terms of fur coat that insulates against cold weather and resists water and wind (Michanek, 2008).

One important concept in this area is thermal comfort, i.e. the temperature is at a comfortable level. Horses experience thermal comfort within the thermoneutral zone (TNZ) and within this zone the horses can easily maintain their heat balance (Charles, 1994). TNZ is limited by a lower critical temperature (LCT) and upper critical temperature (UCT) (Sällvik, 2005). When the temperature of the environment is below LCT the horses must increase the heat production to maintain their body temperature. At temperatures above UCT non-evaporative heat loss decreases and evaporative heat loss increases causing panting (Clark & McArthur, 1994). The critical temperatures are affected by many factors, such as the weight of the horse, breed, feeding intensity, humidity, wind velocity, the number of animals, bedding material, and the health of the horse (CIGR, 1984; Hintz & Cymbaluk, 1994) which result in major individual differences. Several studies have estimated different critical temperatures for the TNZ. A study made by McBride et al. (1985) found that the TNZ for horses ranges approximately between -15°C and 10°C, and according to Sainsbury (1984) and Morgan (1996) it ranges between 5°C – 27°C and 25°C respectively. Neonates are more susceptible to low temperatures than adult horses (Charles, 1994).

2.1.2 Relative humidity

Moisture in the stable stems mainly from respiration of the horse, urine and faeces, showering the horses and stable cleaning (Elfman et al., 2011). The survival of potentially health detrimental airborne microorganisms strongly depends on stable air temperature and RH (Wathes, 1994). Higher humidity leads to increased growth of microorganisms, such as mould and bacteria, which in turn can lead to e.g. respiratory problems in horses (Sainsbury, 1984; Wathes, 1994). Additionally, when the humidity is high condensation is likely to occur and cause moisture which lead to corrosion and rot of the stable interior

(Clark & McArthur, 1994). Thermal comfort of the horse is more affected by high RH when the temperature is high as well (Sällvik, 2005). At high temperature the horse needs to get rid of excess heat and when RH is high evaporative heat loss cannot occur since the stable air is almost saturated with water (Sjaastad et al., 2003). According to S. Nyman (licensed veterinarian, pers. comm. 30th of January 2013) humid air is mainly strenuous for horses that already have a respiratory disease, hence healthy horses are not directly affected by high RH.

According to 3 chap. 18 § *Djurskyddsmyndighetens föreskrifter och allmänna råd (DFS 2007:6) om hästhållning, saknr L101*, RH must not other than exceptionally exceed 80 % in thermal insulated stables unless the stable temperature is less than 10 °C. If the stable temperature is below 10 °C the numeric sum of indoor stable temperature and RH must not exceed 90. In uninsulated stables the maximum level of 80 % RH cannot be applied due to the difficulty in controlling the stable climate during the cold season when outside RH is very high. Therefore, in uninsulated stables RH can only exceptionally exceed the outdoor air RH with more than 10 % units. CIGR (1984) have established recommendations regarding RH in animal houses (figure 1) with regards to building function and animal comfort.

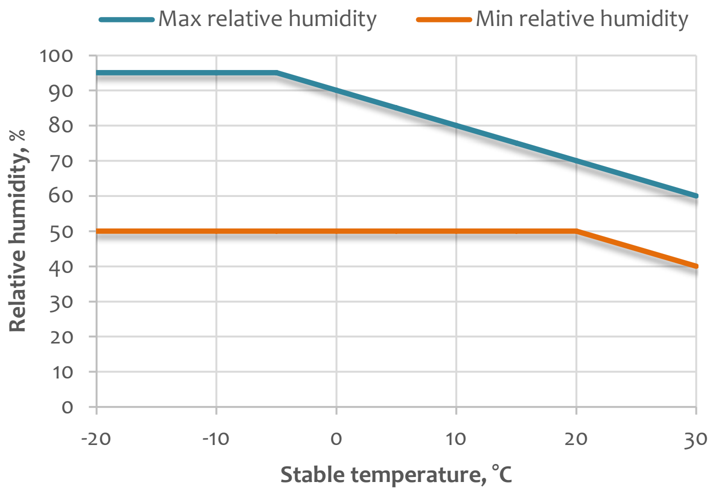


Figure 1. Recommended maximum and minimum RH as a function of stable temperature (CIGR, 1984).

2.1.3 Concentration of airborne contaminants in the stable

The horse's respiratory tract is exposed to approximately 30 million litres of air annually and the defence against aerial contaminants is therefore essential for health reasons (Art et al., 2002). Respiratory health is more critical for horses than for many other farm animals since horses live longer (Curtis et al., 1996; Mills & Clarke, 2002) and are to a greater extent used for training in which clinical signs for respiratory diseases mainly are shown (S. Nyman, licensed veterinarian, pers. comm. 30th of January 2013). Many other farm animal species usually do not display clinical signs due to culling at young ages (Clarke, 1987b, 1994) and some respiratory diseases in horses such as Recurrent Airway Obstruction (RAO) are mainly seen in older horses (Curtis et al., 1996; Mills & Clarke, 2002).

The air in poorly ventilated horse stables is heavily contaminated (Ventorp & Michanek, 2001) and contains inorganic and organic particles (Wålinder et al., 2011) which originate from bedding, feed and manure (Curtis et al., 1996; Elfman et al., 2011). Airborne contaminants consist of dust, ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulphide (H_2S), microorganisms, endotoxins and other substances (CIGR, 1994). Building volume, ventilation rate and release rate of the contaminant determine the concentration of airborne contaminants (Curtis et al., 1996).

Transmission of respiratory pathogenic microorganisms generally occurs through aerial transport (Wathes, 1994). Airborne contaminants can cause both primary respiratory diseases and affect the duration and severity of infections in the respiratory tract (Curtis et al., 1996) through changing the clearance mechanism of invaded pathogens and altering the local resistance of the horse (Clarke, 1987b). A minor alteration of the pulmonary clearance mechanism has a major impact on the amount of active pathogens present in the respiratory tract. The probability of an induced respiratory disease depends on the sensitivity of the horse, the agent's pathogenicity and the amount of pathogens in the respiratory tract (Clarke, 1987b). Therefore, all horses in a stable might not react identically to airborne contaminants.

According to the Swedish legislation maximum values for airborne contaminants in the stable have been established and horses may only be exposed to exceeded values temporarily (table 1). Some of the most important airborne contaminants in horse stables are addressed in more detail below.

Table 1. Maximum values for airborne contaminants in horse stables according to 3 chap. 16 § DFS 2007:6.

Substance	**Maximum value**
Carbon dioxide	3 000 ppm
Ammonia	10 ppm
Hydrogen sulphide	0.5 ppm
Organic dust	10 mg/m^3

Carbon dioxide

The production of CO_2 is generally related to the respiration of the horse and since CO_2 has greater density than air the highest concentration of CO_2 is found at floor level (CIGR, 1994). The CO_2 concentration in a horse stable is a measurement of the ventilation system's function, meaning that high levels indicate poor ventilation (CIGR, 1994). In a livestock stable CO_2 concentration is between 500 – 3 000 ppm under normal conditions which cause no health risk to neither animals nor humans (CIGR, 1994). The CO_2 level of outside air is 350-400 ppm (Swedish Work Environment Authority, 2012) and according to 3 chap. 16 § DFS 2007:6, the maximum permitted level of CO_2 is 3 000 ppm in horse stables (table 1).

Ammonia and hydrogen sulphide

The most common toxic gas that horses are exposed to in stables is NH_3 (Wathes, 1994; Curtis et al., 1996) which is released from urine and manure. NH_3 affect the mucus' natural defence mechanisms and hence decreases the immune response. Horses that are exposed to high levels of NH_3 persistently have higher risk of developing pneumonia (Gore et al., 2008). Concentration of NH_3 tends to rise with increased temperature and humidity as well as due to poor ventilation (Mills & Clarke, 2002). In a study made by Curtis et al. (1996) it was found that NH_3 concentration were lower in horse stables with higher ventilation rates. Additionally, the bedding material is of great importance for the NH_3 levels in the stable and in a study made by Airaksinen et al. (2001) it was found that peat moss absorbs 100 % of released NH_3 compared to wood chips that only absorbs 44 %. The hygiene and quality of the bedding material is also of great importance and NH_3 levels tends to rise when permanent beddings are used, where mocking-out of urine occurs more rarely (Clarke, 1994).

H_2S is a highly toxic gas and is produced from animal's faeces (CIGR, 1994) and NH_3 together with dust and H_2S in the stable air create a burden on the respiratory system which in turn affects the airway defence mechanism by changing the local or systemic resistance (CIGR, 1994). According to 3 chap. 16 § DFS 2007:6, the maximum level of NH_3 and H_2S are 10 ppm and 0.5 ppm respectively (table 1).

Dust

Organic dust consists of bacteria, bacterial endotoxins, virus, fungi and allergens (Curtis et al., 1996; Douwes et al., 2003). The smallest, invisible dust that during inhalation enters the intrathoracic respiratory system is called respirable dust (CIGR, 1994; Clarke, 1994; Art et al., 2002). According to Webster et al. (1987) and Vandenput et al. (1997) the size of respirable dust ranges between 0.5 – 5 µm.

Dust derives from several sources in a horse stable, such as bedding and feed (Wathes, 1994; Curtis et al., 1996). The chemical and physical composition of the feed and the method used to handle feed are important factors for dust concentration (Woods et al., 1993; CIGR, 1994). Both wet and high-fat content feed reduce the dust released to the surrounding air (CIGR, 1994). Hay contains the highest concentration of dust of all feeds used for horses (Webster et al., 1987; Vandenput et al., 1997). The bedding material in the stable is also an important source of dust in the stable. In a study made by Webster et al. (1987) it was found that stables with wood shavings as bedding material, compared to paper and straw, had significant lower dust concentrations. In addition, the combination of different feed and bedding materials in terms of dust concentration has been well studied in several studies. In a study made by Woods et al. (1993) it was shown that wood shavings as bedding material combined with pelleted feed gave lower concentrations of airborne dust than straw bedding combined with hay feed. Clements & Pirie (2007) found that wood shavings bedding and haylage feeding reduced respirable dust concentration compared to straw bedding and hay feeding. According to Woods et al. (1993) dust levels in the stable can only be decreased by changing the source material in bedding and feed.

The animals themselves are producing dust particles through skin and hair shedding and hence the stocking density has a major effect; the higher number of animals, the greater amount of dust (CIGR, 1994). However, the stocking densities in horse stables is low compared to stables with farm animals like pigs or poultry (Curtis et al., 1996). Activity levels in the stable and outside wind conditions can affect the dust concentration (Clarke et al., 1987) and according to Art et al. (2002) dust levels can reach 12 000 000 inhaled particles per breath during mucking-out. A similar finding was made by Clarke et al. (1987), who showed up to a 50-fold increase in airborne particles during mucking out and the main reason for this increase was the release of spores of fungi and actinomycetes. In addition, Curtis et al. (1996) found that straw bedding generated more respirable particles than paper during mocking out.

Dust particles might induce allergy, initiate infection, cause direct toxicity and overwhelm the pulmonary defence mechanisms and hence induce airway inflammation (Art et al., 2002). Airborne dust might directly cause or provoke respiratory diseases such as RAO and Inflammatory Airway Disease (IAD), which cause persistent coughing and reduced performance in stabled horses (Webster et al., 1987; Art et al., 2002; Elfman et al., 2011). RAO is caused by inhaled organic dust containing bacterial endotoxins and mould (Art et al., 2002). The incidence and severity of RAO is affected by the quantity of inhaled dust, the fact that some horses are more or less prone to develop the disease, as well as composition and size of the respirable particles in the stable air (Webster et al., 1987).

Exposure to dust in the stable must be minimized throughout the horse's life (Clarke, 1987b, 1993) due to the negative effects it has on the horse and according to 3 chap. 16 § DFS 2007:6, the maximum permitted level of organic dust in horse stables in Sweden is 10 mg/m^3 (table 1).

2.2 Ventilation and how it affects stable environment

The purpose of ventilation is to create a good stable environment by supplying fresh air while gases, moisture and excess heat is transported by the exhaust air (Ehrlemark, 1995). According to Wathes et al. (1983), there are three main objectives of ventilation:

1. Animal health should be maintained and productivity sustained
2. The handler should not be exposed to any health risks
3. The stable and its interior should be protected from physical damage such as corrosion, rot and mould.

The ventilation system affects concentrations of airborne contaminants, water vapour and temperature (Clarke, 1994) and without adequate ventilation in the stable condensation, odour and concentrations of substances such as CO_2 and NH_3 will increase (CIGR, 1994; Elfman et al., 2011). In a study made by Curtis et al. (1996) airborne particles in horse stables were examined in two different ventilation rates: high and low. The study found that the number of airborne particles was lower in stables with high ventilation rate. Another study by Woods et al. (1993) showed the same results and state that the ventilation system is the most effective particle clearance action. Therefore, it is of great importance for horse health that there is enough fresh air distributed to the areas where horses are kept. According to Swedish legislation all horses in the stables must receive a continuous supply of fresh air and the ventilation system must never be completely shut off (3 chap. 15 § DFS 2007:6).

There are two different ventilation systems that are used in horse stables: natural and mechanical ventilation. They affect air quality and stabled horses differently. According to Ehrlemark (1995) naturally ventilated stables require much larger ventilation openings than stables with mechanical ventilation. Many of the naturally ventilated stables are not dimensioned adequately because most ventilation openings in terms of air diffusers on the market do not have adequate capacity for stables with natural ventilation (Ehrlemark, 1995). This can result in a poor stable environment which negatively affect horse welfare. According to Clarke (1987a) the risk of draught is an important factor to consider in animal stables. Too much ventilation in wrong places causes a chilled spot in the stable and it increases the horse's lower critical temperature (Clarke, 1987a, 1994), and hence affecting thermal comfort. This affects especially neonates but adult horses get affected as well, especially when being clipped, wet, or after exercise (Clarke, 1987a; Charles, 1994). According to Wålinder et al. (2011) installation of mechanical ventilation in a former naturally ventilated stable significantly improved air quality in the stable, due to an increase in air exchange rate. They also saw a tendency towards a lesser impact on stabled horse's airways. Another study made by Elfman et al. (2009a) showed that horses had less mucus in trachea after installing mechanical ventilation. Mucus in trachea triggers coughing, which is a sign of airway disease (Viel, 1985; Robinson et al., 2003).

In mechanically ventilated stables the fans are the most prominent noise source (Nilsson, 1986). Since no mechanical equipment is used in naturally ventilated stables the noise level is much lower compared to mechanically ventilated stables. According to 3 chap. 22 § DFS 2007:6, noise in stables shall not have a level and frequency that affect horse health adversely. In stables, horses may only occasionally be exposed to mechanical noise exceeding 65 dBA.

When designing and dimensioning the ventilation system in thermally insulated stables it is based on two values: minimum and maximum ventilation rates, to make sure that the stable climate falls within the limits where the horse can regulate its heat balance and body temperature with minimal effort. Minimum ventilation is the rate for winter climate and is required for the stable not to exceed the maximum legislated values of RH and CO_2 (Ehrlemark, 1995). Maximum ventilation is the summer ventilation rate which is established to prevent the highest stable temperature being more than 4 °C at an outside temperature of 21 °C (Ehrlemark, 1995).

2.3 Clinical signs caused by poor stable environment

As mentioned earlier, the prevalence of respiratory diseases is strongly associated with poor air quality in the stable (Sainsbury, 1984; Curtis et al., 1996; Mills & Clarke, 2002) and clinical signs of airway diseases are triggered by contaminated stable air (Couëtil & Ward, 2003). The lower airways ranges from glottis to the lungs (Schlaks & Ridgway, 2012) and the most useful predictor of lower airway diseases is coughing at exercise. In a study made by Burrell et al. (1996) it was shown that coughing as a marker for the disease was 84 %. A study by Robinson et al. (2003) also found that coughing is strongly associated with airway inflammation. The horses in the study with RAO coughed after only three days stabled, compared to control horses which showed no signs of coughing. The study also found a positive correlation between coughing frequency and mucus score and the authors suggest that mucus triggers coughing. Horses with IAD show clinical signs of poor performance, coughing (Webster et al., 1987; Couëtil et al., 2007), increased respiratory effort at rest, increased mucus secretion and general signs of infection, such as fever (Couëtil et al., 2007). A study made by Christley et al. (2001) identified risk factors for coughing in thoroughbred racehorses. They found that horses in early training, younger horses, horses that had never raced, and horses that had been transported more than 14 days previously, were at greater risk of coughing. The study also found that coughing was an indicator of airway inflammation.

According to Viel (1985) chronic airway disease symptoms ranges from a minor cough during exercise, to a mild stable cough and in an early stage the disease is referred to as an allergic or infectious disease. Further development might cause a chronic irreversible lung disease, such as RAO. The author stresses that recognition of diseases in an early stage is essential to prevent and reduce the number of horses developing the chronic disease. A subclinical or minor degree of airway inflammation can be shown as poor performance of the horse due to an increased amount of mucus within the airways (S. Nyman, licensed veterinarian, pers. comm. 30th of January 2013). This affects the breathing of the horse particularly during exercise and an increased breathing frequency can be shown (Clarke, 1994). A study made by Couëtil et al. (2001) investigated clinical signs and methods of both RAO and IAD in horses. The authors stress that clinical examination is not accurate enough for diagnosis of these diseases. To early detect the inflammatory respiratory diseases they recommend forced expiration and evaluation of bronchoalveolar lavage (BAL) fluid. According to a study made by Franchini et al. (2000) the neutrophil chemotactic activity in BAL fluid was greater in horses with RAO compared to healthy horses.

3 MATERIAL AND METHODS

3.1 Study design

The study was conducted in November 2012 in four horse stables (see description in chapter 3.2 below) in Uppsala, Örebro and Stockholm County in Sweden. Parameters that were selected for measurements in this study were temperature, RH, CO_2 and NH_3 and both spot and continuous measurements of the selected parameters were made.

In each stable four measuring points were chosen; two horse boxes where stable environment was expected to be good (measuring point 1 and 2) and two boxes where poorer stable environment was expected (measuring point 3 and 4). The selection of representative measuring points was decided in relation to stable design and location of ventilation openings of each stable. Measuring points with expected better stable environment were placed e.g. in a horse box closest to an air inlet or open door while measuring points with expected poor stable environment were placed at the back of the stable, far away from ventilation openings. This is because the ventilation system positively affects RH and concentration of contaminants in the stable air (Clarke, 1994) and hence boxes close to inlet ventilation openings theoretically ought to have better stable environment. For comparison of the measured stable values a fifth measuring point was placed outside each stable.

The measurements were conducted at three consecutive days in the morning at feeding before horses were taken out into paddocks. At this point, stable environment were expected to be poorer than in any other time of the day, since the horses had been stabled all night with closed doors. In addition, in the morning the activity in the stable is low resulting in less disturbing factors than in any other time of the day.

3.2 Stables included in the study

The stables that participated in the study are listed below together with a short description. Two of the stables were prior approved by CAB and the other two had no such approval. All horses in the four stables were stabled during evening and night and taken out for grazing at daytime.

3.2.1 Prior approved stables

Stable 1

Stable 1 was privately owned, was built in 1974 and had nine loose boxes with walls made of wood and grilled steel bars at the upper part of the wall. When the present study was conducted nine warmblood horses were stabled. The bedding material was mainly wood shavings in combination with peat moss in some boxes. The stable was insulated and the ventilation system was mechanical with two outlet fans that were turned on in the evenings. Two doors were occasionally open at daytime and closed at night time.

Stable 2

Stable 2 was a riding school that was built in 1937 and rebuilt in 1982. The stable had tie stalls with walls made of wood and had room for 51 horses whereof four loose boxes with grilled steel bars at the top of the walls. When the study was conducted 48 warmblood horses and ponies were stabled. The bedding material in the stable was peat moss. The stable was insulated and the ventilation system was air handling units with heat exchanger ventilation, i.e. mechanical fans that distribute fresh air heated by the heat recovered from the 'old' air (Svensk Ventilation, 2013). Above the horses there were air filters where inlet air was filtered. This system is most commonly used in residences and industrial premises. Several windows were mostly open throughout the year since the stable owners found the ventilation system not adequate.

3.2.2 Non-prior approved stables

Stable 3

Stable 3 was a riding school, built in 1982 and rebuilt in 1994. It had tie stalls with room for 31 horses whereof 11 individual boxes with wooden box walls and grilled steel bars at the top. When the study was conducted there were 30 warmblood horses and ponies stabled. The bedding material in the stable was peat moss. The stable was insulated and the ventilation system was mechanical with two air inlets and two air outlets in the ceiling, driven by mechanical fans. The air inlets were shut off because they were not working due to improper installation. Some windows were open to compensate for the closed air inlets.

Stable 4

Stable 4 was privately owned, it was built in 1990 and measurements were conducted in a smaller section that functioned as a separate stable. That stable had seven individual boxes with sparse horizontal wood planks as box walls and open tops. When the study was conducted five warmblood and coldblood horses were stabled. The bedding material was wood shavings. The stable was insulated with no installed ventilation system, however, three doors were open at daytime whereof two doors were leading to joint stables, and one outside.

3.3 Data collection

3.3.1 Manual data collecting of temperature, RH, CO_2 and NH_3

On all three measuring days temperature, RH and CO_2 were manually measured at all five measuring points in the stable and outside. Measurements in the stable were done in the middle of the box and in the breathing zone of the horse which is defined by Woods et al. (1993) as 'in the region of the nostrils of the horse' and is approximately at a height of one meter from the floor. Measurements in the breathing zone are well used in previous studies by e.g. Woods et al. (1993) and McGorum et al. (1998). Woods et al. (1993) showed that the total and respirable airborne dust measured in the breathing zone of a horse is higher than levels measured simultaneously at other places in the stable.

Temperature and RH were measured with a handheld instrument (Geo Fennel GmbH, Baunatal, Hesse, Germany) model FHT 100 with an accuracy of ± 2 % and ± 0.5 °C. Measurements of CO_2 were done with a handheld IAQ-Calc (TSI Inc. MN, USA) model 8732 with an accuracy of ± 3 % at a temperature of 25 °C. NH_3 was only measured at two of the measuring points in the stable (1 and 3; measuring points with expected better and poorer stable environment respectively) only the first measuring day, due to expected low values of NH_3 in horse stables in the cold season. The latter because the NH_3 concentration is affected by stable temperature (Mills & Clarke, 2002) and earlier study results show that NH_3 was not detected at all in the winter (Houben, 2008; Elfman et al., 2009b). Instrument used for measurements of NH_3 was Kitagawa gas detector, model AP-1 (Komyo Rikagaku Kogyo K.K., Japan) with Kitagawa precision gas detector tubes.

3.3.2 Continuous data collecting of temperature and RH

To get a diurnal pattern of temperature and RH, four data loggers Tinytag plus 2 (Gemini Data Loggers Ltd., West Sussex, UK) models RGP-4500 and TGP-1500, were used. The accuracy of the data loggers were ± 3 % and 0.45 °C and 0.20 °C respectively at a temperature of 25 °C. The data loggers continuously measured temperature and RH at a desired logging interval of 10 minutes. At the first measuring day they were placed at three of the measuring points in the stable (2-4) and one outside and taken down at the third day due to the limited time schedule of this project. The reason why only three data loggers were placed in the stable was because only four data loggers were available and one data logger had to be placed outside for comparison of the stable data. The placement of the data loggers in the stable was outside the boxes chosen as measuring points due to the safety risk and in the height of the breathing zone to the extent that was possible. Figure 2 shows an example of how a data logger was placed in one of the stables. The data logger outside was placed as much as possible protected from weather and wind.

Figure 2. Placement of a data logger in one of the four stables in the study. This particular data logger was placed at the head of a tie stall at the height of the horse's breathing zone.

3.4 Testing of instruments

In order to identify whether the measurement instruments were generating correct values the instruments were tested. A calibration curve was made with reliable instruments compared to the handheld instrument measuring temperature and RH and the four data loggers. The reliable instruments used were a whirling hygrometer (Casella Measurement, London, UK) for measurements of RH and a thermometer (Wilh. Lambrecht GmbH, Goettingen, Germany) for measurements of temperature. The test was conducted in different temperature and RH intervals: -10 – 22 °C and 25 – 85 % RH in different environments such as outside, in a bathroom and in one of the studied stables. The received values were transferred into Excel 2007 (Microsoft Corp., Redmond, WA, USA) for making of linear regression scatter plots. The instrument measuring CO_2 was tested by measuring outside which normally are 350-400 ppm (Swedish Work Environment Authority, 2012). The instrument used for NH_3 measurements was not tested due to lack of reliable instrument for comparison.

3.5 Data analysis

The data loggers were connected to a computer and the collected data were transferred to the software EasyView 5 (Intab Interface-Teknik AB, Stenkullen, Sweden) which presented all measurements at an interval of 10 minutes. Values from the software, in addition to data collected from the manual measurements, were transferred into Microsoft Excel 2007 for further calculations of descriptive statistics. Data of temperatures received from the data loggers were calculated as hourly averages to decrease the amount of data, since no large variations could be seen during an hour. For comparison and conformation of values generated from the data loggers placed outside, values of average temperature and RH from the Swedish Meteorological and Hydrological Institute (SMHI) were received from weather stations closest to the stables in the present study.

To receive a fair assessment of the results of RH in the different stables the best way is to compare the stable values with the outside values of RH and temperature. Calculation of expected RH (fictive RH) inside the stable at a given stable temperature, provided that no moisture is produced in the stable, was therefore done with regards to outside AH. AH of the outside air was calculated using values from the manual measurements. This value of AH was then used to calculate a fictive value of RH in the stables using the stable temperatures of the different measuring points. The fictive RH value was compared to the real measured RH value to see how well the stables had dealt with moisture production inside the stable. Absolute humidity (AH) was calculated with an electronic humidity calculator (Vaisala Oyj, Helsinki, Finland) using the following formula for calculations (Vaisala, 2013):

$$AH = \frac{C \cdot P_w}{T} \quad (g/m^3), \text{ where}$$

C = Constant 2.16679 gK/J
P_w = Vapour pressure in Pa
T = Temperature in K

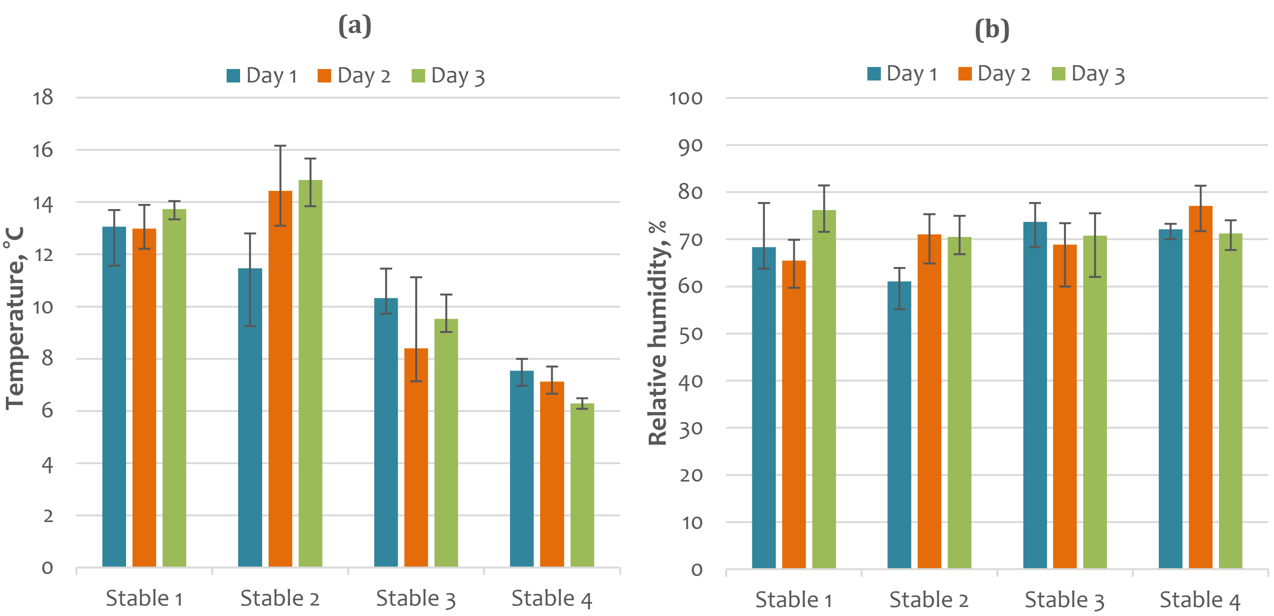
4 RESULTS

4.1 Testing of instruments

The results from the calibration test of the handheld instrument measuring temperature and RH showed that the instrument generated correct values. The calibration curves of the four data loggers showed that values of temperature were correct; however, in terms of RH there were deviations from the real values. It could be seen that when real values were above 75 % RH, which represented approximately a measured value of 80 % RH by the data loggers, the values from the data loggers to a great extent deviated. Because of this, it was decided that all measured values from the data loggers above 80 % RH were not reliable and therefore deleted. The percentages of deleted values in each of the four stables were 58 %, 95 %, 96 % and 100 % respectively. The generated linear regression equation was used to correct all measured values up to 80 % RH. The different equations of the four data loggers are showed in Table 1 in Appendix II. The figures of the calibration curves are presented in Appendices II and III. When testing CO_2 concentration outside the values varied between 350-390 ppm which indicates that the instrument was showing correct values.

4.2 Manual measurements

The results in terms of mean values from the four measuring points from the manual measurements that were carried out in the morning at feeding with handheld instruments are shown in figure 3 (a-d). The weather conditions in addition to the results from the measurements outside of each stable are presented in table 2. Table 3 show calculated mean differences between real measured RH values and fictive RH values in the four stables. Calculations of AH and fictive RH are addressed in more detail in Appendix XIII.



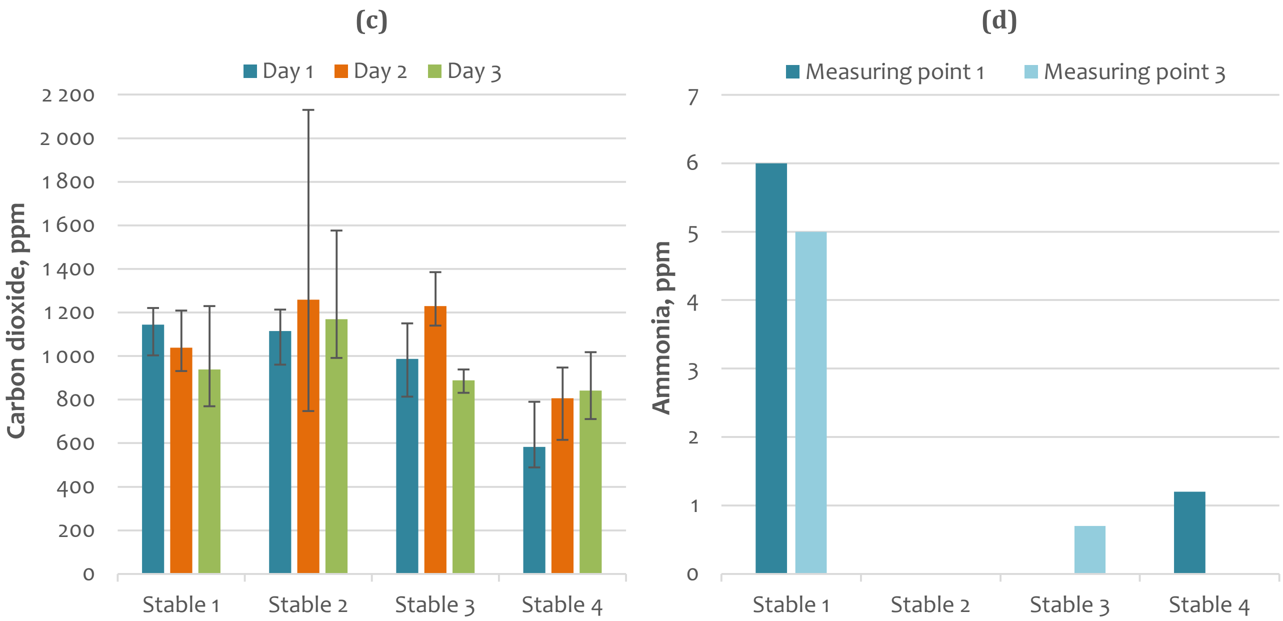


Figure 3. Results from the manually measured temperature (a), RH (b), CO_2 (c) and NH_3 (d) for each stable. The values of temperature, RH and CO_2 are mean values from the four measuring points 1-4 in the stables presented with standard deviation bars. NH_3 is shown as the measured values in the stables and when no bar is presented, no detection of NH_3 was found.

Table 2. Weather conditions for each measuring day as well as manually measured outside temperature, RH and CO_2 outside the four stables, in addition to calculated AH of the outside air.

		Weather condition	Temperature (°C)	RH (%)	AH (g/m^3)	CO_2 (ppm)
Stable 1	**Day 1**	Frosty and uncloudy	3.16	88.74	5.35	377
	Day 2	Mild and light rain	6.88	79.22	6.11	356
	Day 3	Mild and overcast	8.68	83.49	7.24	358
Stable 2	**Day 1**	Frosty and very foggy	2.50	85.35	4.93	390
	Day 2	Mild and light rain	9.15	90.84	8.10	365
	Day 3	Mild and uncloudy	7.32	87.24	6.93	352
Stable 3	**Day 1**	Rainy and a bit windy	6.59	81.20	6.15	400
	Day 2	Frosty and uncloudy	1.74	65.56	3.59	395
	Day 3	Mild and rather cloudy	5.95	79.00	5.74	318
Stable 4	**Day 1**	Rainy	4.61	86.33	5.74	360
	Day 2	Sleet and very windy	1.70	89.18	4.88	342
	Day 3	Snowy and quite windy	-0.50	72.24	3.40	334

Table 3. Percent unit differences between real manually measured RH and calculated fictive RH, presented as mean values from the four measuring points, at all measuring days. Additionally, a mean value for each stable is presented.

	Day 1	Day 2	Day 3	Mean
Stable 1	21	12	15	16
Stable 2	13	6	16	12
Stable 3	4	26	11	16
Stable 4	1	15	25	14

4.3 Continuous measurements

The results from the data loggers in terms of mean temperature every hour is shown in figure 4. More detailed figures of temperature in the stables and outside measured by the data loggers, as well as corrected and uncorrected values of RH in the stables are presented in Appendices IV-VII. Average temperature and RH obtained from SMHI's weather stations nearest from where each of the stables was located can be found in Appendix I. Table 4 present mean temperatures in the four stables, in addition to differences between outside and stable temperature generated from the data loggers. Figure 5 show diurnal temperature differences between stable mean temperature and outside temperature for each stable.

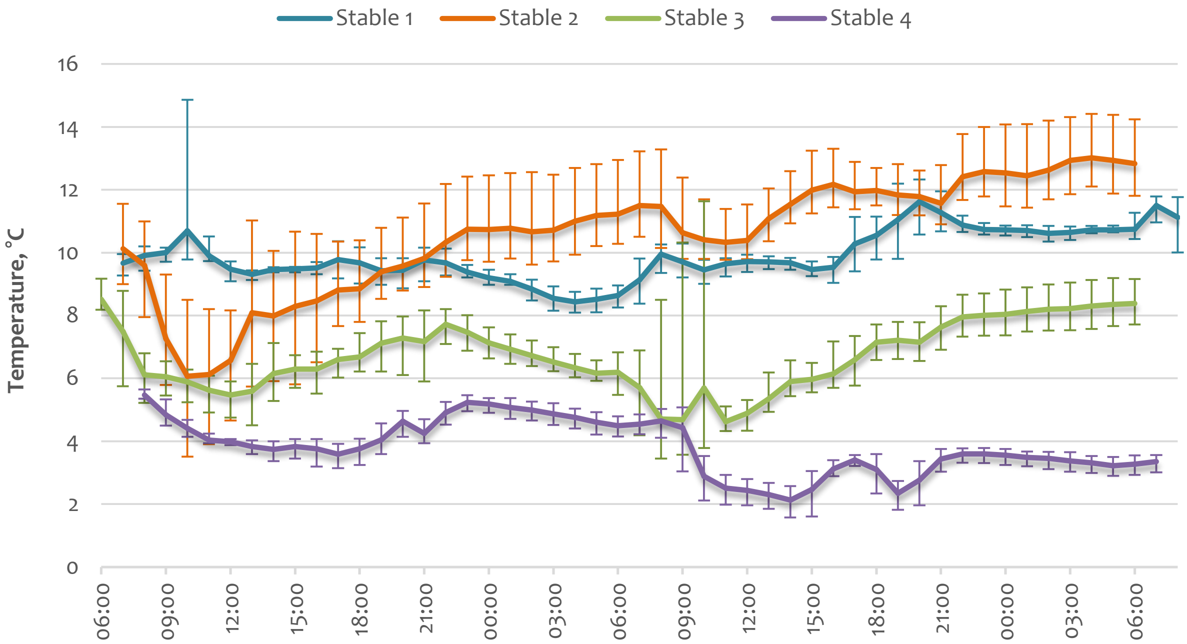


Figure 4. Hourly average temperatures from the three data loggers placed inside each stable. The error bars show standard deviations.

Table 4. Mean temperature from the three measuring points in the four stables generated from the data loggers presented together with the standard deviation. Difference between outside and stable mean temperature is presented as range.

	Mean temperature (°C) ± stdev	**Difference between outside and stable temperature, range (°C)**
Stable 1	10.07 ± 0.88	1.18 – 8.70
Stable 2	10.56 ± 2.11	0.74 – 10.42
Stable 3	6.65 ± 1.22	1.26 – 7.47
Stable 4	3.79 ± 0.80	1.37 – 4.95

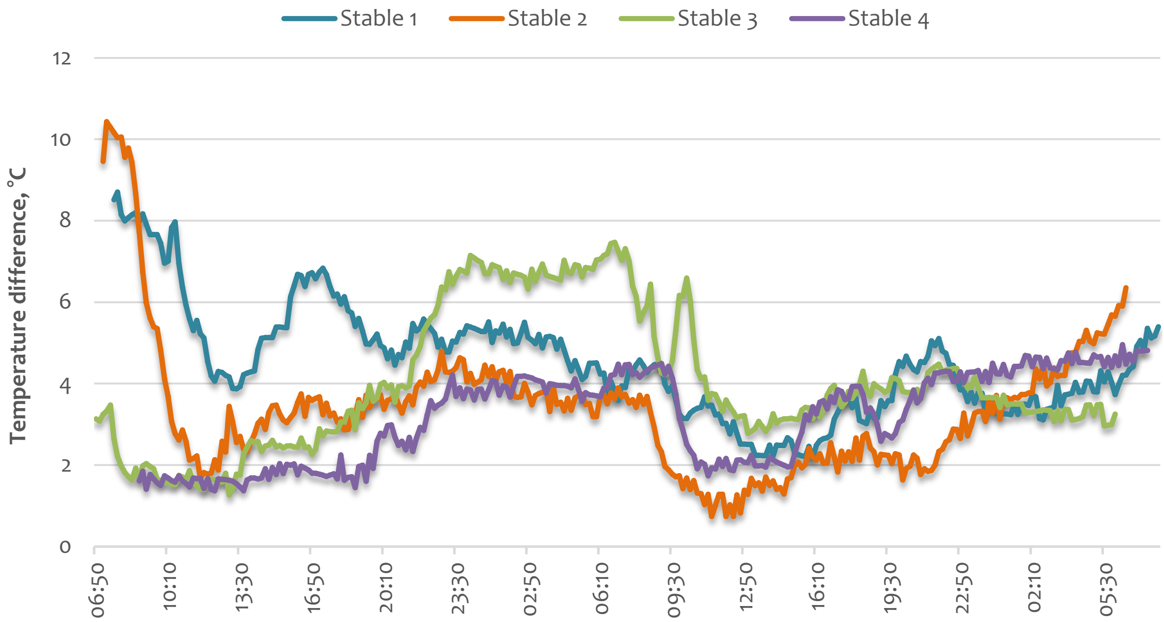


Figure 5. Temperature differences between stable mean values from all four measuring points and outside for each stable respectively, calculated using data from the data loggers.

5 DISCUSSION

According to the Council Directive 98/58/EC regarding protection of animals kept for farming purposes ‘air circulation, gas concentrations, dust levels, temperature and relative air humidity must be kept within limits which are not harmful to animals’. This EU directive is imprecise and therefore the Swedish Board of Agriculture has established maximum limits allowed in Sweden to achieve this goal; 80 % RH, 3 000 ppm CO_2 and 10 ppm NH_3. These limits are the basis for the comparative discussion of the stables in this paper. The discussion that follows will consider the choice of study method, the results of measured parameters in the study and finally discussion of the prior approval process and practical implications of the results of this study for horse welfare.

5.1 Choice of study design and limitations

The study was restricted to only four stables since the time schedule was a limited factor in this project. To receive more reliable results a higher number of included stables would have been desirable. The stables were selected by own personal contacts with stable owners and due to the difficulty of finding non-prior approved stables the stable conditions were not considered in the selection, resulting in differences in e.g. ventilation system and size, between stables which is not ideal when doing comparative studies.

The reason why this season was chosen for the particular study was because in the autumn and winter season outside temperature is low and most horse owners stable their horses at night which causes greater stocking density in the stable than in the summer time (Couëtil & Ward, 2003; Hotchkiss et al., 2007). In addition, horse owners tend to close doors and windows for their own comfort, resulting in fresh air from outside is not distributed in the whole stable and enhanced levels of gases and moisture can be seen. According to Elfman et al. (2011) the stable environment is at its best in the summertime and the most interesting for this study was to measure when the stable environment was poor.

5.1.1 Selection of measuring parameters

The parameters that were selected for measurements in this study were temperature, RH, CO_2 and NH_3. Temperature was chosen since it is an important factor in the stable in terms of stable climate and thermal comfort. Measurements of RH and NH_3 were chosen since high levels affect the stabled horses negatively, but also because it is an easy way of showing the clearance function of the ventilation system in the stable. CO_2 was selected because it is a simple indirect measurement method of showing the function of the ventilation system in the stable (CIGR, 1994). The selected parameters are correlated to each other meaning that high concentrations of e.g. NH_3 could be explained by high stable temperature and RH, which in turn might be due to a poor ventilation function which is expressed in high levels of CO_2. That is the reason why it is so important to measure several parameters in a stable to be able to put the outcomes of the measurements in perspective as well as discuss the likely causes of the results. Dust concentration in the stable air is also an important factor for air quality; however, equipment measuring dust is expensive and not very wieldy due to the size of the measurement instrument. The time schedule in addition to the budget for this project were the reasons why dust concentration was chosen not to be measured in this study. It would also have been desirable to do continuously measurements of CO_2 in the stables to receive a diurnal variation. This could not be carried out due to lack of such equipment. Additionally, air speed and air flow is interesting to measure in order to investigate how the stable air is moving and analyse the ventilation rate efficiency. However, these parameters have no direct effect on the horse and therefore not measured in this study.

5.1.2 Data collection

Both spot and continuous measurements of the selected parameters were chosen for the present study. Spot measurements of different substances give an idea of the average condition in the stable, are relatively simple and do not require any advanced measurement equipment (CIGR, 1994). Spot measurements can be done at places of importance in the stable, e.g. in the horse's box at floor level, in the feeding storage or breathing zone of the horse. In this study the interesting places were inside the boxes in order to investigate the stable environment to which the horses are most exposed, i.e. close to the animals. This was thought to reflect best the risks for disease and poor horse welfare. One disadvantage with spot measurements is that it is time consuming for the person carrying out the measurements. Therefore, continuous measurements are easier to conduct and do not require as much human effort. Equipment that can achieve continuous measurements are necessary to get an average concentration over time and to generate a diurnal variation pattern in the stable (CIGR, 1994).

From the collected data some deviations between data loggers and manual measurements were seen at the same measuring point at the same time. The reason for this is that the data loggers were placed outside the boxes for safety reasons and the most ideal would have been to collect data from exactly the same place. The measuring points in the conducted study were selected in relation to expected better and poorer stable environment in the stables. However, according to the results it could not be seen that measuring points with expected better stable environment in reality had lower values of the measured parameters, or vice versa. The values differed between days meaning that the placement of air inlet is not the only factor affecting stable environment. This finding confirm the information obtained by other studies; air quality and stable climate is also affected by many other factors, e.g. feed, bedding material, management, activity in the stable and stocking rate (Clarke, 1993; CIGR, 1994; Wathes, 1994; Curtis et al., 1996).

The main problem within the conducted study was the data loggers not functioning well enough at high values of RH. From the collected data of the data loggers, there were several values that had to be removed since they showed levels over 100 % or negative values. In the instruction manual of the data loggers it says that when the sensor is wet or moist values may deviate which disappear when the sensor gets dry. Data loggers placed outside mainly generated false values above 100 % RH which is due to the difficulty of finding good placements for the data loggers so that they are protected from precipitation. It was only the data logger in stable 1 that recorded values outside at all; however, they all measured above 80 % RH. Because of the very high outside RH, which is confirmed by the values of SMHI, in addition to precipitation when the study was conducted condensation most likely occurred in the sensor and the moisture never dried off. In a stable with relatively high values of RH the sensors can never dry off resulting in overall deviating values. Since many RH values from the data loggers had to be removed, especially in three of the four stables, no statistical analysis could be made with this data, nor could any diurnal variation in the stables be seen, which would have been desirable in this study. Additionally, more measurements of NH_3 would have been beneficial but these were not carried out due to high costs of gas detector tubes in addition to expected low values of NH_3 in horse stables during the winter. Since NH_3 only was measured at two occasions per stable no statistical analysis could be done with this data.

5.2 Measured parameters

In the following section the four measured parameters are discussed respectively in terms of likely causes of the generated results, comparison between prior approved and non-prior approved stables, how the results meet Swedish legislation, as well as how it might affect the stabled horses in terms of welfare.

5.2.1 Stable temperature

The results from the data loggers show that stable temperature varies in parallel to the outdoor temperature; the lower outside temperature, the lower stable temperature which is an effect of open doors and windows, at least at daytime. Based on the results of both data loggers and manual measurements the two prior approved stables have higher mean stable temperatures because of the higher outside temperatures when the study was conducted. This can be confirmed by the calculated temperature differences between stable mean and outside temperature, which is shown in figure 5. No major variations can be seen between the four stables regarding temperature difference. It is common for all four stables that the difference between outside and stable temperature is greater at night and lesser at daytime, because the horses are out at pasture and no heat loss from the horses are occurring in the stable. In a study made by Houben (2008) it was found that the difference between outside and stable temperature ranged from 11.8 to 18.7 °C in mechanical ventilated stables and in naturally ventilated stables it ranged from 0.3 to 6.1 °C. Three of the studied stables in the present study had mechanical ventilation systems but the difference between outside and stable temperature in those stables does not correspond to the result of temperature difference in mechanical ventilated stables by Houben (2008). The reason for this can be that the stables in the present study had lower stable mean temperatures compared to the stables with mechanical ventilation in the study by Houben (2008), that ranged between 13.8 to 20.8 °C. This resulted in a greater difference between stable and outside temperature.

From the data logger results it can also be seen that the variation in temperature within the stable is greater in stable 2 and 3 due to the size of the stables. The standard deviation is also bigger in those two stables compared to stable 1 and 4 meaning that it is a greater deviation from the mean value. Larger size of stables may result in difficulty to establish a constant temperature in the whole stable. One example of this is stable 2 that had one measuring point constantly showing higher temperature compared to the other measuring points. If the ventilation system is not adequate for the whole stable the temperature in the summer time most likely will be high at some parts of the stable. High temperatures together with humidity can lead to growth of moulds and microorganisms in the stable which in turn lead to respiratory diseases (Sainsbury, 1984; Wathes, 1994).

The manual measurements that were carried out in the morning at feeding show higher mean temperatures than the mean stable temperature generated from the data loggers which represent a daily average. This means that the result show a higher temperature in the morning compared to the rest of the day and the reasons for that is that doors have been closed all night and the stabled horses generate heat to the stable air due to heat loss (Morgan, 1996).

5.2.2 Relative humidity

According to the calibration curves measured values by the data loggers > 80 % RH represent approximately a real value of > 75 % RH. Unfortunately, it is not possible to be more accurate than this because of unreliable data from the data loggers. The majority of the measured values were removed in three of the four stables (stable 2-4) meaning that those values represented real values of > 75 % RH. According to Swedish legislation, the maximum allowed limit in Sweden is 80 % RH for insulated stables with a stable temperature above 10 °C (3 chap. 18 § DFS 2007:6), which also CIGR (1984) recommended. Due to the uncertainty of the measured values it is not possible to determine if any values exceeded 80 % RH but most likely many of them did. Interestingly, in stable 4 all measured values were removed showing that it is a very humid climate which can be due to the lack of an installed ventilation system. It was only stable 1 that generated a decent amount of values below 80 %.

The prior approved stables, 1 and 2, had mean stable temperatures above 10 °C and mean values of manually measured RH below 80 % RH, which meet the legislation. However, stable 1 had one occasion of measurement at 81 % RH, but according to Swedish legislation, RH must not other than exceptionally exceed 80 %; one exception is therefore allowed. The non-prior approved stables, 2 and 3, had mean temperatures below 10 °C meaning that the maximum limit of RH cannot be applied. The sum of temperature and RH must therefore be calculated to decide whether RH is acceptable. When using data from the manual measurements none of the sums exceed 90, which meet the legislation.

When discussing RH, outside values of AH must be considered to receive a fair comparison between stables instead of simple mean values. Since RH is very much dependent on temperature and AH is not, RH will change if temperature changes (Lstiburek & Carmody, 1994). If it is cold outside and higher temperature in the stable, RH in the incoming air will decrease because air with higher temperature can contain more water vapour. Therefore, the RH value does not say so much about the stable's ability to ventilate moisture. The results of difference between real manually measured RH and calculated fictive RH show that all four stables are rather equal with enhanced RH in the stables of 12-16 %. If this result is adequate or not is difficult to determine since no earlier studies have been found using this method. However, it can be compared with Swedish legislation for uninsulated stables where stable RH must not exceed outside RH with more than 10 % units (3 chap. 18 § DFS 2007:6). Since uninsulated stables' climate are close to the outside airs', insulated stables with ventilation systems should be able to ventilate produced moisture better than uninsulated stables. Therefore, the enhanced values of RH in the four stables are not considered adequate. It could be seen that there were major differences within stables at different days, in all four stables. This cannot be explained since only measurement of parameters were made once a day for only three days. This clearly shows that this requires further research to be able to make realistic conclusions.

However, common for all four stables are that the day with lowest outside temperature had highest difference between real measured RH and fictive RH. Lower temperature can contain less water vapour before it gets saturated compared to higher temperatures, which might result in higher values of RH inside the stables when the temperature is lower. Since the values of the four stables were similar no comparison between prior approved and non-prior approved stabled can be done regarding RH. However, because of the high values of RH it is clear that all stables do not ventilate enough, which is not acceptable in horse stables, regardless if it is a result of the ventilation system or outside conditions. If the stable air is saturated with water vapour, which it is at 100 % RH, evaporative heat loss from the animal to the surrounding cannot occur (Sjaastad et al., 2003). This is especially demanding for the animal and its respiratory system (Sainsbury, 1984).

There are many reasons why RH is high in a horse stable. Outside conditions together with the ventilation system's capacity and how it is used are presumably important factors. The activity in the stable can also be a contributing factor to high levels of RH. Stable 2 and 3 are riding schools resulting in more activity in the evening hours together with much sweat, i.e. evaporative heat loss, from both humans and horses, in contrast to the privately owned stables 1 and 4.

5.2.3 Carbon dioxide

The measured values of stable CO_2 in all four stables in the present study are lower than the maximum allowed value of 3 000 ppm in animal stables (3 chap. 16 § DFS 2007:6). The CO_2 concentration is well known to be a measurement of the ventilation efficiency (CIGR, 1994). This can be confirmed by the results from stable 1 where one of the two mechanical fans was not turned on the night before measuring day 1 resulting in higher concentration of CO_2 at measuring day 1 showing the importance of the ventilation rate for the CO_2 concentration. However, stable 4 has lowest CO_2 values which is noteworthy since it has no installed ventilation system. Earlier studies have showed that installation of mechanical ventilation in a former naturally ventilated stable reduce CO_2 levels significantly (Elfman et al., 2011). The reason for this result in the present study can be the number of stabled horses. Stable 4 had only five out of seven stabled horses at the time when the study was conducted. Since CO_2 mainly stem from the respiration of the horses (CIGR, 1994) it could be an explanation for low values of measured CO_2 values in stable 4 compared to the other stables that had greater number of stabled horses. However, stable 1 had low number of stabled horses as well but higher CO_2 values, which could be caused by doors and windows being more often closed than stable 4. Stable 1-3 have similar mean values of CO_2; all of them having mechanical ventilation systems. Due to the fact that stable 4 has such low values of CO_2 the non-prior approved stables have lower values compared to the prior approved stables.

5.2.4 Ammonia

In all of the stables in the present study the concentration of NH_3 was below the maximum limit of 10 ppm. The stable that deviated from the others was stable 1 with values of 5 and 6 ppm NH_3 compared to the other stables that had values below 1.5 ppm. According to Mills & Clarke (2002) the NH_3 concentration tends to rise with increased temperature and humidity as well as poorly ventilated stables. This is interesting since stable 1 has the lowest stable RH values compared to the other stables. However, it has amongst the highest stable temperature. The bedding material is also very important in terms of NH_3 concentration (Airaksinen et al., 2001) and in the present study the horse box that has 6 ppm has wood shavings as bedding material and the box with 5 ppm has wood shavings mixed with peat moss. Since peat moss absorb more than twice as much of the NH_3 gas in the air compared to wood shavings (Airaksinen et al., 2001) it could explain why the horse box with wood shavings has higher values. Both stable 2 and 3 have peat moss as bedding material which can explain the low values of NH_3. However, stable 4 has wood shavings as bedding material but still very low values of NH_3, though higher than in the stables with peat moss. This indicates that the NH_3 concentration is affected by many factors and that it is difficult to explain the source of the measured values. The hygiene and feed is important factors according to CIGR (1994) which are factors that this study has not taken into consideration. Due to the high concentrations of NH_3 in stable 1 the prior approved stables had higher values than the non-prior approved stables.

In terms of horse welfare, McGreevy et al. (1995) found that other bedding materials than straw can be associated with stereotypic behaviours, such as weaving. This is confirmed in a study made by Mills et al. (2000), who found that horses clearly preferred straw bedding since it increased bedding directed behaviour, such as sniffing and ingestion of the bedding. However, straw bedding seems to generate more dust to the stable air (Airaksinen et al., 2001) which can cause respiratory diseases in horses (Webster et al., 1987; Art et al., 2002; Elfman et al., 2011). Peat moss can be very dusty and makes the horse dirty compared to wood chips (Airaksinen et al., 2001). McGorum et al. (1998) recommend stabling the horses in ‘low dust’ stables which are hay or straw free with maximized ventilation, or maintaining the horses at pasture. These aspects are important to consider when choosing bedding material and it seems that there is no optimal bedding material for horse welfare.

5.3 The prior approval process

There are a few aspects in the prior approval process that makes it not entirely ideal. The most important aspect is that measurements in terms of stable environment in the stables are rarely done during the prior approval process, according to L. Webrink at CAB in Uppsala County (pers. comm., 23th of October, 2012). This has been confirmed by M. Mainer and A. Nordblad at CAB in Skåne and Örebro County respectively (pers. comm. 14th of January 2013). The reason is that it is not allowed to put animals in the stable until it is approved and measurements can only be conducted in stables with animals. In general, the most common performed measurements is e.g. sizes of boxes. The ventilation is evaluated using own experiences, capacity, size and placements of air outlets and inlets, which is sometimes difficult, according to L. Webrink.

Another issue with the prior approval process is that CAB does not perform any further inspections after the stable has been approved, and hence there is no immediate pressure on the stable owner to fix any possible faults discovered afterwards or broken equipment. There is also no pressure on stable owners to utilize the building and the ventilation system to which it has been prior approved for. Stable 2 in the present study has air filters that needs to be replaced regularly and that kind of ventilation systems require maintenance, but this is not controlled. Furthermore, stable 1 had functioning fans but they were only turned on in the evening and only when the horse owners remember to do that. In the present study one of the fans were not turned on the night before measuring day 1 which indicates that the stable owners sometimes overlook it. Animal welfare legislation is continuously updated and more strict rules are applied due to an increased knowledge. The stables that were prior approved in the 70's maybe would not have been approved today. The most ideal would be inspections of prior approved stables by CAB for control, although this requires resources and e.g. in Uppsala County, only one person is working with prior approvals at the moment making this not feasible. Therefore, the solution to this problem might not be to increase the number of controls by CAB. Giving information to stable owners regarding poor stable environment and horse welfare might be a more realistic solution to this issue.

Both stables without prior approval in the present study would most likely not have been approved if they would try to get an approval afterwards due to the malfunctioning or lack of ventilation systems. If those stables would go through the prior approval process it would be interesting to analyse the same parameters in those stables after the approval. This is most likely the only way of determining whether the prior approval process has a positive effect on stable environment.

5.4 General discussion and implications for horse welfare

Many of the horses in the world are located in countries with a generally cold climate or countries with cold winter seasons (Langlois, 1994). In the winter it is a common problem with moisture and condensation on cold surfaces (Morgan, 2007). To solve this problem additional heat in the stable is needed to increase the stable temperature and hence reducing the RH. In the winter season shaving of horses is recommended for the stable climate since the evaporative heat loss decreases and the heat from the horses keep the stable temperature up (Morgan, 1996) causing a less humid stable air. When the stable temperature is low it is important to have complimentary feeding or cover the horse with a rug (Morgan, 1996) to prevent the horse from freezing. The weather conditions in Sweden lead to longer stabling periods which can affect the horse welfare negatively. In addition, many dressage and race horses are stabled for longer times since their owners are afraid that the horse should get hurt in the paddock (Michanek, 2008). Furthermore, such long stabling periods can be challenging for the horse's respiratory tract. According to Holcombe et al. (2001) stabling of young horses is associated with both upper and lower airway inflammation. Many horse owners in Sweden have little knowledge about the horse's climate tolerance and believe that cold temperatures are harmful for the horse (Michanek, 2008). In addition, horse owners themselves feel that it is too cold and draughty, thinking that the horses might experience the same. Consequently, this leads to horse owners closing doors and windows, resulting in inadequate ventilation. However, a human has thrice as much body surface in relation to body weight compared to a horse and additionally the horse has a fur coat (Michanek, 2008) resulting in totally different climate tolerances. Therefore, the importance of giving correct information to stable owners is great to be able to prevent poor horse welfare.

It is difficult for horse and stable owners to know whether the stable environment is adequate or not. The clinical sign of respiratory diseases in horses is mainly coughing (Viel, 1985; Burrell et al., 1996; Christley et al., 2001; Robinson et al., 2003) which is shown when the horse already has developed the disease. According to S. Nyman (licensed veterinarian, pers. comm. 30th of January 2013) horses are coughing to clear the airways since mucus is developed in the respiratory tract. Hacking coughs is developed when gas or particles irritate the airways and a horse that often coughs is caused by alterations in the airways. In such horses, very little irritants e.g. mould is needed to cause an allergy reaction. Horses that cough in a stable can be due to acute poor air quality, e.g. when sweeping the stable floor. Therefore, it is not possible to generalize that a horse is coughing because of overall poor air quality (S. Nyman, pers. comm. 30th of January 2013). The main difficulty is to distinguish early clinical signs when the disease is starting to develop. It is of great importance for the horse owners to be aware of early signs to be able to take actions to prevent such diseases. According to S. Nyman early symptoms of respiratory diseases is a horse that is not performing as usual due to mucus in the respiratory tract. Another early symptom is a single cough at the first trotting steps. However, this is very individual and depends on how observant the horse owner is.

There are several factors affecting the stable environment in horse stables: ventilation rate, feed, bedding material, the animals themselves, stable design, management systems, climate, season, stocking density, animal activity and building size (Clarke, 1993; CIGR, 1994; Wathes, 1994). The most effective way to decrease the aerial concentration of contaminants and gases is a sufficient ventilation system (Woods et al., 1993; CIGR, 1994; Clarke, 1994; Wathes, 1994) which makes it essential in an animal stable. Theoretically, the dust concentration in the stable should decrease with higher ventilation rate but it is more complex than that, according to CIGR (1994). Together with a higher ventilation rate the air velocity will change which in turn affects the RH. A lower RH will release more surface dust to the environment. This has been confirmed by Maghirang et al. (1991) who showed that a higher ventilation rate in a poultry layer house resulted in higher concentrations of total particle counts. However, a low ventilation rate can cause a humid climate in the stable, which can lead to fungal growth (Curtis et al., 1996). This has been confirmed by Clarke et al. (1987) who states that insulated stables with poor ventilation could have clean source materials but would still easily mould due to the low air speed (Clarke et al., 1987). This is an important aspect that shows that it is complicated to achieve an adequate environment in the stable in practice.

All previous mentioned aspects are important when discussing this issue since it shows the difficulty in optimising stable environment for horse welfare. There are many factors that need to be considered for the health of horses in order to obtain an adequate stable environment and only some of them have been investigated in this study. Because of this, it is difficult to compare the two stables that have prior approval with the two that have not. In addition, the stables have different sizes, different bedding materials, different feed and different ventilation systems which are not ideal. According to the results of this study the prior approved stables have higher values of CO_2 and NH_3 which is notable. If this is because the few stables used in the study or that the prior approval process is not adequate in terms of stable environment is difficult to determine. However, it clearly points out that the prior approval gives no guarantee that stable environment should be adequate. One interesting finding in the present study was that, according to the values of CO_2 the ventilation rates are adequate for the stabled horses, but when analysing RH, it is not. The reason for this can be the different sources of moisture in the stable, such as shower stalls, urine and faeces (Elfman et al., 2011) resulting in a humid climate which the ventilation system do not manage to ventilate out. When dimensioning the ventilation system in a stable different sources of moisture should be taken into consideration, which possibly not have been done in the prior approved stables in the present study. If only calculating on the horses’ moisture production the dimension of the ventilation system is not correct. This result in too high values of RH in the stable. This finding confirms the problem with high values of RH in stables during wintertime, which needs to be solved to improve horse welfare. More accurate calculations regarding ventilation rates must done to keep moisture levels low. Because of the high levels of RH in the present study, the question still remains, if the prior approval process makes a difference in terms of stable environment and hence a good long term horse welfare.

5.5 Future studies

For future studies in this area a greater number of stables need to be compared as well as more collected data to receive significant results. Fewer measured parameters, e.g. solely RH and temperature, would be effective to analyse the ventilation system's ability to ventilate out moisture produced in the stables. To investigate the effect of the prior approval process on the stable environment the study should be conducted before and after prior approval resulting in more successful results. Ultimately, the compared stables should have as similar conditions as possible to reduce the risk of error sources.

6 CONCLUSIONS

This study concludes that it is not possible to determine whether prior approved stables have better stable environment compared to non-prior approved stables with regards to the stables used in this study. More stables and more data are needed to receive reliable results. However, the study indicates that the prior approval process is not optimal and gives no guarantee of adequate stable environment. Because of the high values of RH, the results of this study clearly show the importance of this issue, which needs to be researched further to improve stable environment. Additionally, giving correct information to stable owners regarding climate tolerance and risk factors for respiratory diseases is essential to prevent poor ventilated stables and hence poor horse welfare.

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8 LIST OF REFERENCES

Ahrens, C. D., Jackson, P. L., Jackson, C. 2012. Meteorology today: an introduction to weather, climate, and the environment. Nelson Education Ldt, Canada.

Airaksinen, S., Heinonen-Tanski, H., Heiskanen, M. L. 2001. Quality of different bedding materials and their influence on the compostability of horse manure. J Equine Vet Sci 21(3): 125-130.

The Animal Welfare Act (SFS 1988:534).

The Animal Welfare Ordinance (SFS 1988:539).

Art, T., McGorum, B. C., Lekeux, P. 2002. Environmental control of respiratory disease. In: Equine respiratory diseases (Ed: P. Lekeux). International veterinary information service, Ithaca, New York, USA.

Burrell, M. H., Wood, J. L. N., Whitwell, K. E., Chanter, N., Mackintosh, M. E., Mumford, J. A. 1996. Respiratory disease in thoroughbred horses in training: the relationships between disease and viruses, bacteria and environment. Vet Rec 139(13): 308-313.

Casey, R. A. 2002. Clinical problems associated with the intensive management of performance horses. In: The Welfare of Horses (Ed: N. Waran). Kluwer Academic Publisher, Dordrecht.

Charles, D. R. 1994. Comparative Climatic Requirements. In: Livestock Housing (Eds: C. M. Wathes & D. R. Charles). CAB International, Wallingford.

Christley, R. M., Hodgson, D. R., Rose, R. J., Hodgson, J. L., Wood, J. L. N., Reid, S. W. J. 2001. Coughing in thoroughbred racehorses: risk factors and tracheal endoscopic and cytological findings. Vet Rec 148(4): 99-104.

CIGR. 1984. Report of Working Group of Climatization of Animal Houses, Scottish Farm Buildings Investigation Unit, Craibstone, Bucksburn, Aberdeen, AB2 9TR, Scotland for Commission Internationale du Genie Rural (International Commission of Agricultural Engineering).

CIGR. 1994. Aerial Environment in Animal Housing - Concentrations in and Emissions from farm buildings, Working Group Report Series No 94.1 International International Commission of Agricultural Engineering, France.

Clark, J. A., McArthur, A. J. 1994. Thermal Exchanges. In: Livestock Housing (Eds: C. M. Wathes & D. R. Charles). CAB International, Wallingford.

Clarke, A. F. 1987a. Air hygiene and equine respiratory disease. In Pract 9(6): 196-204.

Clarke, A. F. 1987b. A review of environmental and host factors in relation to equine respiratory disease. Equine Vet J 19(5): 435-441.

Clarke, A. F. 1993. Stable dust--threshold limiting values, exposures variables and host risk factors. Equine Vet J 25(3): 172-174.

Clarke, A. F. 1994. Stables. In: Livestock Housing (Eds: C. M. Wathes & D. R. Charles). CAB International, Wallingford.

Clarke, A. F., Madelin, T. M., Allpress, R. G. 1987. The relationship of air hygiene in stables to lower airway disease and pharyngeal lymphoid hyperplasia in two groups of Thoroughbred horses. Equine Vet J 19(6): 524-530.

Clements, J. M., Pirie, R. S. 2007. Respirable dust concentrations in equine stables. Part 2: The benefits of soaking hay and optimising the environment in a neighbouring stable. Res Vet Sci 83(2): 263-268.

Cooper, J. J., Mason, G. J. 1998. The identification of abnormal behaviour and behavioural problems in stabled horses and their relationship to horse welfare: a comparative review. Equine Vet J 30(S27): 5-9.

Couëtil, L. L., Hoffman, A. M., Hodgson, J., Buechner-Maxwell, V., Viel, L., Wood, J. L. N., Lavoie, J.-P. 2007. Inflammatory Airway Disease of Horses. J Vet Intern Med 21(2): 356-361.

Couëtil, L. L., Rosenthal, F. S., DeNicola, D. B., Chilcoat, C. D. 2001. Clinical signs, evaluation of bronchoalveolar lavage fluid, and assessment of pulmonary function in horses with inflammatory respiratory disease. Am J Vet Res 62(4): 538-546.

Couëtil, L. L., Ward, M. P. 2003. Analysis of risk factors for recurrent airway obstruction in North American horses: 1,444 cases (1990–1999). J Am Vet Med Assoc 223(11): 1645-1650.

Council Directive 98/58/EC concerning the protection of animals kept for farming purposes.

Curtis, L., Raymond, S., Clarke, A. 1996. Dust and ammonia in horse stalls with different ventilation rates and bedding. Aerobiologia 12(1): 239-247.

Djurskyddsmyndighetens föreskrifter och allmänna råd (DFS 2007:6) om hästhållning, saknr L101.

Douwes, J., Thorne, P., Pearce, N., Heederik, D. 2003. Bioaerosol Health Effects and Exposure Assessment: Progress and Prospects. Ann Occup Hyg 47(3): 187-200.

Ehrlemark, A. 1995. Dimensionering av naturlig ventilation, Report 197. Department of Agricultural Engineering Building Design Section, Swedish University of Agricultural Sciences.

Elfman, L., Riihimäki, M., Pringle, J., Wålinder, R. 2009a. Hur påverkar inhalerbara partiklar i stallmiljön uppkomsten av luftvägsinflammationer hos människor och hästar?, Projektnummer H0647157, Uppsala.

Elfman, L., Riihimäki, M., Pringle, J., Wålinder, R. 2009b. Influence of horse stable environment on human airways. J Occup Med Toxicol 4(1): 1-7.

Elfman, L., Wålinder, R., Riihimäki, M., Pringle, J. 2011. Air Quality in Horse Stables. In: Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality (Ed: N. Mazzeo). p 680. InTech, Rijeka, Croatia.

Franchini, M., Gill, U., Fellenberg, R. v., Bracher, V. D. 2000. Interleukin-8 concentration and neutrophil chemotactic activity in bronchoalveolar lavage fluid of horses with chronic obstructive pulmonary disease following exposure to hay. Am J Vet Res 61(11): 1369-1374.

Gore, T., Gore, P., Griffin, J. M. 2008. Horse Owner's Veterinary Handbook. Third edition. Wiley Publishing, Inc., Hoboken, New Jersey.

Hartung, J. 1994. Environment and Animal Health. In: Livestock Housing (Eds: C. M. Wathes & D. R. Charles). CAB International, Wallingford.

Hintz, H. F., Cymbaluk, N. F. 1994. Nutrition of the horse. Annu Rev Nutr 14: 243-267.

Holcombe, S. J., Jackson, C., Gerber, V., Jefcoat, A., Berney, C., Eberhardt, S., Robinson, N. E. 2001. Stabling is associated with airway inflammation in young Arabian horses. Equine Vet J 33(3): 244-249.

Hotchkiss, J. W., Reid, S. W. J., Christley, R. M. 2007. A survey of horse owners in Great Britain regarding horses in their care. Part 2: Risk factors for recurrent airway obstruction. Equine Vet J 39(4): 301-308.

Houben, R. 2008. Ventilation and air hygiene parameters in horse stables. Doctoral thesis, Faculty of Veterinary Medicine Theses. Universiteit Utrecht, The Netherlands.

Langlois, B. 1994. Inter-breed variation in the horse with regard to cold adaptation: a review. Livestock Production Science 40(1): 1-7.

Lstiburek, J. W., Carmody, J. 1994. Moisture control handbook: principles and practices for residential and small commercial buildings. John Wiley & Sons, Inc., Canada.

Maghirang, R. G., Manbeck, H. B., Roush, W. B., Muir, F. V. 1991. Air contaminant distributions in a commercial laying house. Am Soc Agric Eng 34(5): 2171-2180.

McBride, G. E., Christopherson, R. J., Sauer, W. 1985. Metabolic rate and plasma thyroid hormone concentrations of mature horses in response to changes in ambient temperature. Can J Anim Sci 65(2): 375-382.

McCutcheon, L. J., Geor, R. J. 2008. Thermoregulation and exercise-associated heat stress. In: Equine Exercise Physiology: The science of exersise in the athletic horse (Eds: K. W. Hinchcliff, R. J. Geor & A. J. Kaneps). Saunders Elsevier, Philadelphia, USA.

McGorum, B. C., Ellison, J., Cullen, R. T. 1998. Total and respirable airborne dust endotoxin concentrations in three equine management systems. Equine Vet J 30(5): 430-434.

McGreevy, P. D., Cripps, P. J., French, N. P., Green, L. E., Nicol, C. J. 1995. Management factors associated with stereotypic and redirected behaviour in the Thoroughbred horse. Equine Vet J 27(2): 86-91.

Michanek, P. 2008. Förstudie om hållbar hästuppfödning. Jordbruksverkets satsing på Livskraftigt hästföretagande 2008. Bollerup Lantbruksinstitut, naturbruksgymnasium.

Mills, D. S., Clarke, A. 2002. Housing, Management and welfare. In: The Welfare of Horses (Ed: N. Waran). Kluwer Academic Publishers, Dordrecht.

Mills, D. S., Eckley, S., Cooper, J. J. 2000. Thoroughbred bedding preferences, associated behaviour differences and their implications for equine welfare. Animal Science 70(1): 95-106.

Morgan, K. 1996. Short-term thermoregulatory responses of horses to brief changes in ambient temperature. Report 209. Dissertation, Swedish University of Agricultural Sciences. Department of Agricultural Engineering, Building Design Section. Uppsala, Sweden.

Morgan, K. 2007. Hästens reglering av kroppstemperatur och dess värmebalans. Undervisningskompendium. Ridskolan Strömsholm.

Nilsson, C. 1986. Buller vid mekanisk ventilation, NJF - Naturlig och mekanisk ventilation. Seminarium 104, sektion VII.

Robinson, N. E., Berney, C., Eberhart, S., deFeijter-Rupp, H. L., Jefcoat, A. M., Cornelisse, C. J., Gerber, V. M., Derksen, F. J. 2003. Coughing, mucus accumulation, airway obstruction, and airway inflammation in control horses and horses affected with recurrent airway obstruction. Am J Vet Res 64(5): 550-557.

Sainsbury, D. W. B. 1984. Housing the horse. In: Horse Management (Ed: J. Hickman). p 63-91. Academic Press Inc., London.

Schlaks, S., Ridgway, M. D. 2012. Respiratory. In: Chapter 6 Respiratory. In: Small Animal Internal Medicine for Veterinary Technicians and Nurses (Ed: L. Merill) (Ed: J. Garcia). Wiley-Blackwell, Oxford, UK.

Sjaastad, O. V., Hove, K., Sand, O. 2003. Physiology of domestic animals. Scandinavian Veterinary Press, Oslo.

Statens jordbruksverks föreskrifter och allmänna råd (SJVFS 2012:12) om förprövning av djurstallar.

Svala, C. 2008. Hur hålls hästarna i Sverige och vilka är motiven. En intervjuundersökning med hästhållare i Enköpings, Nyköpings, Lerums, Ängelholms och Hässleholms kommuner genomförd under sommaren 2008. Ett projekt genomfört med stöd av Jordbruksverkets satsning på Livskraftigt hästföretagande. Swedish University of Agricultural Sciences, Alnarp.

Sällvik, K. 2005. Husdjurens värmebalans och termiska närmiljö. Undervisningskompendium Alnarp-Ultuna, Institutionen för jordbrukets biosystem och teknologi, JBT.

Vaisala. 2013. Humidity conversion formulas: Calculation formulas for humidity. Available: http://www.vaisala.fi/Vaisala%20Documents/Application%20notes/Humidity_Conversion_Formulas_B210973EN-E.pdf. Accessed 2013-03-06.

Vandenput, S., Istasse, L., Nicks, B., Lekeux, P. 1997. Airborne dust and aeroallergen concentrations in different sources of feed and bedding for horses. Veterinary Quarterly 19(4): 154-158.

Wathes, C. M. 1994. Air and Surface Hygiene. In: Livestock Housing (Eds: C. M. Wathes & D. R. Charles). CAB International, Wallingford.

Wathes, C. M., Jones, C. D. R., Webster, A. J. F. 1983. Ventilation, air hygiene and animal health. Vet Rec 113: 554-559.

Webster, A. J. F. 1994. Comfort and Injury. In: Livestock Housing (Eds: C. M. Wathes & D. R. Charles). CAB International, Wallingford.

Webster, A. J. F., Clarke, A. F., Madelin, T. M., Wathes, C. M. 1987. Air hygiene in stables 1: Effects of stable design, ventilation and management on the concentration of respirable dust. Equine Vet J 19(5): 448-453.

Ventorp, M., Michanek, P. 2001. Att bygga häststall - en idéhandbok. Institutionen för Jordbrukets Biosystem och Tecknologi, Sveriges Lantbruksuniversitet, Alnarp.

Viel, L. 1985. Diagnostic procedures, prognosis and therapeutic approaches of chronic respiratory diseases in horses. Can Vet J 26(1): 33-35.

Woods, P. S., Robinson, N. E., Swanson, M. C., Reed, C. E., Broadstone, R. V., Derksen, F. J. 1993. Airborne dust and aeroallergen concentration in a horse stable under two different management systems. Equine Vet J 25(3): 208-213.

Wålinder, R., Riihimäki, M., Bohlin, S., Hogstedt, C., Nordquist, T., Raine, A., Pringle, J., Elfman, L. 2011. Installation of mechanical ventilation in a horse stable: effects on air quality and human and equine airways. Environ Health Prev Med 16(4): 264-272.

9 APPENDIX

I	SMHI data
II	Calibration curves RH
III	Calibration curves temperature
IV	Results stable 1
V	Results stable 2
VI	Results stable 3
VII	Results stable 4
VIII	Fictive stable RH and outside AH

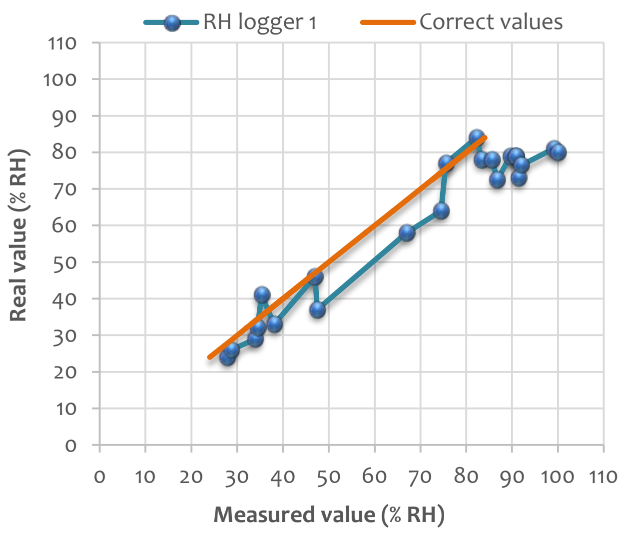
I SMHI data

Table 1. Outside daily averages of temperature and RH of the three days from when the study was conducted at each stable, obtained from SMHI's weather stations nearest the four stables in the present study; Örebro, Uppsala and Svanberga.

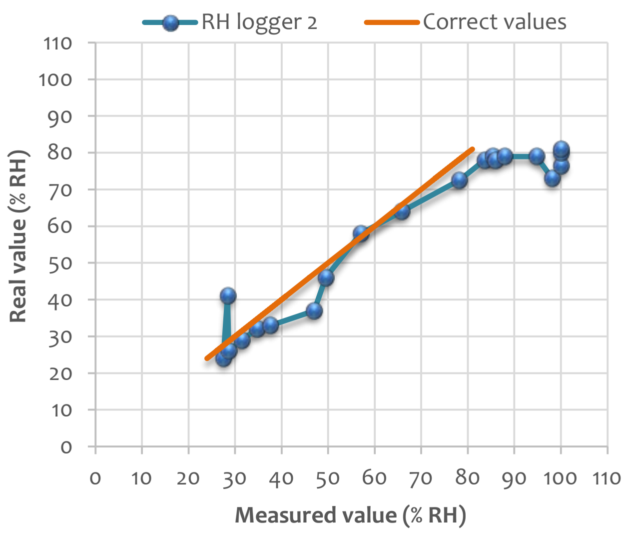
	Temperature (°C)			Relative humidity (%)		
	Day 1	**Day 2**	**Day 3**	**Day 1**	**Day 2**	**Day 3**
Stable 1	7.9	5.4	4.2	90.9	89.3	95.4
Stable 2	3.5	9.5	6.9	96.1	95.1	91.1
Stable 3	3.9	0.2	6.4	97.8	96.1	85.1
Stable 4	2.8	0.7	-0.9	99.9	100	100

II Calibration curves RH

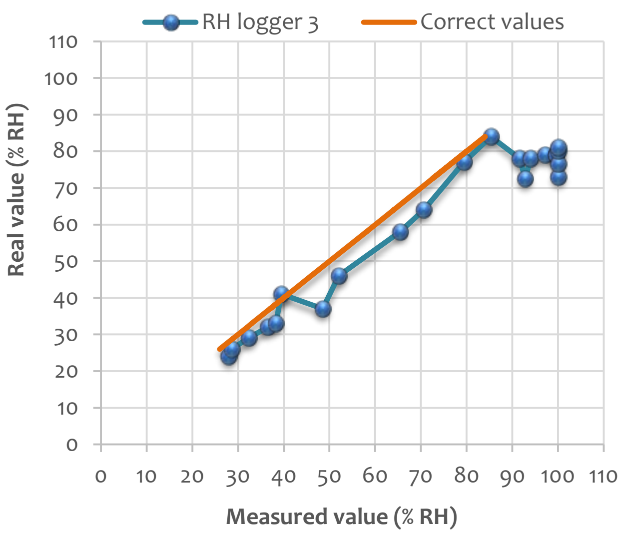
(a)



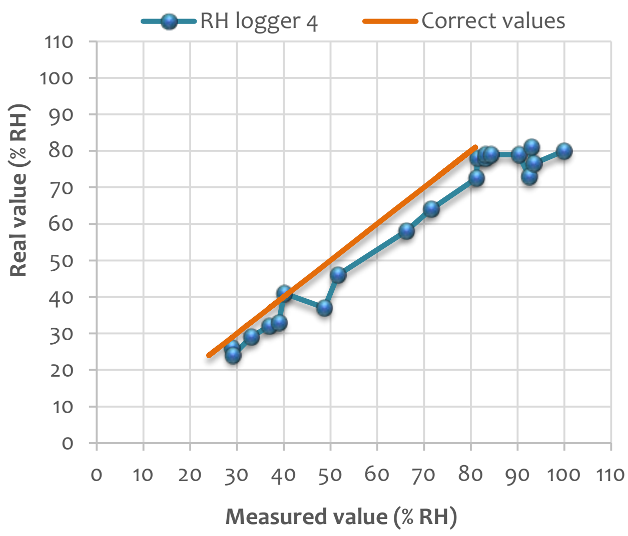
(b)



(c)



(d)



(e)

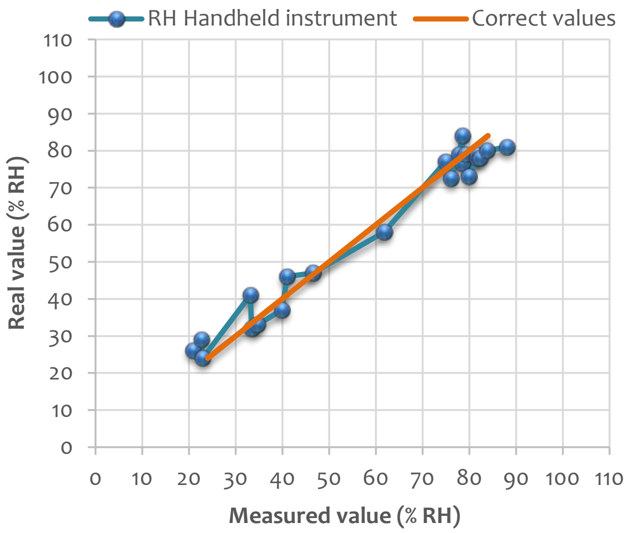


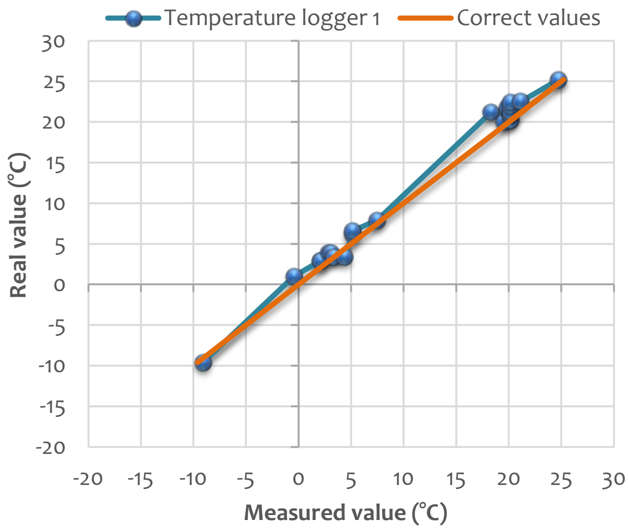
Figure 1. Calibration curves for data logger 1 (a), 2 (b), 3 (c) 4 (d) and handheld instrument (e) regarding RH. On the y-axis the real value is presented and on the x-axis the measured value from the data logger is presented. The orange line represents the ideal curve of correct values.

Table 1. The table shows the generated equation from the linear regression for each of the four data loggers. The equations were used to correct measured RH values up to 80 % RH.

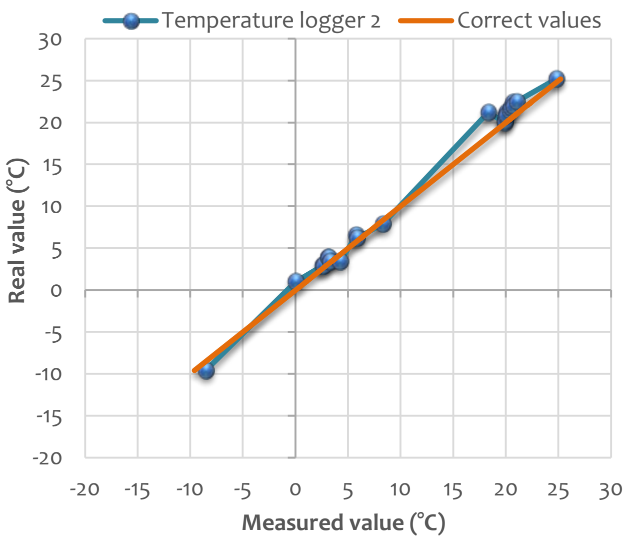
	Linear regression equation
Logger 1	y = 0.9188x - 0.112
Logger 2	y = 0.9036x + 2.140
Logger 3	y = 0.9501x - 2.347
Logger 4	y = 0.8828x - 0.312

III Calibration curves temperature

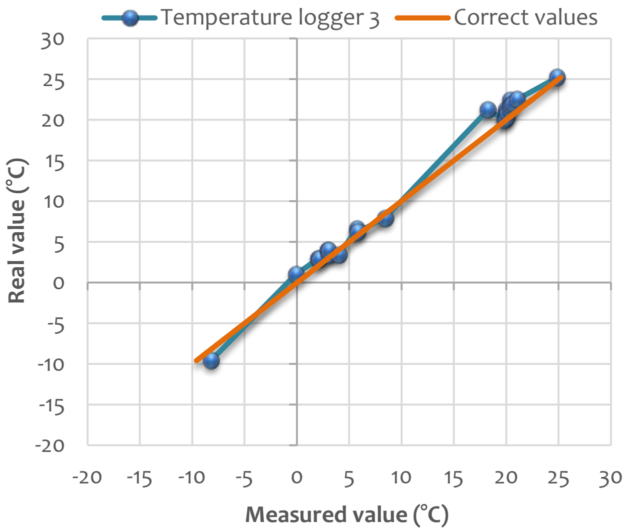
(a)



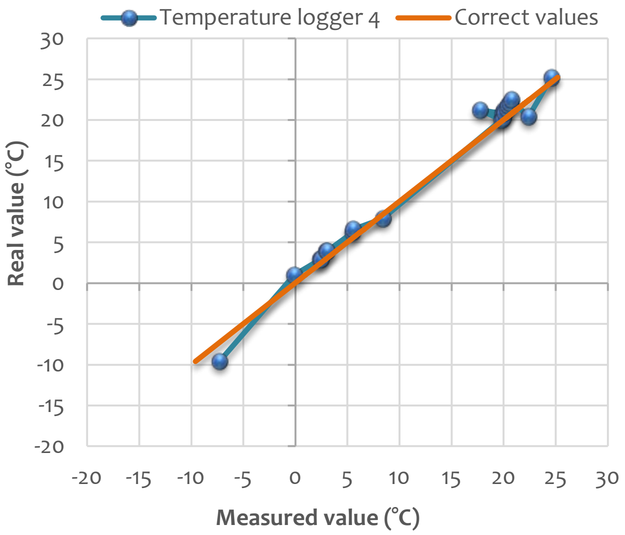
(b)



(c)



(d)



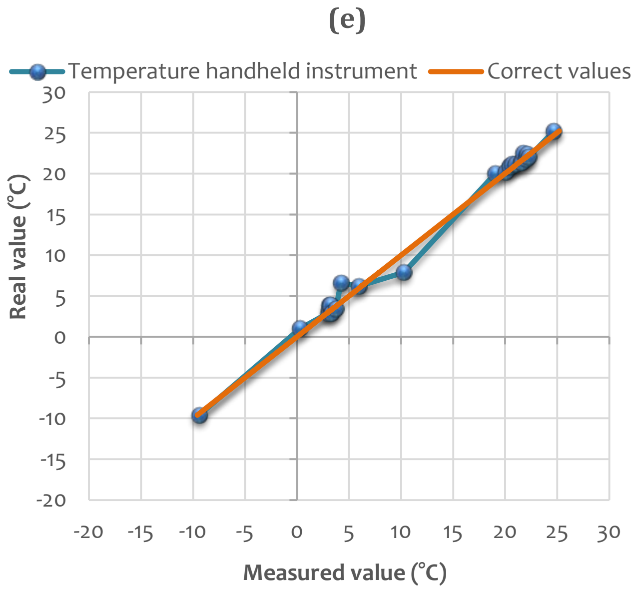


Figure 1. Calibration curves for data logger 1 (a), 2 (b), 3(c), 4(d) and handheld instrument (e) regarding temperature. On the y-axis the real value is presented and on the x-axis the measured value from the data logger is presented. The orange line represents the ideal curve of correct values.

IV Results stable 1

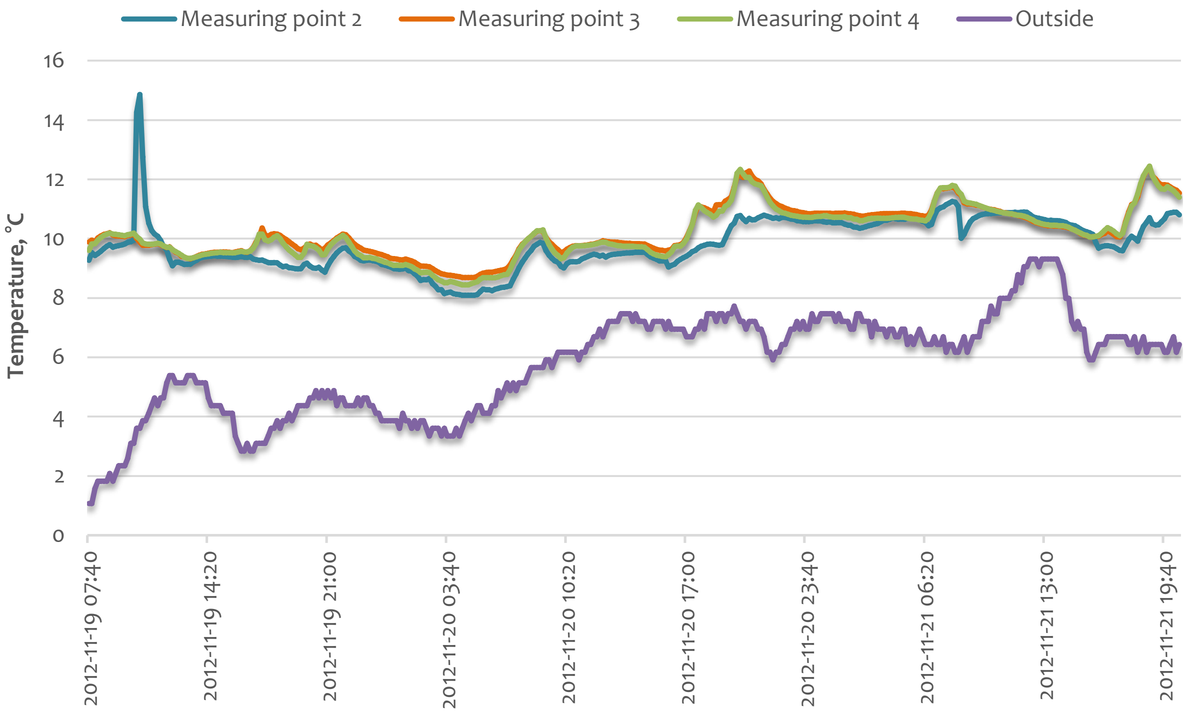


Figure 1. Diurnal variation of temperature in stable 1 at the three measuring points inside the stable and outside measured by the data loggers.

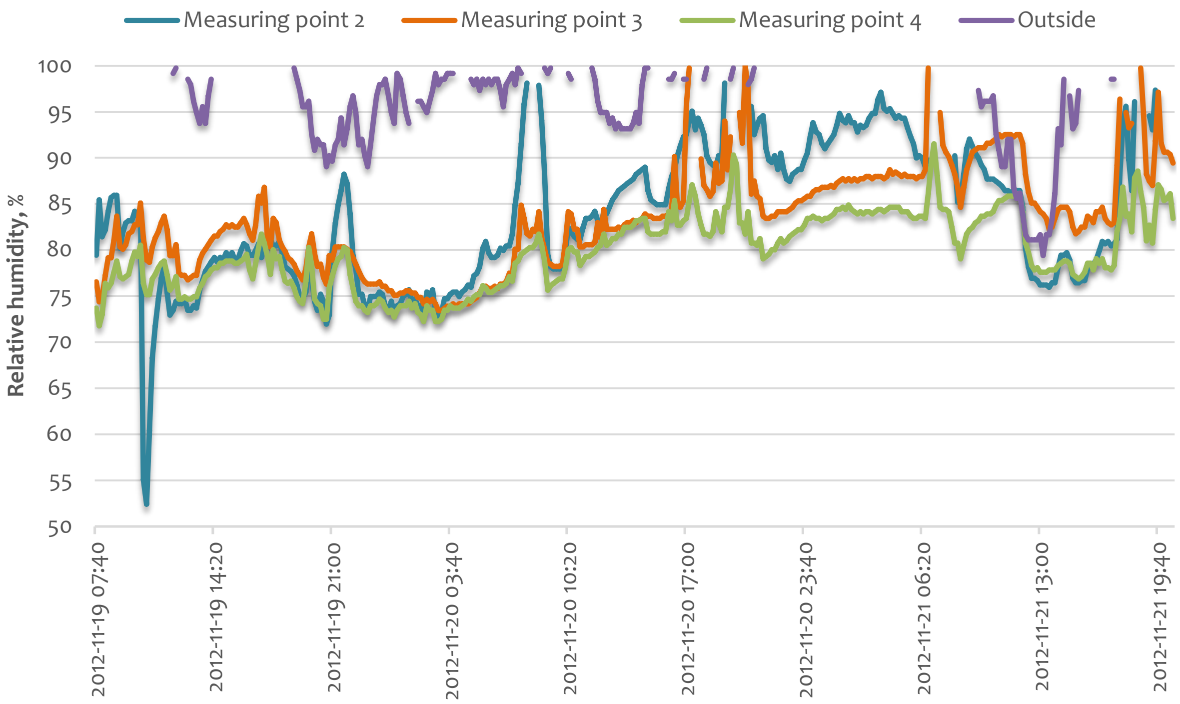


Figure 2. Original uncorrected values of RH in stable 1 at the three measuring points inside the stable and outside measured by the data loggers.

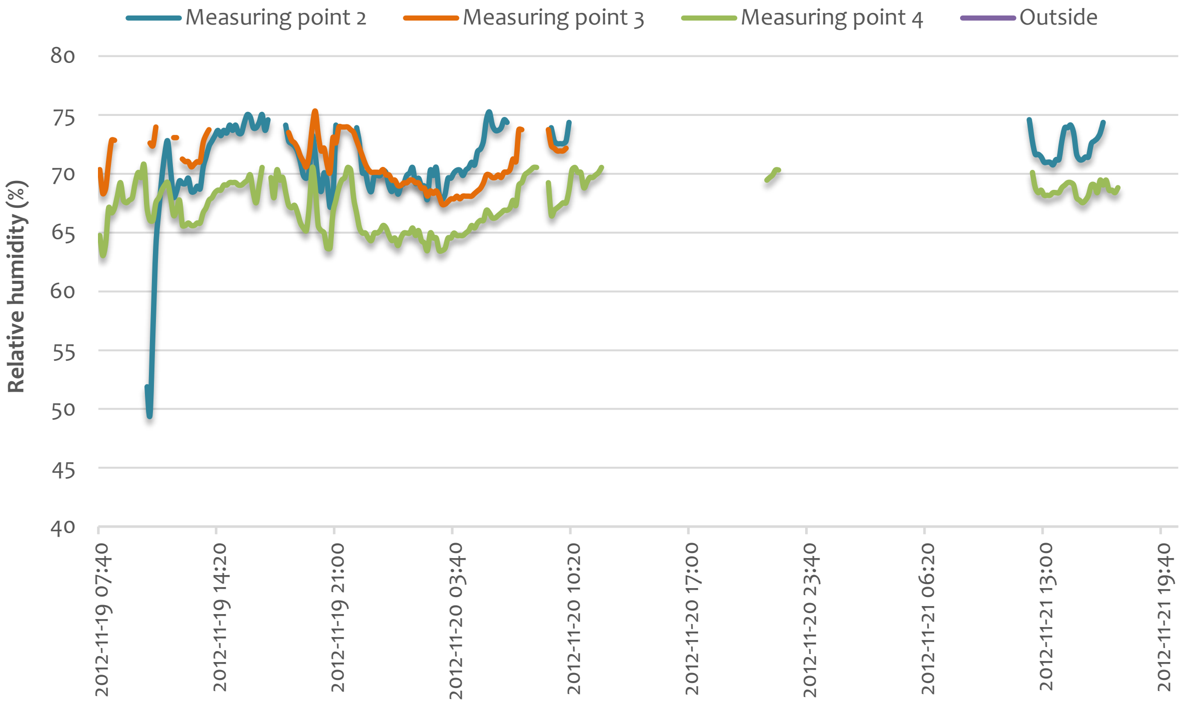


Figure 3. Corrected values of RH in stable 1 at the three measuring points inside the stable and outside measured by the data loggers.

Table 1. Results from the manual measurements in stable 1 and outside in the morning at feeding.

		Measuring point 1	Measuring point 2	Measuring point 3	Measuring point 4	Outside
Day 1	**Temperature, °C**	13.70	11.57	13.51	13.46	3.16
	RH, %	63.78	77.67	64.90	67.00	88.74
	CO_2, ppm	1 195	1 161	1 221	1 003	377
	NH_3, ppm	5	---	6	---	---
	Weather conditions	Frosty, uncloudy and rather cold				
Day 2	**Temperature, °C**	13.89	12.22	13.01	12.84	6.88
	RH, %	59.71	69.89	65.50	66.81	79.22
	CO_2, ppm	1 070	1 209	942	931	356
	Weather conditions	Mild and light rain				
Day 3	**Temperature, °C**	13.68	13.34	14.04	13.86	8.68
	RH, %	76.87	81.46	71.60	74.86	83.49
	CO_2, ppm	936	1 229	820	770	358
	Weather conditions	Mild and overcast				

V Results stable 2

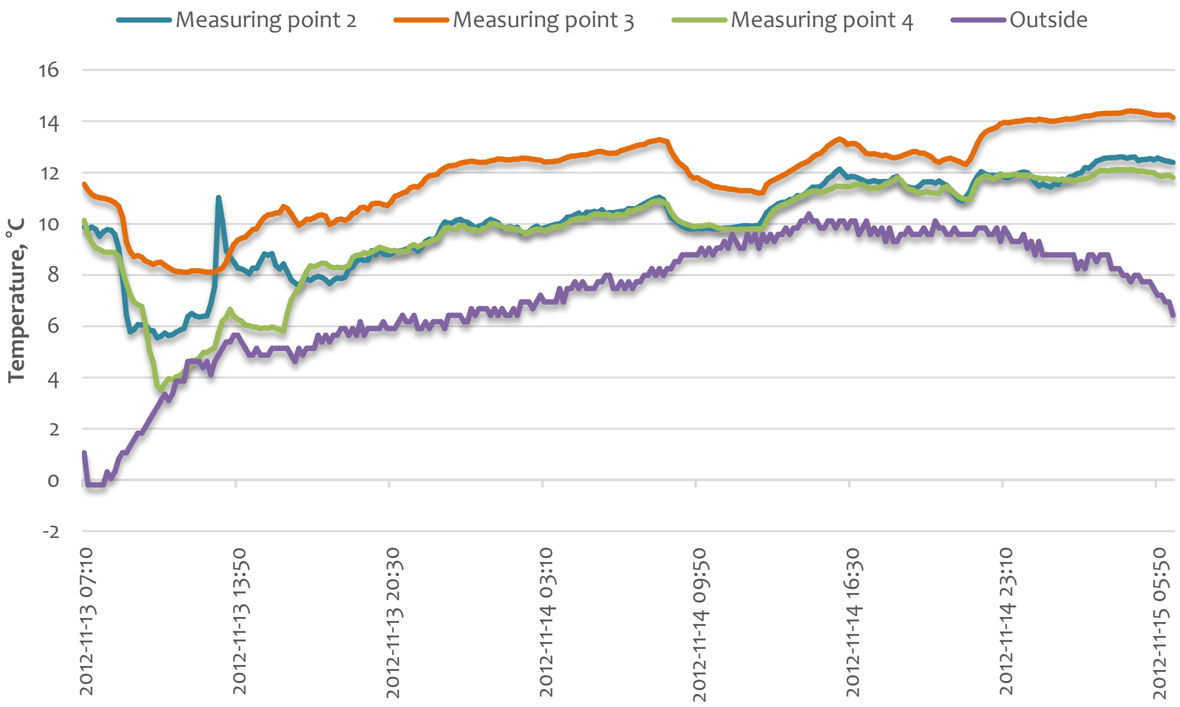


Figure 1. Diurnal variation of temperature in stable 2 at the three measuring points inside the stable and outside measured by the data loggers.

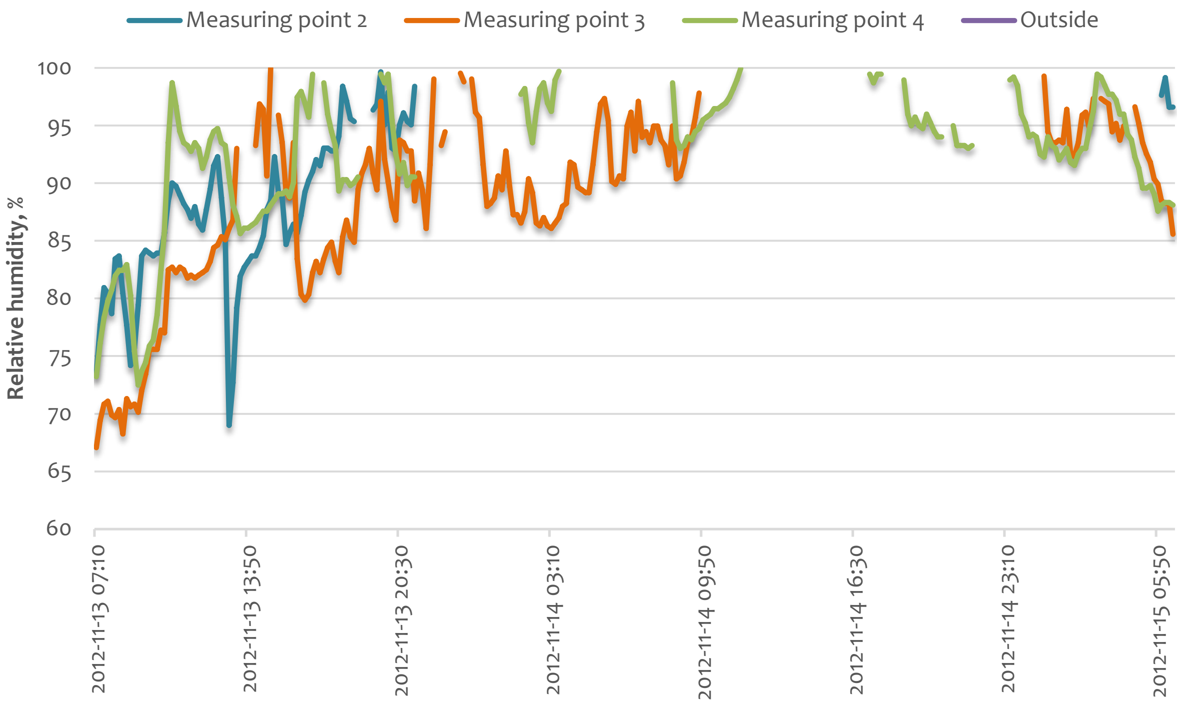


Figure 2. Original uncorrected values of RH in stable 2 at the three measuring points inside the stable and outside measured by the data loggers.

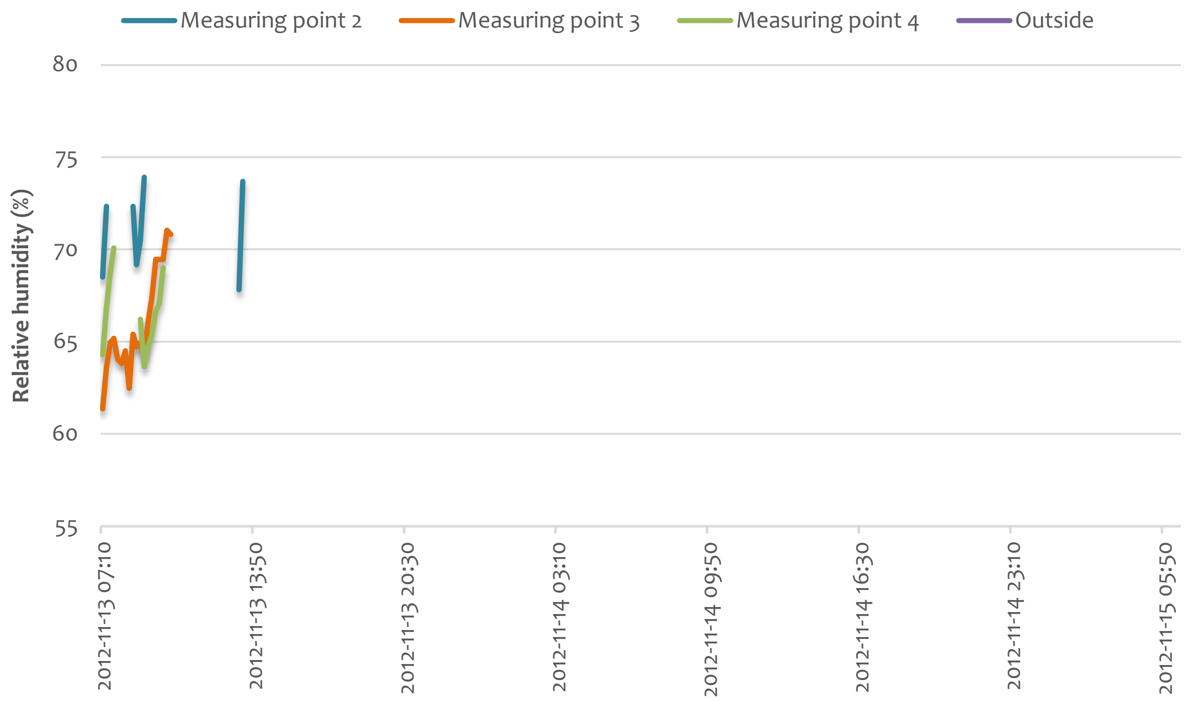


Figure 2. Corrected values of RH in stable 2 at the three measuring points inside the stable and outside measured by the data loggers.

Table 1. Results from the manual measurements in stable 2 and outside in the morning at feeding.

		Measuring point 1	Measuring point 2	Measuring point 3	Measuring point 4	Outside
Day 1	**Temperature, °C**	9.25	12.34	12.80	11.48	2.5
	RH, %	55.14	63.66	61.62	63.91	85.35
	CO_2, ppm	1 154	1 214	961	1 132	390
	NH_3, ppm	No detection	---	No detection	---	---
	Weather conditions	Frosty, very foggy and overcast				
Day 2	**Temperature, °C**	13.10	13.99	16.16	14.49	9.14
	RH, %	75.32	74.84	64.89	69.10	90.84
	CO_2, ppm	748	1 097	2 130	1 063	365
	Weather conditions	Mild and light rain				
Day 3	**Temperature, °C**	15.67	13.85	14.98	14.92	7.32
	RH, %	66.86	75.01	73.26	66.87	87.24
	CO_2	1 576	992	1 091	1 020	352
	Weather conditions	Mild, uncloudy and moisty				

VI Results stable 3

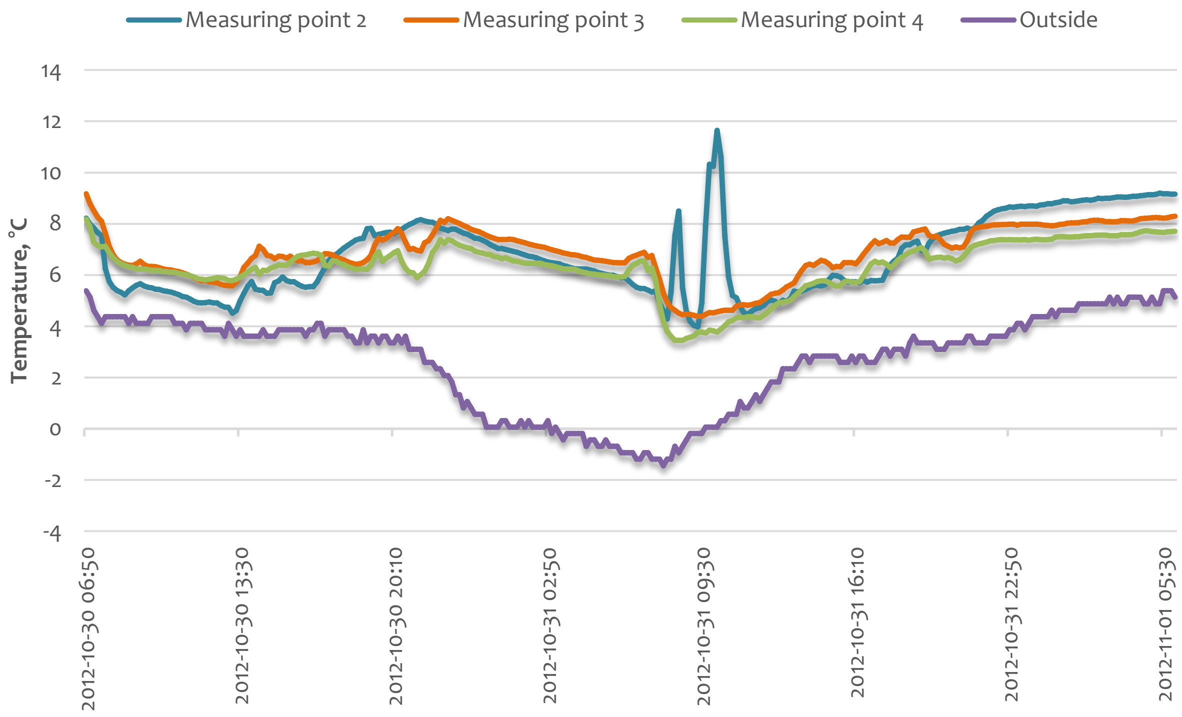


Figure 1. Diurnal variation of temperature in stable 3 at the three measuring points inside the stable and outside measured by the data loggers.

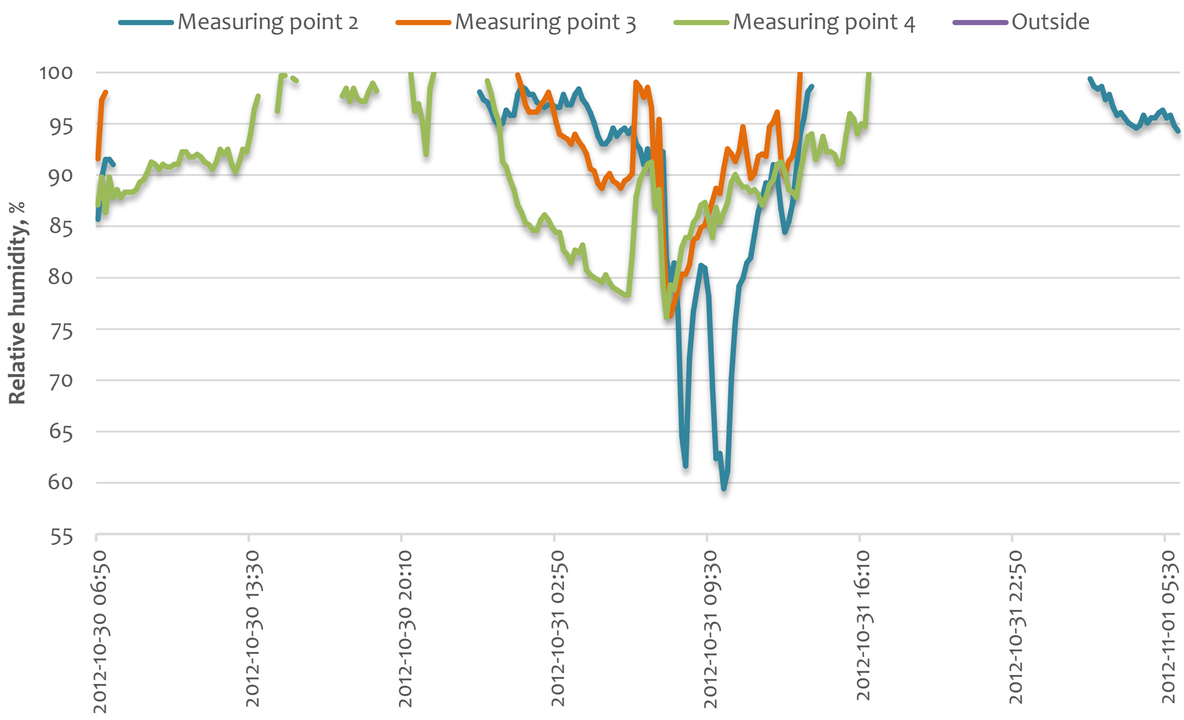


Figure 2. Original uncorrected values of RH in stable 3 at the three measuring points inside the stable and outside measured by the data loggers.

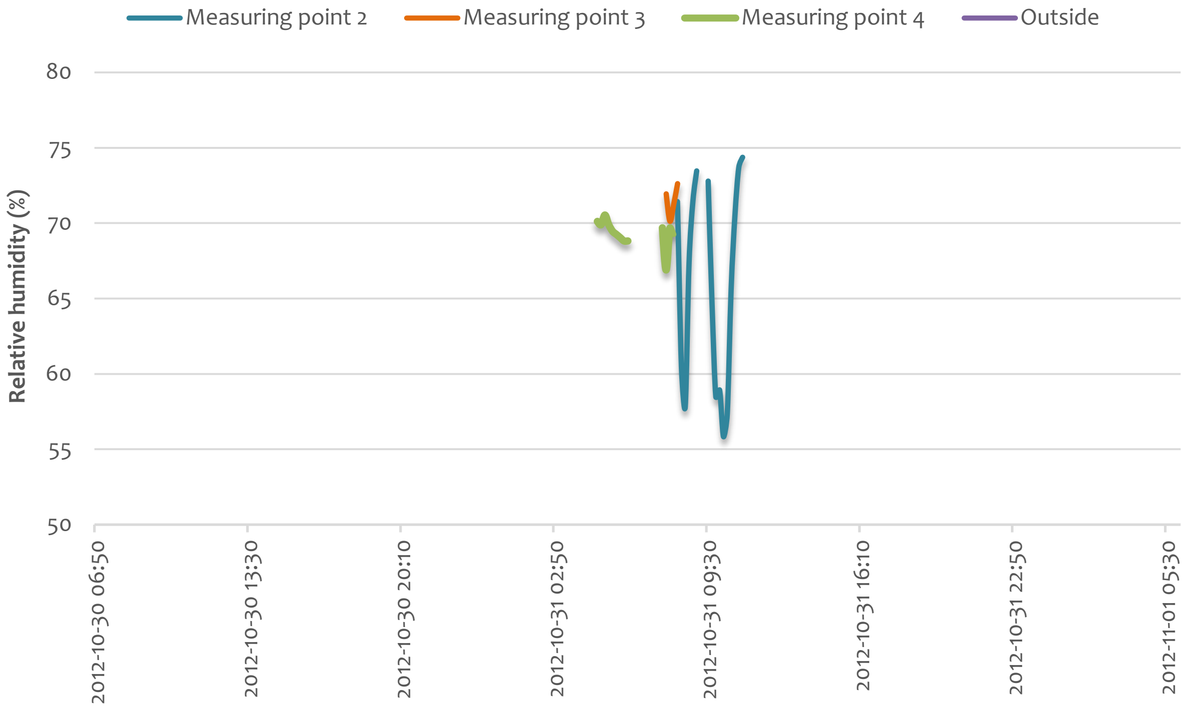


Figure 3. Corrected values of RH in stable 3 at the three measuring points inside the stable and outside measured by the data loggers.

Table 1. The table shows results from the manual measurements in stable 3 and outside in the morning at feeding.

		Measuring point 1	Measuring point 2	Measuring point 3	Measuring point 4	Outside
Day 1	**Temperature, °C**	11.45	10.24	9.87	9.73	6.59
	RH, %	68.30	72.51	76.45	77.74	81.20
	CO_2, ppm	1 150	813	905	1 080	400
	NH_3, ppm	No detection	---	0,7	---	---
	Weather conditions	Rainy, overcast and a bit windy				
Day 2	**Temperature, °C**	11.12	7.88	7.44	7.14	1.74
	RH, %	59.95	70.85	73.41	71.36	65.56
	CO_2, ppm	1 140	1 385	1 173	1 220	395
	Weather conditions	Cold, frosty and uncloudy				
Day 3	**Temperature, °C**	10.46	9.03	9.16	9.47	5.95
	RH, %	62.04	71.01	74.61	75.50	79.00
	CO_2, ppm	939	832	885	900	318
	Weather conditions	Mild and rather cloudy				

VII Results stable 4

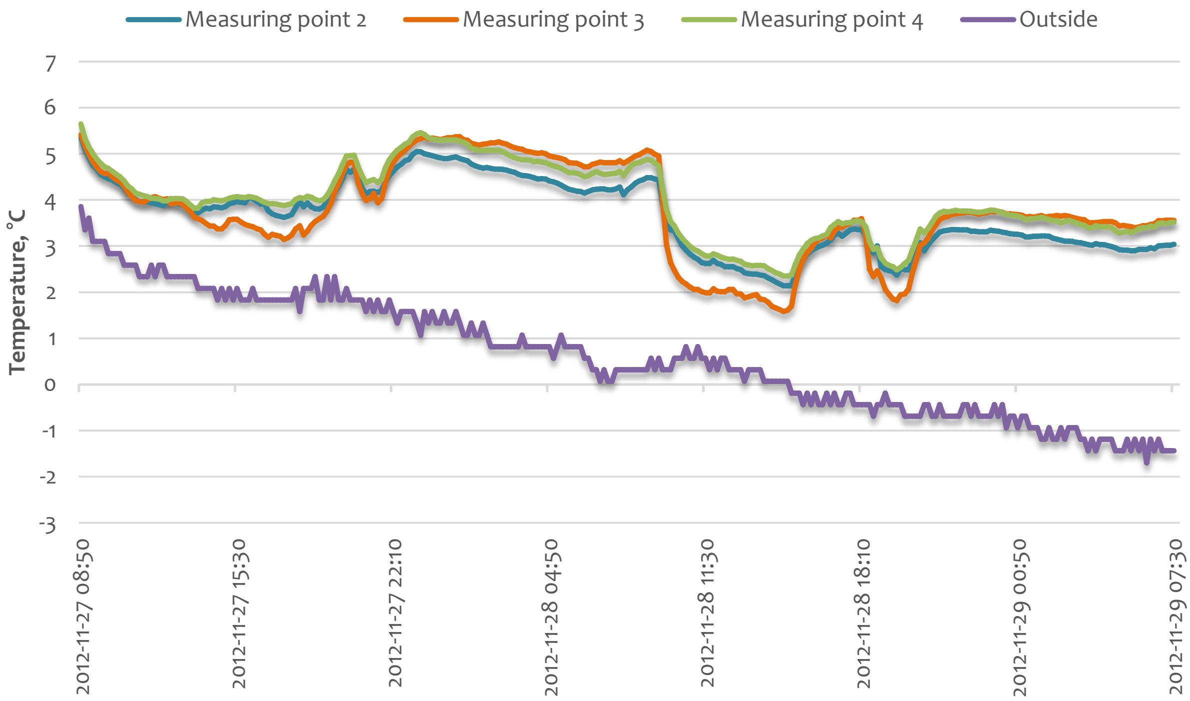


Figure 1. Diurnal variation of temperature in stable 4 at the three measuring points inside the stable and outside measured by the data loggers.

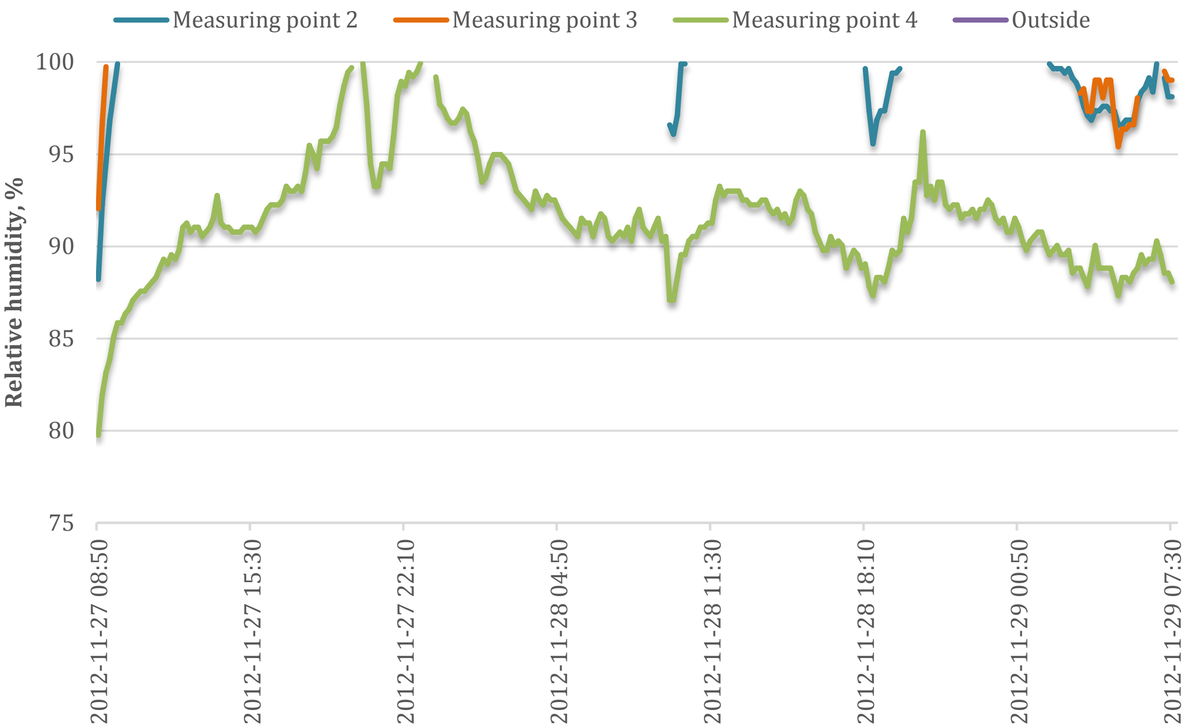


Figure 2. Original uncorrected values of RH in stable 3 at the three measuring points inside the stable and outside measured by the data loggers.

Table 1. The table shows results from the manual measurements in stable 4 and outside in the morning at feeding.

		Measuring point 1	**Measuring point 2**	**Measuring point 3**	**Measuring point 4**	**Outside**
Day 1	**Temperature, °C**	8.00	6.96	7.30	7.90	4.61
	RH, %	72.16	72.91	73.30	70.03	86.33
	CO_2, ppm	790	505	489	550	360
	NH_3, ppm	1.2	---	No detection	---	---
	Weather conditions	Cloudy and rainy				
Day 2	**Temperature, °C**	7.38	6.74	6.66	7.70	1.70
	RH, %	77.74	77.50	81.40	71.70	89.18
	CO_2, ppm	880	780	948	616	342
	Weather conditions	Sleet and very windy				
Day 3	**Temperature, °C**	6.40	6.48	6.08	6.17	- 0.50
	RH, %	73.33	67.72	74.03	70.00	72.24
	CO_2, ppm	1 018	792	846	711	334
	Weather conditions	Snowy and quite windy				

XIII Fictive stable RH and outside AH

Table 1. Results from calculations of outside AH and stable fictive RH at all measuring points inside all stables, using values from the manual measurements. The table also shows the difference between real measured RH and fictive RH at all measuring points, in addition to average values of fictive RH and difference of all measuring points merged.

			Measuring point 1		**Measuring point 2**		**Measuring point 3**		**Measuring point 4**		**Average measuring points 1-4**	
		Absolute humidity outside air (g/m^3)	Fictive RH (%)	Difference measured/ fictive RH (%)	Fictive RH (%)	Difference measured/ fictive RH (%)	Fictive RH (%)	Difference measured/ fictive RH (%)	Fictive RH (%)	Difference measured/ fictive RH (%)	Fictive RH (%)	Difference measured/ fictive RH (%)
Stable 1	Day 1	5.35	45.06	19	51.43	26	45.59	19	46.88	20	47.24	21
	Day 2	6.11	50.85	9	56.38	14	53.68	12	54.25	13	53.79	12
	Day 3	7.24	60.98	16	62.27	19	59.65	12	60.31	15	60.80	15
Stable 2	Day 1	4.93	54.80	0,3	45.10	19	43.83	18	47.59	16	47.83	13
	Day 2	8.10	70.78	5	67.00	8	58.71	6	64.98	4	65.37	6
	Day 3	6.93	51.69	15	57.76	17	53.90	19	54.10	13	54.36	16
Stable 3	Day 1	6.15	59.51	9	64.22	8	65.74	11	66.33	11	63.95	10
	Day 2	3.59	35.51	24	43.65	27	44.91	28	45.80	26	42.47	26
	Day 3	5.74	59.09	2	64.71	6	64.18	10	52.92	23	60.23	11
Stable 4	Day 1	5.74	69.16	3	73.98	-1	72.36	1	69.61	0,4	71.28	1
	Day 2	4.88	61.17	17	63.76	14	64.10	17	59.91	12	62.24	15
	Day 3	3.40	45.41	28	45.41	22	46.37	28	46.10	24	45.83	26

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