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**Welfare and housing in animal production:  
air quality evaluation and new experimental device  
in different species**

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*In memoria del Professor Andrea Simoni, con  
affetto.*

V.v.v.

## **Abstract**

The research has been divided into two steps: the first one concerning the evaluation of ventilation in cattle and broilers houses, the second one concerning the study of a new experimental device for pigs breeding.

Ventilation flow in livestock buildings can determine the indoor climate and air quality and so it affects directly the welfare of the reared animals. The realization of the animal houses in many cases, has not allowed the correct activation of the plants caused by the objective difficulty of testing and the absence of regulations with fixed numerical parameters. Studies were carried out in a typical dairy farm and in a broiler house in Molise region (central Italy). It was set up a control procedure and the planning of the ventilation using the measured carbon dioxide concentration in animal houses as basis for estimation of ventilation flow (as the ventilation flow is a key parameter of aerial emissions from animal houses).

In dairy farm, after the evaluation of the air quality through the analysis of temperature, humidity and CO<sub>2</sub> production, it was installed a fan to improve ventilation rates and air quality and then we evaluated climate conditions by means of temperature distribution in space and time and carbon dioxide in two given points inside the building in order to highlight not so good air mixing and renewing.

In the experimental study carried out in poultry house different configurations of the ventilation system were tested to find the optimum ventilation system to improve the rearing conditions in broiler house. In broilers breeding the contact with gaseous emissions produced by different factors is continuous, so it is necessary an appropriate ventilation in order to discharge them. Climate conditions were evaluated by means of temperature, relative humidity and carbon dioxide concentration. During experimental trials the tested different configurations of the ventilation system showed a little influence on CO<sub>2</sub> average concentration and an irregular distribution was detected due to a wrong activation of the fans in the ventilation system. A more homogeneous condition of temperature and R.H. in the farm could be reached working on smoother ventilation and testing the cooling. The optimization of the ventilation system could be done changing the ON-OFF working with the VFD working. The VFD system, thanks to the opportunity to control the speed, guarantees a better ventilation control and a higher energy saving.

### *Experimental device for pigs breeding*

Many studies have indicated the large effect that good vs. poor handling and housing systems can have on pig physiology, behavior, and pork quality. Ease of routine moving and handling of pigs can affect the final outcome of meat quality and overall welfare of pigs. Despite the need for pork producers to move large numbers of farm animals, little is published about how best to move animals based on scientific evaluations. The broad objective of this case study was to evaluate the efficacy of a new moving devices for pigs. Considering the animal well-being concept and the rules that regulate it, the ethology and the behavior of pigs, it was investigated a “more appropriate” handling method, both from the ethological and operative point of view; it was planned and assembled a new tool, to be used inside the pens, to support the pigs during the handling and transfer procedures limiting the stress phenomena. The use of the tool during the trial showed a positive effect on the time requested by pigs to go out of pens; in fact, when the tool was used fewer stops were observed. Moreover, the tool requires the presence of one worker only in order to move the animals. Consequently, the animals are calmer and no squirrels/vocalizations have been recorded during the experimentation; that is why they did not require of any external stimuli for going on and, additionally, they were less dangerous for workers also. Finally, the need of one worker only is an important factor even for the economic efficiency.

## Riassunto

Valutare correttamente la progettazione dei ricoveri e la funzionalità degli impianti in essi presenti è il primo passo da fare per salvaguardare il benessere degli animali. L'isolamento termico, il riscaldamento e la ventilazione devono consentire di mantenere entro limiti non dannosi per gli animali, la circolazione dell'aria, la quantità di polvere, la temperatura, l'umidità relativa dell'aria e la concentrazioni di gas (anidride carbonica, ammoniaca, ecc.). Al sistema di ventilazione è affidato il compito di ricambiare l'aria all'interno dei locali di allevamento; esso deve essere in grado di controllare la temperatura ambiente, l'umidità relativa e la velocità dell'aria all'altezza degli animali e, inoltre, deve mantenere tollerabile la concentrazione dei gas, della polvere e dei microorganismi nell'aria. In Italia la norma non fornisce limiti ai suddetti parametri, ma dispone che le condizioni microclimatiche siano tali da non essere nocive agli animali allevati. La quantità di aria di ricambio, necessario al benessere degli animali, dipende dalle dimensioni degli stessi, dalla densità di allevamento, dal tipo di animale, e dalla temperatura dell'aria in entrata. Il controllo della ventilazione si può attuare monitorando la temperatura, l'umidità relativa e la presenza di anidride carbonica. Quest'ultima grandezza si presta molto bene sia per il calcolo della portata minima di ventilazione sia per il controllo del sistema adottato per realizzare il ricambio d'aria (Pedersen et al, 2002). La produzione di CO<sub>2</sub> dipende dalla specie, dalla massa corporea e dal livello di alimentazione, variando da circa 0,16 a circa 0,21 m<sup>3</sup>h<sup>-1</sup>hpu<sup>-1</sup>.

Per quanto riguarda le valutazioni operative derivanti dal monitoraggio dell'anidride carbonica occorre predisporre un abaco di calcolo della portata di ventilazione collegato alle dimensioni del ricovero e alle caratteristiche dimensionali, e di specie, degli animali ospitati. Nella sperimentazione effettuata all'interno della

struttura per l'allevamento di vacche da latte, dopo la valutazione della qualità dell'aria mediante lo studio della temperatura, dell'umidità relativa e dell'Anidride Carbonica è stato installato un ventilatore per migliorare il ricambio d'aria ed è stata verificata nuovamente la qualità dell'aria. I risultati ottenuti hanno evidenziato un "microambiente" generalmente ottimale all'interno della struttura anche se non sempre uniforme.

In merito alla valutazione del microclima nell'allevamento avicolo, sono stati rilevati i valori di temperatura, umidità, velocità dell'aria e anidride carbonica. Le misurazioni sono state effettuate durante un intero ciclo di allevamento, con cadenza settimanale, durante la tarda mattinata. Al fine di valutare il corretto funzionamento dell'impianto di ventilazione, i rilievi sono stati eseguiti nel periodo estivo, quando è richiesta la massima portata di aria. I risultati ottenuti hanno dimostrato che la temperatura e l'umidità presenti all'interno della struttura potrebbero essere distribuite in modo più omogeneo mediante un sistema di ventilazione in grado controllare la velocità dell'aria e garantendo allo stesso tempo anche risparmio in termini energetici.

#### *Realizzazione e sperimentazione di un nuovo strumento per la movimentazione dei suini.*

Diversi studi hanno dimostrato che una buona od una cattiva manipolazione può influenzare la fisiologia, il comportamento ed anche la qualità della carne dei suini. Considerando da un lato il concetto di benessere animale e le leggi che lo regolamentano e, dall'altro, l'etologia ed il comportamento dei suini è stato progettato e realizzato uno strumento, da utilizzare all'interno dei box, per movimentare in maniera più agevole i suini e limitarne lo stress. Per verificare l'efficacia dello strumento è stata predisposta una sperimentazione con l'obiettivo di valutare il tempo che gli animali impiegavano per uscire fuori dai propri box. Gli animali movimentati con l'ausilio dello

strumento hanno fatto registrare un tempo inferiore rispetto agli animali movimentati senza di esso e, inoltre, non hanno richiesto sollecitazioni per proseguire il percorso. Si vuole precisare, infine, che lo strumento richiede la presenza di un solo operatore per il suo utilizzo.

## **CONTENTS**

Abstract

Riassunto

Aknowledgement

	Page
<b>1. Introduction</b>	<b>1</b>
<b>2. Concepts and the measurement of welfare</b>	<b>6</b>
2.1 Welfare measurements	6
2.1.1 Physiological measurements	7
2.1.2 Behavioral measurements	10
<b>3. Housing and management</b>	<b>16</b>
3.1 Cattle	16
3.2 Poultry	19
3.3 Pigs	20
3.3.1 Handling	22
<b>4. Air quality</b>	<b>26</b>
4.1 Cattle	26
4.2 Poultry	30
4.3 Pigs	34
4.4 Ventilation	37
<b>5. Aim of the research</b>	<b>42</b>
5.1 Evaluation of ventilation in cattle and broilers houses	42
5.2 Experimental device for pigs	42
<b>6. Material and methods</b>	<b>43</b>
6.1 Evaluation of ventilation in cattle and broilers houses	43
6.1.1 Cattle	43
6.1.2 Broilers	48
6.2 Experimental device for pigs	51



<b>7. Results and discussion</b>	<b>55</b>
7.1 Evaluation of ventilation in cattle and broilers houses	55
7.1.1 Cattle barn	55
7.1.2 Broilers house	61
7.2 Experimental device for pigs	65
<b>8. Conclusions</b>	<b>67</b>
8.1 Evaluation of ventilation in cattle and broilers houses	67
8.1.1 Cattle barn	67
8.1.2 Broilers house	67
8.2 Experimental device for pigs	68
<b>9. References</b>	<b>69</b>

## 1. Introduction

Social and political interest in animal welfare and welfare management has increased substantially in recent years (Bayvel and Cross 2010, Ingenbleek and Immink, 2010) but, in any case, every definition of animal welfare is influenced by the moral or ethical standards of society. Welfare as a biological function, embracing the continuum between positive and negative welfare, should take into account the dynamics of the individuals' adaptive capacity. Positive welfare implies that the animal has the freedom and capacity to react appropriately (i.e. adaptively) to both positive and potentially harmful (negative) stimuli (Ohl and Van der Staay 2012). In 2012, the World Organization for Animal Health adopted 10 'General Principles for the Welfare of Animals in Livestock Production Systems' to guide the development of animal welfare standards. The General Principles draw on half a century of scientific research relevant to animal welfare: (1) how genetic selection affects animal health, behavior and temperament; (2) how the environment influences injuries and the transmission of diseases and parasites; (3) how the environment affects resting, movement and the performance of natural behavior; (4) the management of groups to minimize conflict and allow positive social contact; (5) the effects of air quality, temperature and humidity on animal health and comfort; (6) ensuring access to feed and water suited to the animals' needs and adaptations; (7) prevention and control of diseases and parasites, with humane euthanasia if treatment is not feasible or recovery is unlikely; (8) prevention and management of pain; (9) creation of positive human–animal relationships; and (10) ensuring adequate skill and knowledge among animal handlers (Fraser *et al.*, 2013). Animal breeding and the use of breeding technologies is a dynamic and growing field that has the potential to influence animal welfare in a positive, as well

as negative, way (MacArthur Clark *et al.*, 2006) and the behavior can be a very useful indicator to assess animal welfare (Absmanner *et al.*, 2009). To assess welfare systematically and target insurance of good welfare, it is essential to be able to interpret species-specific normal behavior combined with clinical symptoms. Health and welfare are entangled concepts and cannot be discussed independently (Søndergaard *et al.*, 2011). One important clinical aspect of animal welfare is pain (Weary *et al.*, 2006) being an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage (IASP, 1994). Per definition the existence of pain will always lead to reduction in animal welfare (Moberg *et al.*, 2000). In humans, the best evaluation of pain is self-report, on the basis of oral or written communication (Herr *et al.*, 2006). In animals, it is necessary to use indicators that can be detected by external observers. Consequently, pain assessment in animals is difficult. The numerous reviews of literature or guidelines that have been written focused mainly on mammalian species (Molony and Kent 1997, Holton *et al.*, 2001) and more recently on birds (Gentle 2011). Indicators used for animals are often similar to those described for humans. Most of them are based on physiological or behavioral reactions aiming at stopping the cause or reducing the consequences of the noxious stimuli (Molony and Kent 1997, Mellor *et al.*, 2000). Indicators of injuries and lesions may be used additionally as they often cause pain. Finally, pain can lead to a decrease in production performance, such as growth rate (Earley and Crowe 2002) or milk production (Fourichon *et al.*, 1999), which may also be used as a pain indicator. Numerous postural and behavioral indicators of pain have been described in mammals. They can be distinguished in five main categories. Four of these aim directly or indirectly to avoid or alleviate the painful stimulus:

(1) *Avoidance and defensive behaviors* (the nociceptive withdrawal reflex, leg and body movements) as if animals were trying to avoid or escape the painful stimuli, were observed during castration (Marx *et al.*, 2003), teeth resection and tail docking in young piglets (Noonan *et al.*, 1994; Torrey *et al.*, 2009). Similarly, dairy cows or growing calves jumped or kicked when subjected to hot-iron or liquid-nitrogen branding (Lay *et al.*, 1992; Schwartzkopf-Genswein *et al.*, 1998).

(2) *Vocalizations*. Vocalizations are often used to identify pain in pigs, sheep and cattle. Many studies found that the number and features of these vocalizations (peak frequency, pureness and entropy of the sound) were modified in case of painful situations (Watts and Stookey 2000; Manteuffel *et al.*, 2004). For example, during painful interventions, the number or duration of vocalizations increased in lambs (Molony *et al.*, 1997), cattle (Schwartzkopf-Genswein *et al.*, 1997) and pigs (Weary *et al.*, 1998). Detailed studies on pigs found that high-frequency screams (>1000 Hz) were more frequent, lasted longer and were more powerful when piglets were castrated than when they were just handled to simulate castration, and the high-frequency screams were much reduced when piglets received a local anesthetic before castration (White *et al.*, 1995; Marx *et al.*, 2003). Anyway there is a strong goal conflict as castration is painful and should be avoided to improve welfare (Rault *et al.*, 2011). Watts and Stookey (1999) observed that, compared with controls, calves subjected to hot-iron branding showed a greater frequency range in the fundamental or lowest harmonic of the audio spectrogram of their vocalizations, a higher maximum frequency and a higher peak sound level. However, many animals also vocalize during non-painful handling. Consequently, sometimes, no differences are found between the control and painful situation (Lay *et al.*, 1992; Schwartzkopf-Genswein *et al.*, 1998). It was further shown in ruminants that after the acute response

to a painful intervention, monitoring of vocalizations was of little efficacy to detect pain (Molony *et al.*, 2002; Grant, 2004).

(3) *Behaviors directed towards the painful areas.* Licking or scratching are probably performed to relieve the pain, as simultaneous activation of non-nociceptive sensory receptors of the skin inhibits the transmission of nociceptive signals. When licking is not possible for anatomical reasons, animals may scratch the painful area. For example, calves scratched their head with the hind foot after heat cauterization of the horn-producing area (i.e. disbudding; Morisse *et al.*, 1995). Similarly, the days following surgical castration, pigs displayed scratching of the scrotum against the floor (Hay *et al.*, 2003; Llamas Moya *et al.*, 2008) or dog-sitting postures (Llamas Moya *et al.*, 2008). Other specific movements directed to the painful area may involve head movements towards the painful area after castration and/or tail docking in lambs (Molony *et al.*, 2002), teeth champing (opening and closing of the mouth not associated to feeding) after teeth clipping in pigs (Noonan *et al.*, 1994) and head shaking after disbudding in calves (Morisse *et al.*, 1995).

(4) *Postures and behaviors aiming to reduce stimulation of the painful area.* Postures and behaviours to reduce stimulation of the painful area can also indicate the presence of pain. The most common example is lameness. Foot lesions frequently stop the animal putting weight on the affected leg (O'Callaghan *et al.*, 2003; Flower and Weary 2006). Pigs (Hay *et al.*, 2003), lambs (Molony *et al.*, 1993) and calves (Robertson *et al.*, 1994) were more often lying on their sides with their legs extended after castration than before. Abnormal ventral lying also occurred in lambs after castration combined or not with tail docking (Molony *et al.*, 1993, 2002). Animals that suffer from pain may lie with legs

tucked under the body. Being motionless or agitated may both occur after a painful procedure and can be a pain indicator. For example, 'statue standing' (standing still for more than 10 s) and being awake without any activity were more frequent after rubber-ring castration in lambs (Molony *et al.*, 2002) and after surgical castration in pigs (Hay *et al.*, 2003), respectively, compared with non-castrated controls. Jumping, foot stamping and kicking, rolling from one side to the other side and restlessness measured by the frequency of alternating standing and lying postures were also more frequent after rubber-ring castration and/or tail docking (Molony *et al.*, 1995; Grant 2004). Pain may influence other behaviors such as those related to feeding, drinking, social and grooming. For example, less suckling or feeding behaviour, social isolation, behavioural desynchronization with littermates and/or less social interactions with the dam were observed in pigs after surgical castration (Hay *et al.*, 2003; Llamas Moya *et al.*, 2008) or tail docking (Torrey *et al.*, 2009). Similarly in calves, reduction in feed intake was observed after castration (Fisher *et al.*, 1996).

(5) *The fifth category is related to general changes in activity, being motionless or agitated, feeding, drinking, social and grooming behaviours (Prunier et al., 2013) .*

## **2. Concepts and the measurement of welfare**

### **2.1 Welfare measurements**

The scientific evaluation of animal welfare is a fast-progressing science, based on different indicators (pathological, emotional, physiological, behavioral, as well as immunological parameters) which should be considered in an integrated system (Scipioni *et al.*, 2009). The major categories of indicators of how good or how poor the welfare of an animal are behavioral, physiological, injuries, other aspects of health, growth, reproduction and life expectancy (Scientific Veterinary Committee 1997). The majority of indicators of good welfare, which we can use, are obtained by studies demonstrating positive preferences by animals (Dawkins, 1990). Methods of assessing the strengths of positive and negative preferences have become much more sophisticated in recent years (EFSA 2007). Behavioral and physiological measures have been used for many years to evaluate the ability of domestic animals to cope in the systems in which they are reared. Both types of measure are useful but care must be taken in data collection and in the interpretation of the results for the assessment of animal welfare (Scientific Veterinary Committee 1997). Welfare is poorer when there is an injury or a disease condition than when there is not but there is a range of effects from the trivial to the severe. If growth or reproduction are prevented or impaired, or if life expectancy is reduced, welfare is poorer than if there is no such effect. Whenever possible, when using all of these indicators, the feelings of the individual are assessed but all indicators of good or poor welfare should be used. Since animals use a wide range of methods of trying to cope with adversity and there are various consequences when individuals are not coping, it is important that a wide range of indicators be used when assessing welfare (Scipioni *et al.*, 2009). An individual which shows no clinical

signs of disease and no behavioral abnormality may be showing physiological changes which indicate that it is having much difficulty coping with its environment so its welfare is poor. Another individual might grow well but be clearly abnormal in its behavior so its welfare is poor (Scientific Veterinary Committee 1997).

### **2.1.1 Physiological measurements**

#### ***Hypothalamic-pituitary-adrenocortical activity***

Adrenal cortex response occurs in diverse difficult situations and is useful in welfare assessment. The function of cortisol or corticosterone (glucocorticoid) production is to provide extra energy for forthcoming activity. Hence production of these hormones can occur in situations which are not harmful to the individual as well as in situations which are potentially or actually harmful. (Broom 1993). Because elevation of adrenal cortex hormones can sometimes indicate a substantial problem for the animal and on other occasions do not indicate poor welfare or the likelihood of stress, care must be taken in interpreting such hormone level elevations. If cortisol levels increase when animals are, for example, hit, chased, forced to climb a steep loading ramp, or confined, there can be no doubt that this is a response to difficulty (Mason and Mendl 1993). If there is a larger increase in cortisol in one difficult condition than in another, then it may be concluded that the first condition is more taxing for the individual than the second. On all occasions when adrenal cortex measures are taken it is essential that other information about the animal, especially its behavior, is obtained (Rushen 1991). Other considerations when measurements of glucocorticoid levels in body fluids are made in order to assess animal welfare are: 1) the duration of the response; 2) the extent of daily fluctuations in normal adrenal cortex



activity; 3) the variation in the magnitude of the response to different kinds of problems.

*1) Duration of the response.* When an animal is disturbed sufficiently by an event for an adrenal cortex response to occur, in most domestic animal species the elevation of glucocorticoid in the blood takes approximately two minutes to become evident. It then rises to a peak after 5 to 20 minutes and starts to decline after 15 to 40 minutes, the larger figures referring to more extreme responses. Further responses may occur subsequently. Hence the effects of short term experiences such as handling, or brief transport can be assessed readily by measuring the magnitude of the glucocorticoid increase in blood, saliva or, after a longer time lag, urine. Tests of adrenal function are capable of revealing whether animals have frequently used adrenal cortex responses because frequent use results in greater synthetic enzyme activity. The major test used is to challenge with an injection of sufficient adrenocorticotrophic hormone (ACTH) to produce maximal glucocorticoid secretion. In some circumstances it appears that animals do show a greater response to ACTH after experiencing difficult conditions over a long period. For example, sows which have often been in fights but have lost have a larger cortisol response to ACTH challenge than sows which have avoided conflicts or have won most of their contests (Mendl *et al.*, 1992). If the conditions are prolonged and very severe in their effects, adrenal function may be impaired and a reduced response to ACTH challenge may result. Hence while an increased cortisol response to ACTH challenge indicates poor welfare, the lack of such a response does not necessarily indicate that the conditions posed no problem for the animal (Scientific Veterinary Committee 1997).

*2) Extent of daily fluctuations in normal adrenal cortex activity.* For exact measurement of corticosteroid levels the frequency and amplitude of endogenous secretory episodes

must be considered as well as the plasma concentration of corticosteroids that is not only dependent upon the rate of hormone secretion, but also upon its rate of clearance from the blood (Scientific Veterinary Committee 1997).

*3) Variation in the magnitude of the response to different kinds of problems.* The nature of the aversive stimulus may influence the animal's reaction to it (Mason and Mendl 1993). Rushen (1992) observed that increased glucocorticoid levels have been associated with states of fear and anxiety, while pain does not always affect plasma glucocorticoid concentration. Prolonged pain can result in a reduced corticosteroid concentration (Lay *et al.*, 1992).

### ***Heart rate***

When animals are disturbed by a situation they often substantially change their heart rate in preparation for action, so heart rate measurement is also of value in assessing welfare (Broom 1991). As with glucocorticoids, heart rate is influenced by factors other than fear and anxiety. The level of heart rate reflects the animal's general metabolic demands, and is also influenced by circadian rhythms. In order to avoid conflicting and equivocal results it is important to distinguish between metabolic and emotional effects and to ensure that the measurement itself does not cause much disturbance to the animal (EFSA 2007). Heart rate changes provide useful information about the effects of short-term problems on animals, but the measure gives little information about the long term effects of housing on animals.

### ***Immune response***

The plasma white blood cell count is responsive to stress-induced changes in corticosteroid levels, but it can also be influenced by a number of factors unrelated to stress. Other immunological indices are more reliable, such as the ratio of eosinophils to

lymphocytes and the activity of certain populations of lymphocytes such as T helper cells and T suppressor cells (EFSA 2007). Levels of suppression of lymphocyte division have proved to be more sensitive indices of welfare than alternative measures, such as the total lymphocyte count, the proportion of different types of lymphocyte in the plasma and delayed hypersensitivity (Broom 1993).

### **2.1.2 Behavioral measurements**

Behaviour is one of the most commonly used and sensitive indicators of animal welfare (Haley *et al.*, 2001; Krohn and Munksgaard, 1993) but many of the behaviors that we would like to use to assess welfare occur only for short periods and do not occur equally throughout the day (Rushen *et al.*, 2011). The time spent lying down, the number of lying bouts, the average bout duration (Haley *et al.*, 2000), and the laterality of lying behaviour (Tucker *et al.*, 2009) can indicate underlying changes in cow comfort and welfare (Fregonesi and Leaver, 2001). Cows with mild clinical mastitis present behavioral changes in lying behavior and at milking time, which could be associated with discomfort (Medrano-Galarza *et al.*, 2011). As for other intensively kept species, it is often difficult to distinguish the pig's adaptive behaviors caused by intensive rearing conditions from its inner species-linked behavior; the latter is indeed also influenced by rearing conditions and management. Furthermore, the behavior of domestic pigs is influenced by bio-rhythms which affect the sleeping/waking sequence and other important moments of its life: e.g., time of farrowing which, similarly to man and horse, mainly occurs during the night, when the maximum peacefulness is achieved. The social behaviors, including sexual and maternal behaviors, are the most important fields of study for pig welfare evaluation, since pigs often express within this framework the

abnormal behaviors indicating a state of distress (Scipioni *et al.*, 2009). Changes in behavior patterns are among the first readily detectable responses of an animal to perceived changes in its environment. Behavior occurs as a consequence of the animal's motivational state and therefore the quantification of behavior patterns is in fact a measure of motivation (Dellmeier 1989). A wide variety of behavioral parameters have been used to assess welfare, and the validity of particular behavioral indices has been the subject of several discussion (Barnett and Hemsworth 1990, Rushen and de Passillé 1992, Mason and Mendl 1993). Stereotypes have a great importance in pigs since their frequency is high. A stereotypy is a repeated, relatively invariable sequence of movements that has no obvious purpose. Stereotypes generally appear in conditions such as lack of motivation, restriction and fighting; they may be seen as compensatory reactions to a lack of stimuli, as defense mechanisms by which the pig ceases its higher nervous functions, and as cathartic reactions to emotional tension or frustration. Together with abnormal postures (the best known is the dog-sitting posture), stereotypes are included among somatic abnormalities. Many of these are represented by abnormal feeding behaviors (vacuum chewing, bar biting, drinker playing, polydipsia, etc...), often linked to frustration of oral and feed-related needs (Scipioni *et al.*, 2009). Recent studies investigated the indicators of emotions in pigs, for which it is not only relevant what an individual pig feels but also the extent to which its pen mates are affected by its distress or pleasure (emotional contagion), and they showed play, barks and tail movements for positive emotions while freezing, defecating, urinating, escape attempts, high-pitched vocalizations (screams, squeals or grunt-squeals), tail low, ears back and ear movements for negative emotions (Reimert *et al.*, 2013).

### ***Preference tests***

Preference tests present the animal with choices and are only capable of providing relative information about the welfare problems or benefits of the treatments tested. For example, they cannot indicate whether a particular housing design actually causes the animal stress or suffering (Rushen and de Passillé 1992). Moreover, the behavioral choices that an animal makes following brief exposure to a stimulus may be distinguished from its choices following prolonged exposure. However, preference tests are very useful when designed to answer a specific question as they enable the question to be put directly to the animal. The strength of an animal's preferences and thus whether they can be said to constitute needs, can be assessed by monitoring the incidence of abnormal behaviour patterns and physiological indicators of stress when the animal's preference is denied (Scientific Veterinary Committee 1997). It is also possible to quantify the strength of preferences by measuring how hard the animal is prepared to work in order to have them met.

### ***Tests of aversion***

Measurements of the animal's aversion to a stimulus are the most direct indices of short-term suffering (Rushen and de Passillé 1992), although it is not known whether they are of use in the assessment of chronic suffering owing to a lack of studies on this subject. They may therefore be of limited value in assessing the effect of housing systems upon welfare. Moreover, the results of aversion tests may be confounded by factors affecting memory or learning ability (Scientific Veterinary Committee 1997).

### ***Behaviour deprivation and measures of motivation***

Animals remain motivated to perform certain behaviors even if they are prevented from doing so by their physical environment. It is possible to identify

behavior patterns which the animal is highly motivated, but unable to perform, from the occurrence of abnormal behavior patterns. For example, the animal may perform the motivated behavior in an altered form or in an unusual context. The occurrence of apparently unrelated activities may also be indicative of behavioral frustration (Dawkins 1990). Some of these activities are termed redirected behaviors because their performance, or the excessive degree to which they are performed, is a consequence of an inability to perform some other highly motivated behavior pattern. The identity of the motivated behavior pattern may not be clear from the morphology of redirected activities. However, it may be deduced by comparing the extent to which the redirected behaviors are performed in experimental environments which differ only in respect to their suitability for the expression of particular behavior patterns. An additional technique may be used to assess the strength of an animal's motivation to perform a particular behavior pattern. The amount that an animal is prepared to "pay" for the opportunity to perform the behavior can be measured in terms of its cost to the animal in energy or time expended (Dawkins 1990). The possibility that animal welfare is reduced because animals cannot perform behavior that they normally would perform is one of the enduring concerns the public has about the welfare of animals in modern husbandry systems. However, problems with the concept of natural behavior have been discussed many times (Špinka 2006). Briefly, there is no reason to think that an animal will inevitably suffer simply because it does not perform all the behavior patterns shown by its wild ancestors. Indeed, allowing animals to perform some natural behaviors, such as aggressive behaviors or infanticide, may lead to reductions in animal welfare (Rushen *et al.*, 2011). Furthermore, a multitude of detailed studies on different species have revealed how much artificial selection has altered the behavior of domestic

animals (Jensen 2006), so we are uncertain about how much of the behavioral repertoire of their wild ancestors domestic animals have retained.

### ***Abnormal behaviors***

Broom (1993) described abnormal behaviors as those which differ in pattern, frequency or context from those which are shown by most members of the species in conditions which allow a full range of behavior. There can be abnormalities of feeding, grooming, sexual behavior, gait etc. One category of abnormal behavior is the stereotypy. Stereotypies are repeated, relatively fixed sequences of movements which have no obvious purpose (Fraser and Broom 1990). A considerable amount of discussion is focused upon stereotypies and their causes, function and consequences for animal welfare. Regardless of the function of stereotypies (as a coping mechanism or otherwise), their presence in an animal's behavior helps to pinpoint the specific problems of the animal's environment for its welfare (Rushen and de Passillé 1992). Stereotypies develop when the animal is severely or chronically frustrated. Hence their development indicates that the animal is having difficulty in coping and its welfare is poor. Other abnormal behaviors include those which are directly attributable to a physical restriction and those which are responses, perhaps as part of attempts to cope with problems (Scientific Veterinary Committee 1997). KilBride *et al.*, (2009) reported the prevalence of abnormal gait in finishing pigs from a representative cross-section of indoor and outdoor herds in the United Kingdom to be 19.7%. The lowest prevalence of abnormal gait in finishing pigs occurred in pigs housed outdoors. However, the difference was not significant because only three farms in the study housed finishing pigs outdoors. In indoor-housed finishing pigs, there was an increased risk of abnormal gait in pigs housed on solid concrete floors with sparse bedding, partly-slatted floors or

fully-slatted floors compared with those housed on solid concrete floors with deep bedding in all areas. There was an increased risk of abnormal gait associated with increasing callus, bursitis and capped hock score on the limbs of finishing pigs (EFSA 2007).



### **3. Housing and management**

Housing system designs are affected by a number of factors including, climate, legislation, economics, farm structure and ownership, research and traditions. Recent EU legislation, combined with certain socio-economic issues, has had a great impact on housing systems in Member States. For example Council Directive 91/630 (EEC, 1991), as amended by the Council Directives 2001/88/EC (EC, 2001a) and 2001/93/EC (EC, 2001), dealing with animal welfare and Council Directives 1996/61/EC (EC, 1996) and 2003/87/EC (EC, 2003), covering environmental concerns. And, in addition to the legislation, changes have also come about because of retailing standards applied in certain State Members that have had a major effect on the production methods used by some producers. All livestock houses represent a compromise between cost and animal performance, defined as productivity, health and welfare (Webster, 1994). The modern housing systems, as well as the development of intensive animal production, have gained the attention of scientists on the effects of microclimate inside the animal houses, the management practices and animal welfare. Housing systems may offer improved welfare and health of livestock by protecting animals from heat- or cold-stress and by supplying adequate feeding (Caroprese 2008).

#### **3.1 Cattle**

Basically, cattle can be kept indoors, or outdoors feeding (grazing or being fed) or exercising. Housing can be used because land conditions do not allow grazing, to allow for structured feeding under controlled management conditions, or to protect animals from adverse weather conditions. During the grazing period, animals can sometimes choose between being indoors or at pasture. Dairy cows can be kept indoors

during part of the day. A number of housing options are available. When housed indoors dairy cattle can be loose, tied or confined to group or single pens or crates. Loose animals are kept in groups in straw yards (deep packs) or cubicle systems. Husbandry might vary considerably between different stages in the productive cycle, keeping for instance dry and lactating cows separately. In cold climates, housing facilities can be cold (uninsulated), temperate (partly insulated) or warm (insulated). Floors can be solid or slatted, with varying amounts of litter. Herd size spans from a few individuals to thousands of head, which relates to differences in e.g. grouping, feeding, reproductive management, calving and milking. Furthermore, breeding, housing, feed composition, grazing practices, production strategy and production levels vary between regions, due to differences in geography, climate, tradition and legislation. Grazing is usually seasonal, depending on climatic conditions, but is sometimes practiced all year round. Some cattle are kept indoors all year round (zerograzing). Variations in husbandry are seen in all cattle categories, both replacements, adult dairy cattle and beef cattle. In short, cattle husbandry varies between European countries and regions in a number of ways, almost on a farm-to-farm basis. Due to unfavourable climatic conditions, lack of grass or other forage, or poor conditions of the sward, European dairy cattle are kept indoors for the main part of the year, roughly 5-7 months, during the winter season. The length of the housing period differs between regions in Europe, with variations in climatic condition as the primary reason. In addition, dairy cows are likely to be indoors during a part of the day in the summer season. This is because of milking, water supply, supplementary feeding or even protection against extreme weather such as hot sunshine or heavy rainfall. Loose housing of cows in cubicle barns is presently the most common housing in intensive dairy farming. The cubicle system

focuses both on saving labor and on the increase of production, developed as part of a process of rationalization and intensification of dairy production. The cows move themselves to the necessary commodities and facilities in the system, so that a substantial step in mechanization and automation is made. The cubicle house consists of a number of specific facilities. The cubicles or free-stalls for lying and resting are arranged in one or more rows within the available building space. Each cubicle is a rectangle floor area made of concrete (or soil, in some instances), usually covered with a rubber mat, a mattress or bedding material. Various alternatives of cubicle flooring exist and/or are still under development, but in all cases the aim is to provide the cow with a stable, even and somewhat soft lying surface for comfortable resting. Cubicles are around 1.15 to 1.25 m wide and separated from each other by a metal, wooden or textile framework that also guide the cows' movements. The type of partition has undergone many changes in the course of time, with the aim to allow cows maximum freedom of motion within the available space. The cubicle length is around 2.20-2.30 m, but rails in the front of the cubicle can restrict the actual space of the cow. According to recommendations and legislation, there should be at least as many cubicles as cows but, in practice, higher rates of occupation are often applied, especially when roughage is fed *ad libitum*. If cubicles are also used for feeding, they are called feeding cubicles, which is a less common housing system, applied e.g. when a tie-stall system is restructured and the old feeding platform and stalls are kept intact while a new milking parlour is constructed. The floor in walking areas of a loose-housing system has two main functions, it is the area where cows stand and perform most locomotive, social, sexual, eliminative and grooming behaviors, and it provides a means for collecting manure. In a cubicle system, walkways are usually located between cubicle rows and along the

feeding platform (typically two main walkways in a system with three cubicle rows). The walkway floor is usually made of concrete, presumably because of its durability, low cost and ease of cleaning, and it can be either solid or slatted. To offer a more yielding and comfortable surface, both solid and slatted floors can be coated with e.g. rubber or, less frequently, mastic asphalt (EFSA 2010).

### **3.2 Poultry**

The poultry building's main role is to protect animals against climatic conditions. The major problems encountered are cold weather and hot weather, and high humidity. Broilers can be very sensitive to excess temperature if they become unable to lose and regulate heat effectively due to high ambient temperatures combined with high humidity. The standard broiler house in Europe is window-less, artificially lighted and actively ventilated. Walls and roof are well insulated and the floors are concrete and covered with litter. The vast majority of broilers is kept in floor systems with 100% litter floors. Under conventional production systems in Europe the used litter is usually completely removed after each batch, and the house is cleaned and disinfected. Litter-bedded floor systems are common for raising broiler chickens used for meat production. In contrast, the egg industry has relied heavily on battery cages—small, wire enclosures that typically hold five to ten laying hens. Although cages for broiler chicken production have been available for many years, they were not widely adopted because heavy broiler chickens are prone to leg deformities, breast blisters and other skin imperfections such as enlarged feather follicles due to abrasion against the wire cage floor. Another problem is the comparatively short time period that broiler chickens are confined to cages before they reach market weight, and the concomitant labor

requirements associated with moving chickens into and out of cages (Shields *et al.*, 2013). Light usually is provided by means of fluorescent light. According to EU-Directive 2007/43 light intensity should be at least 20 lux. Water is provided by means of nipples or cups. About 12 birds per nipple or 1000 birds per bell drinker are advised. Feed usually is provided in pans or in tracks (4 cm track length per bird or 1,6 cm per bird for round feeders is advised). The first days feed is also scattered on paper on top of the litter, to facilitate a quick start of the chicks. Stocking density is regulated by EU-Directive 2007/43; the maximum permitted stocking density in the European Union is 33 kg/m<sup>2</sup>, with derogations permitting up to 42 kg/m<sup>2</sup> if specific air quality, temperature and humidity requirements are met and in 7 consecutive flocks mortality should not exceed 1% + 0.06% times age at slaughter (in days). Mortality in broilers can be divided in mortality at young age, usually as a result of poor chick quality, and mortality at later age, usually due to metabolic disorders. Apart from feeders, drinkers and litter, no other items are provided in broiler housing (EFSA 2010) . The Directive 2007/43/ EC regulates the characteristics of: drinkers, litter, ventilation and heating, noise and light. The same directive gives indications on the management of housing to guarantee good level of animal welfare (inspections, cleaning, etc.).

### **3.3 Pigs**

The most important regulation on welfare of pigs is the EU Directive 2008/120/EC (adopted in Italy through Legislative Decree 122/2011), which lays down minimum standards for the protection of the pigs. The above mentioned directive regulates every aspect of the animal life: starting from the place where the pigs live (right light intensity, adequate heating and ventilation conditions, absence of disturbing

and sudden noise, smooth floors so as to prevent injury or suffering to the pigs, lying area physically and thermally comfortable as well as adequately drained and clean which allows all the animals to lie at the same time, etc.) to the diet. Even the social life of the pigs is safeguarded: animals shall have the possibility to get together and take care of the piglets without any difficulties. In Italy the attention to the welfare of the pigs is even higher due to the specialization in keeping heavy pigs for farming purposes. Adult pigs belonging to this race can reach a weight of 156/176 Kg and, given to their meat characteristics, they are particularly suitable for the production of Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) products; Heavy pigs represent over 90% of the whole Italian pig production. Most pigs in the EU are raised indoors under intensive farming conditions. Intensive systems include mainly four separate phases of production (breeding, farrowing, rearing, and, growing and finishing), with different feeding and housing conditions (EFSA 2010). Weaner pigs and fattening pigs are typically housed indoors, although there are housing systems that provide indoor housing with access to an outside area. In few cases, these pigs are also kept outdoors during the whole rearing period. Different climatic conditions and the availability of bedding material in various European regions also greatly influence the type of housing chosen (EFSA 2007). Housing with fully or partly-slatted flooring is the accommodation for fattening pigs that predominates within the EU. Traditionally, fattening pigs are housed in groups of 10-15, but recently the number of fattening units with large group sizes (24 pigs up to 40 and more) on perforated floors is increasing. Accommodation for fattening pigs may be fully-slatted, partly-slatted, minimally bedded with scraped dunging area or deep bedded with straw or straw dust. Slatted floors show a great variation in choice of construction materials such as concrete, cast

iron, steel, aluminum or plastics, or other polymer materials, as well as combinations of materials. The design may be slatted, perforated, meshed or expanded, all with a great variation of surface design and treatment.

### **3.3.1 Handling**

The general public, livestock producers and research scientists have shown an increasing interest in assuring proper animal care and handling. There is a corresponding increase in effort by research and educational institutions, government agencies, enterprise managers, health care providers and others in developing and accessing information that assists in creating appropriate management procedures and humane conditions for handling and transportation (Von Borell and Schaffer 2005). Animals handling inside the barns is always a critical phase both for animals and for employees so management methods and selection of the appropriate animals are being studied to minimize handling problems and the negative consequences for the handlers and the animals (Le Neindre *et al.*, 1996). Many studies have demonstrated the importance of a positive human–animal relationship for reducing stress and facilitating high productivity in farm animals (Waiblinger *et al.*, 2006; Hemsworth and Coleman, 2011). Negative handling, for example using physical force, electric shock, shouting and rapid movement, can also affect the health of animals (Fraser *et al.*, 2013). The majority of negative effects of handling on animal performance and health are likely due to fear. Animals can be stressed by either psychological stress (restraint, handling or novelty) or physical stresses (hunger, thirst, fatigue, injury or thermal extremes) (Grandin, 1997); thus, reducing stress during handling will provide advantages of increasing productivity (Grandin, 1998). The stress of handling can be reduced by using well-maintained

systems (Goddard *et al.*, 2006), consequently, the development of appropriate systems should be guided by the requirement to ensure high standards of animal welfare (Yardimci *et al.*, 2013). In pigsties we can observe many operations during which animals are moved, and it can depend on different physiological state and on organization's requirements. Usually the handling of animals is carried out through traditional methods: the operator drives the group or the single animal, remaining behind it and using frequently goads and blows. It's known that the handling of pigs can cause a stress response in pigs and ultimately affects the meat quality. Studies investigating the influence of pig handling on subsequent meat quality have examined the handling of pigs during transportation from the farm to the abattoir and at the abattoir itself. The major pre-slaughter stressors that can affect meat quality are transportation, loading and unloading of pigs, mixing of unfamiliar pigs, and use of an electrical goad (Warriss *et al.*, 1995; Küchenmeister *et al.*, 2005). Most of the effects have been attributed to alterations in the rate and extent of pH decline postmortem which in turn are related to muscle glycolytic potential (an estimate of muscle glycogen *in vivo*) and a stress induced increase in glycolysis (Hambrecht *et al.*, 2005). Moreover, in pigs, a myriad of both animal-related and environmental factors that can affect muscle metabolism, pH and temperature and that predispose to the development of the PSE syndrome have been observed (Hambrecht *et al.*, 2003). Among such factors are genotype (Sellier 1988), nutrition (Coma 2001), feed withdrawal (Eikelenboom *et al.*, 1991), transport and lairage (Geverink, *et al.*, 1998). Handling and processing in slaughter plants is well-known to have a large impact on meat quality (Hambrecht *et al.*, 2003); stress immediately prior to slaughter (van der Wal *et al.*, 1999; Warris *et al.*, 1994), stunning method (Channon *et al.*, 2000) and chilling rate (Offer, 1991) play



important roles in the conversion of muscle to meat. Also the equipment used to handle animals can have important effects (Fraser *et al.*, 2013). The most common hand-held moving devices used for pigs are electric prods, paddles, boards and flags (McGlone *et al.*, 2004). Overuse of electric prods when pigs are moved can cause severe stress, leading to increased lactate and glucose levels, and poorer pork quality if negative handling occurs just before slaughter (Hambrecht *et al.*, 2005b; Edwards *et al.*, 2010). Studies have shown that negative handling of pigs by stock handlers (i.e. use of electric prodders) on-farm can result in marked reduction of growth and reproductive performance (Hemsworth *et al.* 1986, 1987; Hemsworth and Barnett 1991; D'Souza *et al.*, 1998) and, at the slaughterhouses, the use of a nose snare or electrical goad during preslaughter handling can affect meat quality (Küchenmeister *et al.*, 2005). Both aversive and minimal handling of pigs can have adverse consequences on their behaviour and productivity (Hemsworth and Coleman, 1996). Conversely, sympathetic handling and provision of a more varied environment can have beneficial effects (Beattie *et al.*, 1996). Abbott *et al.* observed that a combination of sympathetic handling and novelty in the environment in the weeks before slaughter can greatly improve the ease with which pigs can be moved, and may make them better able to cope with the stressors they inevitably encounter during the preslaughter period (Abbott *et al.*, 1997). The novelty of an object is important for initiating exploration (Gifford *et al.*, 2007) and has been reported to be intrinsically rewarding to pigs (Kittawornrat and Zimmerman 2010). Normally when an animal, such as man, see something unknown, it becomes a reason of meditation that, if the animal is moving, implies a momentary stop (Hemsworth *et al.*, 1996). Researchers observed that pigs, when stimulated, immediately look for the border lines of place in which they are and, if the stimulus

persists, they move along walls and partitions and only sporadically they go toward the stressor source. They also observed that in many cases blows or goads on animals did not cause any movement probably because of pigs don't connect stimulus to the movement and so, instinctively, they wait. McGlone *et al.*, (2004) observed that the use of electric prod and paddle often cause the pigs to vocalize and some pigs became also aggressive. During handling the most common behavioral indicators of stress are: open mouth breathing (panting), vocalization (squealing or barking), blotchy skin (reddish/purple color), stiffness, muscle tremors (animals begin shaking) increased heart rate and increased body temperature (Anderson *et al.*, 2002). In a research on the efficacy of moving devices for finishing pigs the authors showed that the use of the board was the most efficacious moving device when compared to electric prod, paddle or flag. A handler using a board required less time ( $P < 0.05$ ) to move pigs compared with an electric prod or paddle and, moreover pigs vocalizations were similar after being touched with either the paddle or electric prod, but these devices caused more pigs vocalizations than the board (McGlone *et al.*, 2004).

## 4. Air quality

### 4.1 Cattle

Main gases in livestock buildings that may affect animal health are ammonia, carbon dioxide, carbon monoxide, hydrogen sulphide and methane. Decomposing wastes give off odorous gases such as amines, amides, mercaptans, sulphides, and disulphides. In a properly designed and managed naturally ventilated building, noxious gases usually do not reach harmful concentrations but also low levels of these gases could be contributed to chronic diseases.

*Ammonia* ( $NH_3$ ) is released during anaerobic decomposition of urine. Anaerobic decomposition of nitrogen containing compounds in manure is also possible. Ammonia levels tend to be high in buildings with litter, solid floors, or scrapers because manure spread over the floor area increases ammonia release. Concentrations above 30 ppm may increase the incidence rate of respiratory diseases. The threshold limit for  $NH_3$  is 20 ppm, in some countries 10 ppm.

*Carbon dioxide* ( $CO_2$ ) is mainly from animal respiration and manure decomposition.  $CO_2$  concentration in well-ventilated rooms may be 2000 ppm (0.2%). Without ventilation in a closed building, the level can rise rapidly. Carbon dioxide triggers breathing, but at high concentrations contributes to oxygen deficiency. The threshold limit for  $CO_2$  is 3000 ppm.

*Hydrogen sulphide* ( $H_2S$ ) is the most toxic gas from liquid manure storage. Hydrogen sulphide is produced by anaerobic decomposition of organic wastes. Concentrations are usually negligible in well-ventilated buildings except during agitation and pumping of liquid wastes. High ventilating rates can help reduce dangerous conditions during agitation and pumping of stored manure. At low

concentration, hydrogen sulphide smells like rotten egg. H<sub>2</sub>S can rapidly destroy the sense of smell; lack of H<sub>2</sub>S odour is not an adequate warning. CIGR-report (1992) recommendations for threshold limit were 0.5 ppm.

*Methane (CH<sub>4</sub>).* Ruminant animals exhale a little methane, but most come from manure decomposition. Methane is lighter than air. It dissipates rapidly with some ventilation. Methane is not usually considered toxic. Accumulations in stagnant areas can be asphyxiating. Methane is explosive at concentrations of 5%–15% in the air.

*Carbon monoxide (CO)* can be produced from incomplete combustion of fuels inside buildings (for example, if a tractor is used for feeding and manure removing). The gas is toxic for humans and animals. The threshold limit for CO is 10ppm. (Praks *et al.*, 2009).

### ***Temperature***

The maintenance of a comfortable indoor climate with respect to temperature, humidity, noxious gases (ammonia, hydrogen sulphide, carbon dioxide) and protection from draught is an important part of cattle management. Air temperature, relative humidity and air velocity are important factors of animal heat exchange. Cattle are more temperature tolerant than other farm animals. Their thermo-neutral zone is generally wide, and often extends to much lower temperatures; exceptions are neonate and young animals, sick or underfed animals, animals exposed to high air speeds or which have wet coats. The range of thermal neutrality is variable between breeds and between cows with different productivity. When environmental temperatures move out of the thermo-neutral zone (or comfort zone) dairy cattle begin to experience either heat stress or cold stress. Either stress requires the cow to increase the amount of energy used to maintain the body temperature and there is less energy available to produce milk. Thermo-neutral

zone is the range of environmental temperatures where normal body temperature is maintained and heat production is at the basal level. The ranges of thermo-neutral zone are from lower critical temperature (LCT) to upper critical temperature (UCT). LCT is the environmental temperature at which an animal needs to increase metabolic heat production to maintain body temperature. UCT is the environmental temperature at which the animal increases heat production as a consequence of a rise in body temperature resulting for inadequate evaporative heat loss. Thermo-neutral zone depends on the age, breed, feed intake, diet composition, previous state of temperature acclimatization, production, housing and stall conditions, tissue (fat, skin) insulation and external (coat) insulation, and the behaviour of the animal. UCT is given as 25-26 °C, LCT as a range from -16 to -37 °C for dairy cows . LCT for newborn calves is 10 °C in dry and draught-free environment. LCT decreases to 0 °C by the time the calf is 1 month old. The lower critical temperature is affected by:

1. *The rate of heat production* (feed intake, digestibility of the feed, the level of production, the efficiency of utilization of ME), the amount of activity and locomotion.
2. *The rate of heat loss*. Heat loss is affected by coat thickness, coat thermal insulation, tissue insulation, the minimal rate of evaporative heat loss, irradiative environment. Coat insulation is affected by wetness and air speed (Praks *et al.*, 2009).

The common opinion is that the neutral air temperature for European breeds of dairy cows is about –5 °C to 25 °C (Management and Welfare of Farm Animals, 1999) and the optimum ambient temperature for dairy cows is 0-15 °C (EFSA 2010);

### ***Humidity***

The recommended relative humidity in cowsheds is 70±10% (Management and Welfare of Farm Animals, 1999) while optimum relative humidity for EFSA (2010) is between 50-80%. Relative humidity is important, inside cowshed, to determine the Temperature Humidity Index, a common method for heat stress evaluation in animals and could be used as an indicator of thermal climatic conditions. THI is determined by equation from the relative humidity and the air temperature and is calculated for a particular day according to the following formula (Kadzere *et al.*, 2002):

$$\text{THI} = 0.72 (W + D) + 40.6$$

W: wet bulb temperature °C

D: dry bulb temperature °C

The principle of THI is that as the relative humidity at any temperature increases, it becomes progressively more difficult for the animal to cool itself. (RCI). THI values of 70 or less are considered comfortable, 75 – 78 stressful, values greater than 78 cause extreme stress (Praks *et al.*, 2009). Several studies documented negative relationships between THI and productive and reproductive performances in dairy cows (Bouraoui *et al.*, 2002; García-Ispuerto *et al.*, 2007). Conversely, the relationships between THI and mortality in dairy cows have not been established previously. Yet, even if experimental evidence supporting categorization of THI values in hazard levels were not clear, Silanikove (2000) reported that a THI of 80 would be the upper critical THI above which most domestic ruminants enter in a noxious stage, which was defined as a stage compromising their survival. Vitali *et al.*, (2009) in their research observed that summer was the season with the highest

risk of death for dairy cows, and THI of 80 and 70 were the values of maximum and minimum THI, respectively, above which the number of deaths starts to increase significantly. Furthermore, THI of 87 and 77 should be considered the upper maximum and minimum critical THI values, respectively, above which the risk of death for dairy cows under intensive management conditions becomes maximum.

## **4.2 Poultry**

The environment in the poultry house is a combination of physical and biological factors which interact as a complex dynamic system of interactions between birds, husbandry system, light, temperature and the aerial environment (Sainsbury 2000). Aerial environment (air quality) including temperature, humidity, dust level and concentrations of carbon dioxide, carbon monoxide and ammonia should be controlled and kept within limits where the welfare of the birds is not negatively affected (DEFRA 2002). The EU Broiler Directive (Commission, 2007) advises 20 ppm for ammonia, 3,000 ppm for carbon dioxide and 70% for relative humidity as upper limits. Pollutants include organic and inorganic dust, pathogens and other micro-organisms as well as gases such as ammonia, nitrous oxide, carbon dioxide, hydrogen sulphide and methane or other compounds like endotoxins and even residues of antibiotics (Kristensen and Wathes, 2000; Saleh, 2006). Gases, dust and micro-organisms form bio-aerosols and there is strong epidemiological evidence that bioaerosols cause directly infectious and allergic diseases in farm workers and animals. Chronic exposure to some types of aerial pollutants may exacerbate multifactorial environmental diseases (Saleh 2006). In addition, air contaminants may depress the growth of the birds (Wathes 1998). The main sources of aerial pollutants are the feed, the litter and the chickens themselves. They are indirectly or directly

influenced by season, diseases, nutrition and the management (Wathes 2004). It is remarkable that broiler chickens tolerate the high burden of aerial pollutants, and yet there are reasons for concerns that their welfare may be compromised by chronic exposure (Wathes 2004). Wathes (2004) suggested that the current guidelines for air quality should be revised and lower limits considered (EFSA 2012). Indoor poultry units often have high levels of ammonia and dust. High levels of atmospheric ammonia can cause keratoconjunctivitis in poultry, as well as damage to the lungs and trachea (Fraser *et al.*, 2013). Ammonia is a colourless gas with a pungent odour, produced in the litter by microbial decomposition of nitrogen-containing substances. Ammonia can irritate eyes, throat and mucous membranes in humans and farm animals. Its excessive concentration in the air may cause blindness, skin burns and a decreased weight gain in broilers. The smell of ammonia can be detected by humans at concentrations of less than 10 ppm. Ammonia levels of 10 ppm or more in the broiler house can damage the lung surface and increase the susceptibility for respiratory diseases. Damage to the mucous membranes of the respiratory system increases the susceptibility of birds to bacterial respiratory infection, especially *E. coli* infection. High levels of ammonia have a negative impact on overall livability, weight gain, feed conversion, condemnation rate at processing and the immune system of the birds. Ammonia concentrations at 25 and 50 ppm induced eye lesions after 7 days after initial exposure. The growth rate of broilers is reduced at ammonia levels higher than 50 ppm (ROSS 2010). In broiler houses, the most important factors influencing ammonia production are air temperature, ventilation rate, humidity, feed composition, age of the litter, litter pH, moisture content, litter type, stocking density and age of birds (EFSA 2012). Considering the behavioural and



physiological responses of broilers to increased levels of ammonia (DEFRA 2002) recommended a maximum ammonia concentration of 20 ppm. N<sub>2</sub>O and CH<sub>4</sub> do not occur in broiler houses in concentrations which may influence health or welfare of animals. Other gases, such as CO and H<sub>2</sub>S, are potential risk factors for broiler welfare, but there are little data available on commonly occurring concentrations or on risk levels. Carbon dioxide (CO<sub>2</sub>) is a non-reactive gas, which is removed only by ventilation contrary to a reactive gas like ammonia which may interact chemically, for example, by absorption on wet building surfaces or dust particles. CO<sub>2</sub> is a metabolic by-product of both broiler chickens and litter processes. Levels of CO<sub>2</sub> of 1% do not, by itself, cause any harm for animals. However, an increase in CO<sub>2</sub> levels is usually accompanied by increased levels of other detrimental air pollutants such as ammonia, dust and micro-organisms. Therefore CO<sub>2</sub> is used as an air quality indicator and the minimum ventilation rate is calculated on the basis of CO<sub>2</sub> production by the chickens and the litter (EFSA 2012).

### ***Temperature***

Broiler houses are heated as young chicks cannot maintain their body temperature. Sometimes floor heating systems are used, but in the majority of the houses local or central heating systems are used. If the temperature is too low, birds increase their feed intake but have to use more of that feed energy to keep their bodies warm. If temperature is too high, they reduce feed intake to limit heat production. At each stage of a bird's development, there is one narrow temperature range where maintenance energy requirements are lowest and the bird can make maximum use of feed energy for growth. If temperature goes just a few degrees outside the optimum performance zone, cooler or warmer, birds will be using a

higher proportion of their feed energy for body maintenance and less for growth. For example, university research in the United States showed that exposing day-old chicks to an air temperature of 13°C for only 45 minutes reduced 35 day weights by about 110 grams (ROSS 2010). The first day the temperature on chick level should be 30°C. During the rearing period the temperature is lowered according to the guidelines of the breeding companies. At 27 days of age the temperature should be around 20°C. (EFSA 2010). The target temperature for best broiler performance changes during a grow-out, typically from around 30°C on day one to near 20°C or lower at harvest time, depending on bird size and other factors. (ROSS 2010).

### ***Humidity***

Humidity depends mainly on factors within the building but also on outside humidity. Examples of important factors in the building are stocking density, live weight of the birds, ventilation rate, indoor temperature, number, type and management of drinkers, water consumption and water spillage. Birds are basically air-cooled. That is, air moving over the birds picks up their body heat and transfers it to the environment. Birds do not sweat, they do get some evaporative cooling effect through breathing and panting (ROSS 2010). Temperature and relative humidity influence the thermal comfort of the birds. A relative humidity of 60-70% in the house is necessary in the first three days (ROSS 2009). Relative humidity above 70% can occasionally be reached with high stocking densities in winter time when the ventilation rate may be reduced to retain heat and save energy (ROSS 2009). At later ages high relative humidity causes wet litter and its associated problems. During summer, broilers may often experience discomfort due to the combined effect of high humidity and high temperature. Relative humidity below 50% leads to

an increase in dust and micro-organisms, which increase the susceptibility to respiratory diseases. This situation is not very common and normally occurs only in the first or second week of life. Adequate ventilation rates provide the most effective method of controlling temperature within the house and also allows for control of relative humidity and can play a key role in alleviating the negative effects of high stocking density and of wet litter. Litter moisture is positively correlated with the incidence of foot pad dermatitis, one of the most important welfare indicators (EFSA 2012).

### **4.3 Pigs**

It is known that inside piggery one of the most dangerous compound for pig's health is the ammonia. Acute and prolonged effects of 35 and 50 ppm concentrations of atmospheric ammonia (NH<sub>3</sub>) were associated with an increase in absolute monocyte, lymphocyte and neutrophil counts, as well as in serum cortisol and haptoglobin concentrations, but no effect was found on pig growth performance (EFSA 2011). Atmospheric ammonia at commonly experienced concentrations may undermine social stability of groups of finishers, particularly in the presence of low lighting, though the mechanisms are currently unknown (Parker *et al.*, 2010). Banhazi *et al.*, (2008) reviewing the likely benefits that might be gained from air quality improvements and the factors affecting airborne pollutants and environmental parameters, identified ammonia, carbon dioxide, viable bacteria, endotoxins, and inhalable and respirable particles as major airborne pollutants which could compromise the health, welfare and production efficiency of animals. In buildings housing pigs, ammonia and other gases released from feces stored under slatted floors can irritate the respiratory tract, and sudden releases of hydrogen sulphide, especially when manure is agitated for pumping

out, can prove fatal (Fraser *et al.*, 2013).

### ***Temperature***

Pigs are homoeothermic animals that cannot lose heat by sweating and rely on behavioural measures such as a reduction in physical contact with pen mates, lying laterally, panting and reducing general activity, as well as evaporation by making the skin wet through wallowing (EFSA 2005). Amongst the several environmental variables that can potentially affect the welfare of pigs, temperature is certainly the most important (EFSA 2007). Pigs have great difficulty adapting to both low and high temperatures, especially modern and genetically improved genotypes, which in the majority of cases have white bristles and pink skin, and are therefore very sensitive to direct exposure to the sun (Scipioni *et al.*, 2009). The domestic pig, in contrast to most domesticated species, has very sparse thermal protection offered by hair. The sparse hair cover allows ready evaporation from the skin but, as swine do not sweat when exposed to heat, body cooling is based on skin wetting or wallowing (EFSA 2007). Climate is actually the main factor responsible for the high incidence of new born mortality and for the low indexes of fertility which are often reported for outdoor farming (Guégen *et al.*, 2000; Waller and Bilkei, 2002; Akos and Bilkei 2004). It is well known that pigs do not seem to suffer greatly from being exposed to rain or sunshine, although they often get their skin burnt when exposed to sunshine for a long time in summer and, in contrast, pigs greatly dislike to remain exposed to wind and, consequently, look for a convenient shelter and, if in a group, huddle to conserve warmth (EFSA 2007). In response to cold, perceived as a consequence of a low temperature or high air velocity, pigs require less space for lying, as they prefer to lie in body contact with pen mates and show huddling behavior (Hillmann *et al.*, 2004). In pig production the lower threshold, i.e. the lower

critical temperature, is obviously of interest because pigs maintained at ambient temperature below thermal neutrality will have lower food conversion efficiency. As the pig increases in size, its critical temperature decreases. Although it is difficult to generalize the thermo neutral temperature for each stage of production, it is likely to be around 34°C for newborns (which have little subcutaneous fat), 25-30°C for 4-6 kg piglets, 25°C for piglets aged 8 to 14 weeks, and 20°C for growers (EFSA 2005). Bockisch, *et al.*, (1999) recommend the following air temperatures (if two values are mentioned, the lower one refers to pens providing the pigs with litter): more than 30°C for piglets up to 10 days, 16°C (20°C) for piglets up to 10 kg, 14°C (18°C) from 10-20 kg, 12°C (16°C) above 20 kg, 17°C for non-pregnant sows kept single, 15°C for pregnant sows kept in groups and 12°C (16°C) for fattening pigs. Investigating the lying behaviour and the adrenocortical response (by taking saliva samples for the analysis of cortisol concentration), the results of Hillmann *et al.*, (2004) indicate temperature ranges within the thermal tolerance of pigs to be 19-21°C for pigs weighing 25-35 kg, 10-17°C for pigs between 50 and 70 kg and 5-17°C for pigs of more than 85 kg (all kept in pens with partially slatted floor. Maintaining pigs at low temperature has both health and behaviour-related adverse effects: the frequency of coughing, diarrhea, and tail biting increase with temperature reduction. On the other side, pigs maintained at high temperature have a decreased feed consumption and delayed return to estrus (EFSA 2005).

### ***Humidity***

The pig is more adapted to live in humid conditions than in a dry atmosphere; a dry environment can even be a cause of irritability, and humid or frequently wet skin is essential for thermoregulation. When the relative humidity is very high, pigs become

more dependent on water loss from their skin, even though the respiration rate increases. Therefore it is necessary for them to wallow or lie on a wetted floor. If no adequate possibility to wet the skin is offered, as temperature rises there is an increasing rate of dirty pigs as they wallow in their own excrement in order to cool down (EFSA 2007). Massabie and Granier (1996), housing fattening pigs at different levels of air relative humidity and maintaining the temperature at 24C, found the growth rate significantly reduced by a hygrometry reading of 90% as a consequence of a reduction in spontaneous food consumption. There are no studies indicating the optimal range of relative humidity for pigs kept indoors, nevertheless, a moderately high level of humidity is necessary for keeping the respiratory system in good condition. In fact, the incidence of respiratory diseases is greatly reduced by keeping pigs in a very humid environment. A dry atmosphere increases skin evaporation and the consequent lowering of skin temperature. This is harmful for pigs because it removes them from their thermo neutral zone (EFSA 2007). Bockisch *et al.*, (1999) recommend a relative humidity of 60% to 80% for sows, 50% to 70% for sows with piglets, 50% to 80% for piglet rearing and 50% to 70% for fattening pigs and remark that immoderate dry air leads to coughing. On the other hand, high air humidity values at low temperatures lead to wet skin, loss of body temperature and increasing discomfort (EFSA 2007).

#### **4.4 Ventilation**

Ventilation systems in livestock housing serve an important function, maintaining a comfortable animal environment. Ventilation systems continuously remove the heat, moisture, and odors created by livestock, and replenish the oxygen supply by bringing in drier, cooler outside air. Adequate air exchange also removes gases such as ammonia (NH<sub>4</sub>), hydrogen sulfide (H<sub>2</sub>S), and methane (CH<sub>4</sub>) which can

be harmful to both animal and operator health (ROSS 2010). Carbon dioxide (CO<sub>2</sub>) is a non-reactive gas, which is removed only by ventilation contrary to a reactive gas like ammonia which may interact chemically, for example, by absorption on wet building surfaces or dust particles (EFSA 2012). There are two basic ventilation types: natural ventilation and fan-powered ventilation. Natural ventilation relies on opening up the house to the right extent to allow outside breezes and inside convection currents to flow air into and through the house. This is often done by lowering (or raising) sidewall curtains, flaps or doors. Sidewall curtains are most common, and natural ventilation is often referred to as “curtain ventilation”. In curtain ventilation, the curtains are opened to let in outside air when it gets warm; when it gets cold, they are closed to restrict the flow of air. Opening house curtains allows a large volume of outside air through the house, equalizing inside and outside conditions. Curtain ventilation is ideal only when outside temperature is close to the target house temperature. The air exchange rate depends on outside winds. On warm to hot days with little wind, circulation fans may be used to provide some wind-chill cooling effect. Natural ventilation as a system does not allow a great deal of control over in-house conditions. In the early days of the industry it was commonly used, especially in mild climates, and houses were specifically designed to facilitate natural air convection currents for ventilation purposes. In more recent times, managers of more modern curtain sided houses equipped with fan-powered ventilation systems have used natural ventilation as an “in between” option, when outside air temperature is close to desired in-house temperature and neither heating (and minimum ventilation) nor cooling is needed (ROSS 2010). Fan-powered ventilation uses fans to bring air into and through the house. Powered ventilation generally allows much more control over both the air exchange rate and the airflow-through pattern,

depending on the configuration of fans and air inlets and the type of control used. Fan-powered ventilation systems can use either positive or negative pressure. Positive-pressure wall-mounted fan systems, which push outside air into the house, are most often seen in setups used for cooler weather. However, some house fan-powered systems now use negative-pressure ventilation. This means that the fans are exhaust fans, pulling air out of the house. This creates a partial vacuum (negative pressure) inside the house, so that outside air is drawn into the house through inlets in the house walls or under the eaves. Achieving a partial vacuum inside the house during ventilation allows for much better control of the air-flow through pattern in the house and for more uniform conditions throughout the house (ROSS 2010). Inaccurate knowledge of the ventilation rates inside barns is the major cause of production losses and ventilation-related health problems in cattle breeding (St-Pierre *et al.*, 2003); Doherty *et al.*, (2001) showed, for example, that environmental diseases act as a major limiting factor in Irish calf production. Adequate ventilation rates can play a key role in alleviating the negative effects of high stocking density and of wet litter and the incidence of foot pad dermatitis in poultry (EFSA 2012). Ventilation of animal houses should be based on maintaining desired thermal conditions and air quality. This requires no buildup of heat and/or gases in the inside air (Pedersen *et al.*, 2008). The ventilation control inside the farms can be done using various parameters like the relative humidity, the CO<sub>2</sub> production (CIGR 1984, 2002) and using gas tracer (Freon 134a, Müller *et al.*, 2006). The measures of the real ventilation given by the environmental concentrations of the relative humidity is more difficult to get because the air humidity continually changes during the day and, therefore, it would need continuous control to guarantee optimal ventilation conditions inside the shelters. Estimation of the gas emission needs



knowledge on both the air exchange to the environment and the gas concentration in the animal house. To estimate the air exchange rate by performing a carbon dioxide (CO<sub>2</sub>) balance in the house an accurate estimation of the CO<sub>2</sub> production in the building is crucial. The total CO<sub>2</sub> production includes CO<sub>2</sub> produced by the animals and CO<sub>2</sub> emitted from the manure. CO<sub>2</sub> production from the animal can be derived from its energy metabolism rate, which is related to feeding level and nutrient composition of the diet (CIGR 2002). In animal houses where the manure is not stored in the barn for a long period (e.g. slatted houses with regular emptying of manure pits) the CO<sub>2</sub> production from the manure is small compared to the CO<sub>2</sub> production from animals. However, in animal houses with deep litter (i.e animal houses where the depth of the litter is > 0.5m), the CO<sub>2</sub> production from the deep litter can be considerable (Jeppsson 2000, 2002). The calculation of ventilation through the study of the CO<sub>2</sub> concentrations is directly connected to the total heat produced by the animals (CIGR 2002, Pedersen *et al.*, 2008). The production of total heat depends on the animal, on the body weight and on the production level of the considered animals and it can change during the day cause the influence of feed level and the micro-environmental conditions on the animal activity (Sousa and Pedersen 1994). In the mentioned studies, and particularly in the report of the Committee Internazionale of the Rural Genius (1984 and 1992) and in the works of Chepete and Xin, (2002) there are the equations for the calculation of the total heat production in thermo-neutrality conditions. For every type of animal and different productive destination, the quantity of total producible heat is calculated depending on ( $\Phi_{tot}$  in Watt) the body mass (m, kg) (C.I.G.R., 2002). For example: calves  $\Phi_{tot} = 6,44 m^{0,70} + [13,3 Y_2 (6,28 + 0,0188 m) / 1 - 0,3 Y_2]$  where: Y<sub>2</sub>= daily increase, 0,5 kg / day. Cows  $\Phi_{tot} = 5.6 m^{0,75} + 22 Y_1 + 1,6 \times 10^{-5} p^3$  where: Y<sub>1</sub> = milk production, kg / day ; p =

days of pregnancy. When the temperature goes down under the thermo-neutrality value, or rather under 20 °C, the production of total heat increases and, in opposite, when the temperature increases the heat production decreases. The equation to determine the correction factor of total heat expressed in hpu (1 hpu is equivalent to 1000 Watts of total heat production at 20 °C) is (C.I.G.R., 2002): Cattle  $\Phi_{tot} = 1000 + 4 (20 - t)$ ; where :  $\Phi_{tot}$  = total heat production for hpu expressed in Watt; t = environmental temperature in °C. To determine the Kc correction coefficient we have to divide the quantity obtained with the previous equation for 1000 Watts : Cow  $K_c = \Phi_{tot} / 1000 = (1000 + 4 (20 - t)) / 1000$ .

Considering that environmental CO<sub>2</sub> is nearly stable during the day and it is attested on values of about 380 ppm. and knowing the number and the size of animals inside the shelters, it is possible to determine the ventilation flow and therefore also the necessary air exchange rate to guarantee the comfort of the reared animals.

## **5. Aim of the research**

The research has been divided into two step: the first one concerning the evaluation of ventilation in cattle and broilers houses, the second one concerning the study of a new experimental device in pigs breeding.

### **5.1 Evaluation of ventilation in cattle and broilers houses**

**Cattle.** These studies were carried out in a typical dairy farm in Molise region (central Italy). It was set up a control procedure and the planning of the ventilation using the literature available. Special emphasize was given to the direct measure of the Carbon Dioxide amount, detected directly inside the buildings, and considering it as gas traces for the real control of ventilation. The experimental procedure was planned to improve air quality inside the barn through a proper fan.

**Broilers.** The experimental study was carried out in a poultry house located in Molise region (Italy). During experimental trials different configurations of the ventilation system were tested to find the optimum ventilation system to improve the rearing conditions in broiler house.

### **5.2 Experimental device for pigs**

Considering the animal well-being concept and the rules that regulate it, the ethology and the behavior of pigs, we have investigated a “more appropriate” handling method, both from the ethological and operative point of view; it was planned and assembled a new tool, to be used inside the pens, to support the pigs during the handling and transfer procedures limiting the stress phenomena.

## 6. Material and methods

### 6.1 Evaluation of ventilation in cattle and broilers houses

#### 6.1.1 Cattle

The search was carried out in a farm is located in Sepino (CB) built in the 80's Years. The used housing is the stall one with short seat and with a head to head disposition. The shelter, connected to service and deposit structures, has an area of 260 m<sup>2</sup>, and the external walls realized by cement face bricks with 2 air spaces. The roof is made by two undulated cement asbestos boards with a glass wool sheets cavity and it is supported by purlins and iron beams. The group was composed by 12 cows (average weight 600Kg/head) and 18 calves (average weight 325kg/head).

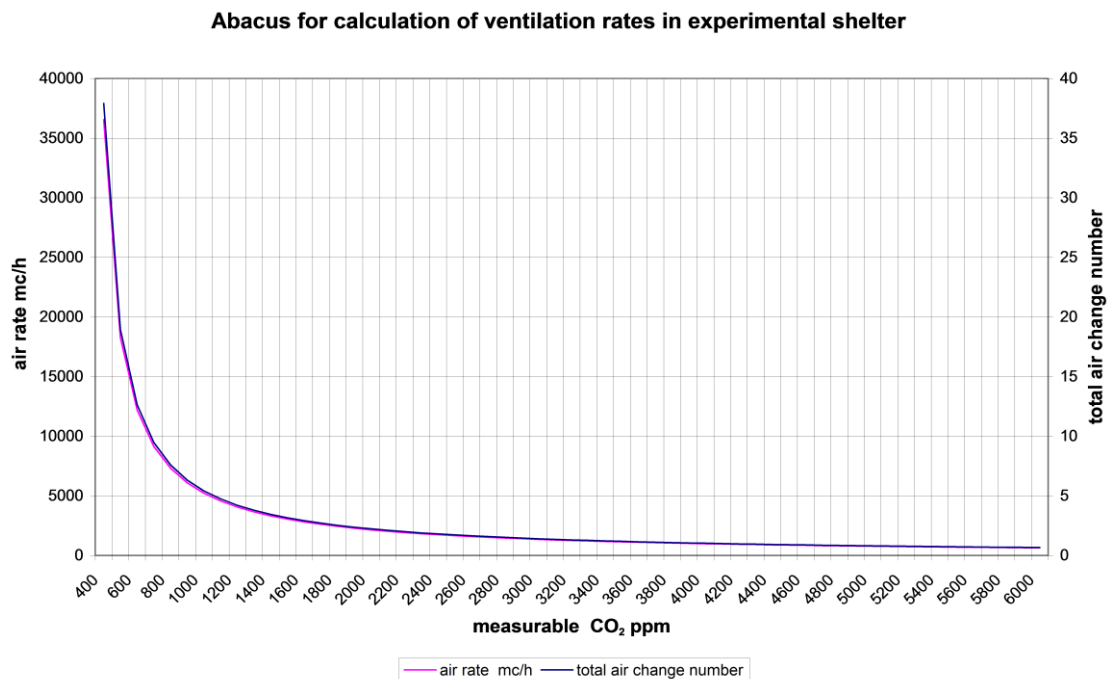
*Calculation of ventilation flow based on measured CO<sub>2</sub> production.*

After the determination of total heat production inside the building it was planned the abacus of calculation for the airflow rate. The formula that connects the ventilation rate with the quantity of CO<sub>2</sub> inside the barn and the CO<sub>2</sub> of the air external to the building it is the following (CIGR 2002):

$$Q_v = \frac{a * \Phi_{tot} * K_c}{(x - G)}$$

where: Q<sub>v</sub> = ventilation rate (m<sup>3</sup>/h); a = CO<sub>2</sub> production per produced hpu (0.185 \* 10<sup>6</sup> ppm); Φ<sub>tot</sub> = total heat production expressed in hpu; K<sub>c</sub> = correlation factor of the heat production for temperatures different to 20°C, considered the thermo-neutrality temperature; x = carbon dioxide quantity measured in the indoor air (ppm); G = carbon dioxide quantity in the outdoor air. For the construction of the abacus it has been considered, in this case, the thermo-neutrality condition and so the K<sub>c</sub> was not considered. The producing plan is a Cartesian diagram that shows the function that

connects the ventilation rate and the carbon dioxide quantity measurable inside the barn.



Considering this abacus it is possible to realize an example of its business use. After the detection of 2200 ppm of CO<sub>2</sub> inside the shelter, starting from the 2200 value on the abscissa it is possible to intercept the curve of the rates and continuing horizontally toward the left ordinate to obtain the value of the ventilation rate inside the building. If we want to maintain, inside the shelter, a concentration of nearly 2200 ppm of CO<sub>2</sub>, it is possible to do the same on the graph, and get the ventilation rate that has to be guaranteed and that, in this specific case, is about 3000 m<sup>3</sup>/h, equal to 2.5 total air changes per hour. The research was divided in two tests.

**1<sup>st</sup> test;** it was planned for a 100 days duration; it was determined the total heat produced by the animals inside the shelter using the previous formulas and the required minimum ventilation rate, using the abacus, to guarantee an average quantity of carbonic dioxide equal to 1500-1600 ppm. To be able to improve ventilation rates it was installed a fan.

**2<sup>nd</sup> test:** climate conditions were evaluated by mean of temperature distribution in space and time and carbon dioxide in two given points inside the building.

*Detected micro – environmental parameters and used instruments.*

The first test has been planned for a 100 days duration (from 06/12/07 to 14/03/08). We have installed the temperature, the moisture and the light intensity detectors, data loggers HOB0, one inside the shelter, located in the same box of the CO<sub>2</sub> detector, and the other in a particular airy box outside the building. The data logger HOB0 were set to detect every hour temperature, moisture and light intensity. It was used the Drag r X-am 7000 with an infrared sensor to detect the carbonic dioxide. The instrument stores, every 10 minutes, the middle, the maximum and the minimum value. The detector, inside the shelter, was been placed in the middle of the feeding course (lane) up to 1 mt from the ground level. To be able to get a relationship between the traditional breeding adopted in the barn (natural ventilation managed by the breeder) and the experimental one (automatic forced ventilation by a fan), the period of test has been divided in sub periods of ten days, alternating the two types of management in the shelter. During all the search it was evaluated the productive level of the cows by the milk quantitative and qualitative production, often under the veterinary control. In the first period of the trial it was applied the theoretical calculation for the abacus related to experimental structure. The previous formulas were applied to determine the total heat produced by the animals inside the shelter. The total heat produced  $\Phi_{tot}$  is: 20139 W. The barn volume used for the air changes calculation is 964 m<sup>3</sup>. Using the abacus it was determined the required minimum ventilation rate, inside the refuge, to guarantee an average quantity of carbonic dioxide equal to 1500-1600 ppm. The minimum ventilation rate is 3000 m<sup>3</sup>/h that is about 3 total air changes per hour.

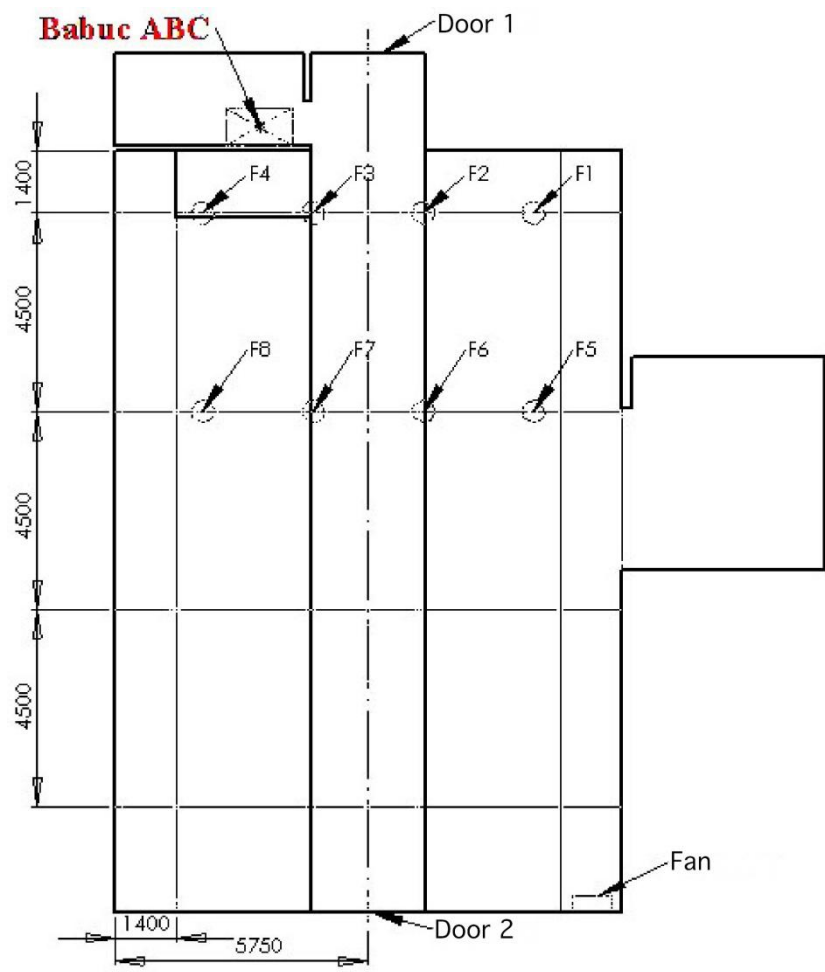
To be able to realize these ventilation rates it was installed a 17000 m<sup>3</sup>/h maximum rate fan. The used fan with such a big nominal rate gave the possibility to select conditions inside the shelter, because it was necessary also to use the same equipment for the summer ventilation, the seasonal period that needs greater air rate in comparison to the winter. Therefore, during the test, the fan has worked in timed mode. To determine the fan working periods, it was used a bigger air rate value (in comparison to the abacus value), 3200 m<sup>3</sup>/h rather than 3000 m<sup>3</sup>/h, to have a safety margin if the heat produced by the animals increases because of the weight or the number. After calculation the fan worked for 11.3 min/h. It was decided to divide the 11.3 minutes into eight cycles 100 s. each: therefore the fan worked for 100 s. and was in stand by for 440 s.

During the second test measurements were performed using a multi-channels data logger equipped with resistance temperature sensors for its distribution in a half side of the whole space of the tested livestock building and two temperature-CO<sub>2</sub> sensors located in the centre and in a low air-mixing zone of the building. For temperature acquisition the LastemBabuc ABC was used equipped with 24 thermo-resistors located in 8 horizontal positions and vertically arranged in groups of three. Moreover Onset Hobo located in two other points and equipped with the Telaire CO<sub>2</sub> detector were used to acquire both temperature and carbon dioxide concentration

The data was detected during:

- ∅ forced and natural ventilation since 05/11/2009 to 11/11/2009;
- ∅ natural ventilation since 31/12/2009 to 07/01/2010;
- ∅ natural ventilation with translated Hobo since 21/01/2010 to 29/01/2010.

Figure 1. Shelter plan with temperature sensor and CO<sub>2</sub> detector locations.





### 6.1.2 Broilers

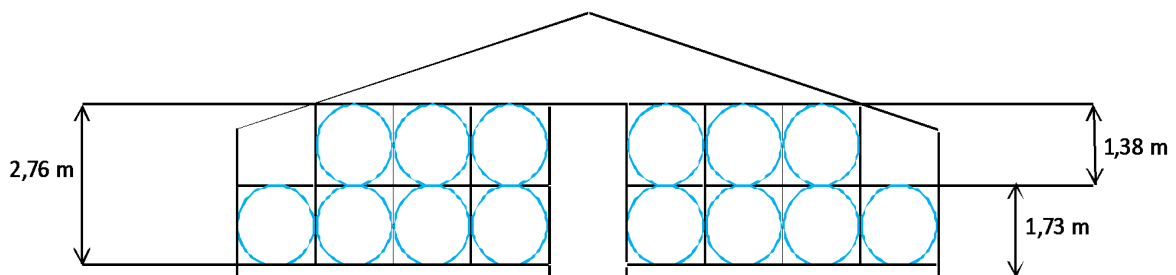
Experimental tests were carried out in an recently built building placed in S.Elia at Pianisi (CB Italy); it is able to breed 30000 heads/cycle (9500 females and 20500 males). Every cycle goes on 80 dayes: 60 to grow animals (60 for males and 35 for females) and 20 needed to the health rest.

The building size is 13,00 x 14,20 metres with an inner surface of 1874,40 m<sup>2</sup> and an height of 2,65 m. Inside the building 14 electric fans (fig.2), that can be operated one by one, supply the change of air. These fans are set in motion by a 1.0 CV three-phase engine and a fixed speed of 1400 revolution per minute (rev/min).

An impeller with 6 blades and a diameter of 1270 mm whirls at a nominal speed of 368 rev/min. Every fan has a maximum capacity of 36000 m<sup>3</sup>/h. The cooling or pad climate system is a water cooling that uses latent heath of the water evaporation. Water circulates inside the system through a pump, goes across the delivery pipes, located in the superior part of the system, and finally is sprayed into the deflector.

The air takes up the heath useful to water evaporation and, through a panel, gets cold and humid.

Figure 2 – Fans location



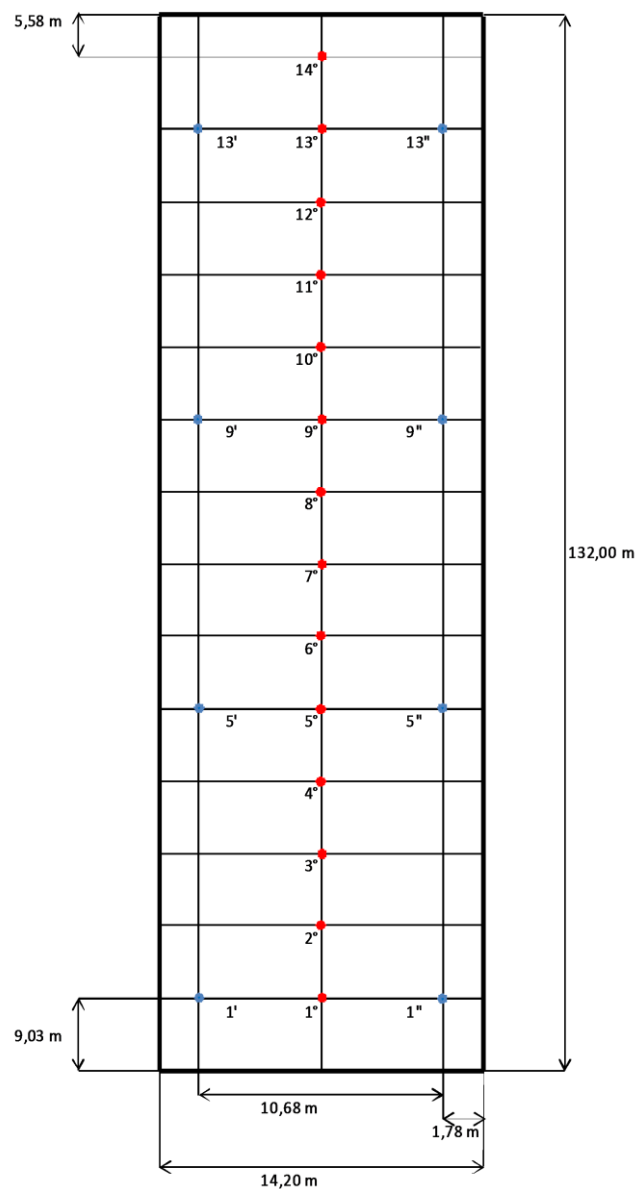
Two cooling systems are located on the sidewall of the warehouse near the service area: in this way the air entering through the cooling runs across the whole warehouse before being discharged outside. Each cooling is composed of two parts: the first one is longer and located in the middle of the warehouse. The overall length is 30 m. This division helps to restrict heating air during the transit inside the warehouse. The warehouse switches on the cooling at 27 °C and switches off at 24 °C. For the evaluation of microclimate conditions inside the building, temperature, humidity, air speed and carbon dioxide have been measured using a multichannel BABUC/A data logger. The tests have been carried out during the whole breeding cycle, every week before midday in summertime when the maximum air quantity is requested. Each test was carried out during June 2011 for a overall length of about 1 hour and 40 minutes each, with the storage of the mean values of the measured properties. The used feelers were:

- a psychrometer BSU 102 supplied with two thermometers: the first one, with a dry bulb, measures air temperature, the second one, which has a wet bulb and an hydrophilic sheath soaked in distilled water, measures the water temperature on contact with air. The psychrometer is provided with a little fan that sets up the testing at air velocity of 4 m/s.
- an anemometer BSV 101 with warm wire that measures the air velocity in every direction. The wire is platinum and is covered by a cylindrical bearing, let down during the testing so that the air flow is not obstructed. BABUC/A is able to calculate the number of the air changes, if the volume of the building is known.
- a infrared feeler BSO 103.1 to measure carbon dioxide with a range from 0 to 3000 ppm.

The building was divided in 14 vertical sections and 3 detections at the height of 20,100

and 150 cm have been taken in the middle part of each one. In the sections 1, 5, 9, 13 two more sets of testing on the lateral positions of the same sections have been carried out; so the values of the parameters at the different heights have been obtained for each set. The following schedule shows the points where the measuring have been taken inside the building (Fig. 3).

Figure 3 - detections points



## 6.2 Experimental device for pigs

The used tool was assembled using a cloth wrapped around a steel rod with a pivot welded on a right angled steel base (fig 4 and 5); the base, after a preliminary test, has been equipped with two wheels to easily move the tool. On the top side of the rod the following parts are assembled: a metallic plate (fig. 6) (with a hole in the center to allow the passage of the pivot, 3 holes for 3 screws to fix plate to the rod, 6 holes to stop the cloth at the desired length) and a hand grip, welded on the plate, to rewind the cloth after its use; on the bottom part of the rod a metallic plate with the same hole in the center and same holes for screws is fixed to hold up the cloth and to simplify unwinding/rewinding operations. The upper part of the pivot is threaded to allow to screw a locking tool to stop the cloth on required length (depending on the pen size), in correspondence of one of the 6 plates holes. The cloth is 20.0 m long and 1.20 m high, much more than animal's height to ensure animals could not see what it is happening beyond it; the selected color is grey to have continuity with color walls and a waterproof synthetic material was chosen as it is easy to clean. Finally, the initial side of the cloth is stiffened with another rod to keep the cloth stretched and with an adjustable clamp to fix it to the wall (fig.7).

Figure 4: cloth wrapped around a steel rod.



Figure 5 pivot welded on a steel base



Figure 6: metallic plates.



Figure 7: initial part with adjustable clamp.



Figure 8: a view of the realized device.



The trial was carried out in a pigsty built in the 80's years located in Bonefro (Molise region). The building size is 16,05 x 38,50 meters with an inner surface of 617,925 m<sup>2</sup>; inside building there are 19 pens of about 20 m<sup>2</sup> each one, 8 on one side and 11 on the other, divided by the handling course, and all provided of dejections area (defecation) on the back side. The handling course is 38,50m long × 1.00m wide with solid walls; pen's doors are used to open and close the pen and, at the same time, to stop animals along the handling course. Pigsty is able to breed 300 animals. Pigs arrived in the pigsty at approximately the same age (about 2 months) and the same weight (about 20 kg.) from a commercial unit and, therefore, had been subjected to normal (minimal) levels of interaction with humans. The trial involved pigs that were not familiar with the presence of others humans, excluding the breeder, and with going in and out of their pens. A total of 89 pigs, weighing 130-150 kg, were used in the experiment; pigs were moved from their pens to other free pens through the handling course. 48 animals, divided in 4 groups (group 1,2,3,and 4), were moved without use of the tool and 41, also divided in 4 groups (group 5,6,7 and 8), were moved using the tool. If pigs stopped moving they were gently pushed with a sorting panel (boar) to reinitiate movement and to drive them in the direction of the exit. A preliminary test was carried out to verify if the tool could be properly used to rapidly move pigs and to assess the correct methodology to be used for final tests evaluation. During this test several spontaneous stops have been observed through the handling course and the reasons were animal curiosity and breeding organization (e.g. pen's gates that allow pigs to watch inside): pigs stopped every time they found something new/different to observe or to sniff along the way like faeces, urines and/or other pigs. Thus, only the time used to exit animals from pen, the only place where the tool was used, was determined in order to correctly assess tool

capabilities. A camera was used to detect the time used by animals to go out of their pens, precisely the time between the beginning of the operations of animal moving and the release of each pig beyond the pen's door. When the tool has been used the time required to assemble it inside pens was not considered mainly for two reasons: first of all, the time required for its assembly is negligible, except for a few trials (not considered here) in which the tool was damaged or difficult to roll out; second main aim of the study was to evaluate the efficiency regardless of some constructive details which can be modified to adapt and optimize the tool to the various types of pens. Data obtained were first separated in:

- time of the first animal to exit the pen;
- global time required by all animals to leave the pen.

Global times were processed by non-parametric Kruskal-Wallis test to detect significant differences between groups as there are more than 5 samples in each group that is the accepted definition of "too small" (McDonald 2009)

## 7. Results and discussion

### 7.1 Evaluation of ventilation in cattle and broilers houses

#### 7.1.1 Cattle barn

The data, detected by HOBO data loggers, on indoor and outdoor temperature, relative humidity and CO<sub>2</sub> concentrations are in the plots shown in the figures 9, 10, 11.

Figure 9 – Temperature in the housing during the experimental period

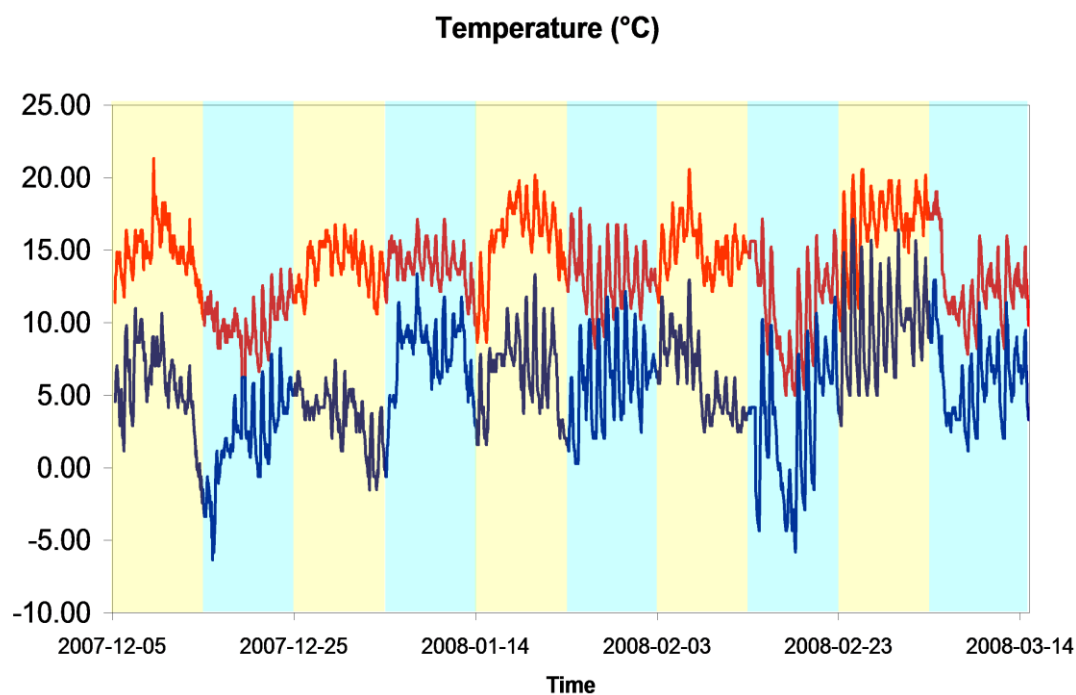




Figure 10 – Relative humidity in the housing during the experimental period

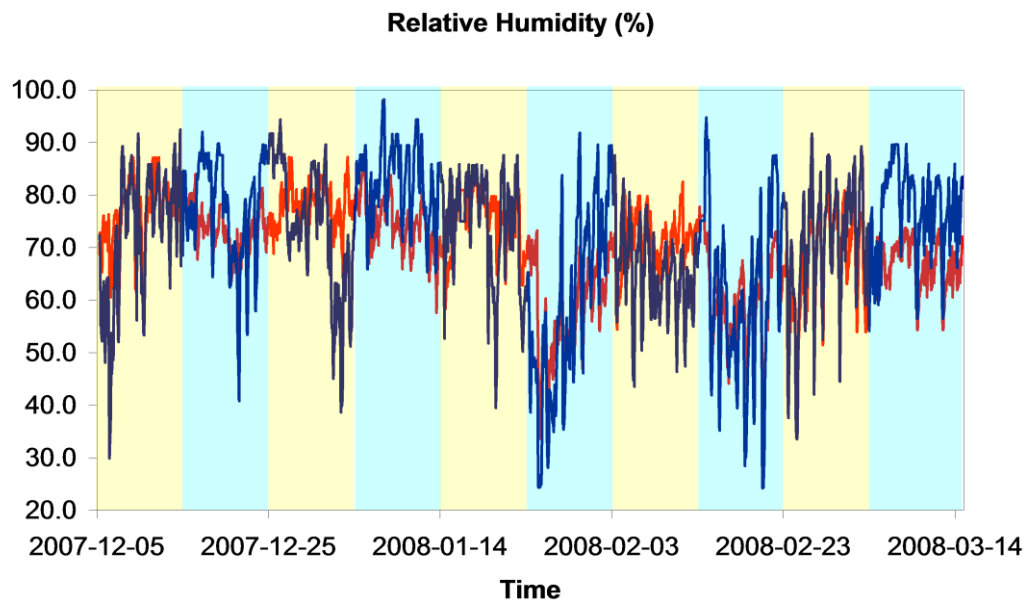
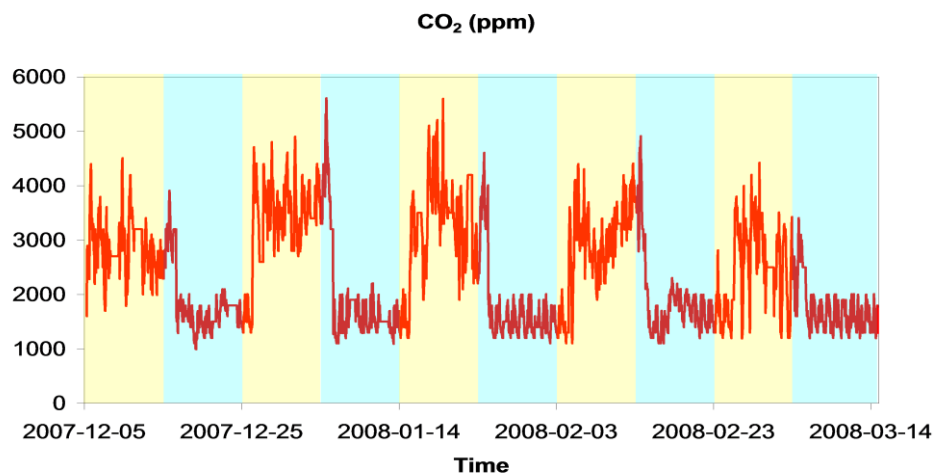


Figure 11 – CO<sub>2</sub> in the housing during the experimental period



The study of the data related to the indoor and outdoor temperatures (Fig. 9), shows that when the fan was turned off there was a 5-6°C difference among the two temperatures; this difference was lower when the fan was turned on. In the figure 10 it's clear that

during the turned off fan periods the inside moisture is higher, even if a bit, than outdoor one. When the fan is turned on we have the opposite situation. As a consequence of the examination of two more detailed graphs, according to previous results, it was observed that the inside moisture oscillations, in both cases, are smaller than the external. Moreover, with the turned on fan, the indoor humidity course seems more similar to the outdoor one, even if it is lower. As shown in figure 11, during the natural ventilation periods, the environmental carbonic dioxide concentration was extremely high, and we have even detected concentration higher than 5000 ppm. Moreover, the variation of concentration is very big, in fact, it was between 1600 ppm and 5300 ppm. During the forced ventilation periods, the range was extremely smaller, from 1000 to 2200 ppm, with daily average values of 1500 - 1600 ppm. These values are the attended ones, in fact, through the previous calculations on the theorized ventilation rates, our purpose was to guarantee a micro-environmental carbonic dioxide concentration of 1500- 1600 ppm. When the fan was turned on the range of carbonic dioxide concentration is extremely narrow instead of the natural ventilation. By the examination of the curve of the CO<sub>2</sub> hourly average values we can observe that at 9:00, 13:00, and 19:00 the carbonic dioxide concentration increases in comparison to the others times. This is due to the animals digestion that produces a great quantity of carbonic dioxide.

During the winter, abundant vapor condensations were observed; they were determined by the attainment of the dew point in several parts of the structure. During the first test the condensations were observed during the switched off fan periods, and, sometimes, it was also possible to see "the rain in the shelter"; with the turned on fan we never saw any condensations. These phenomena were quantified through some direct inspections on the surfaces of the shelter to appraise the wall temperature and to calculate, by the

psychrometric diagram, the dew point that depends on the temperature values and the air moisture. It was used the infrared thermometer Eurotron IR Tec P500. The surfaces interested in the detection were: North wall, South wall, West door, East door, glass of the first window on north side, internal side of the roof and third truss. Table 1 shows the instantaneous measurements of some parts of the structure to appraise the condensation phenomenon. As we can see we have the dew point only with the natural ventilation. With the forced ventilation, it is difficult to have the dew point and so, also "the rain effect" inside the shelter, an extremely deleterious phenomenon for the constructions, for the animals inside and for the workers.

Table 1 – Infrared thermometer measurement results

Date	Hour	N. Wall	S. Wall	W. Door	E. Door	Window Glass	Roof	Truss	D. Point
13/2	20.30	12.7	13.5	7.4	7.5	6.5	11.4	12.7	9.95
14/2	7.30	9	11	5.6	6	5.2	10.4	10.7	8.54
14/2	12.30	10.5	14.4	8.6	11.5	11	15.9	15.1	7.23
4/2	19.30	10.2	13.5	5.9	7.2	6.5	9.2	10.9	4.52
20/2	11.15	8.7	11.3	7.1	13.5	9.5	15.5	14.7	5.4
23/2	18.30	14.7	17.6	10.9	12.2	11.3	14.2	15.9	7.83
26/2	7.15	13.3	15.4	9	10.9	10.5	13.8	15.1	12.15
29/2	8	14.8	15.9	10.5	17.1	11.5	14.4	15.3	11.8
29/2	19	16.8	19.9	12.8	14.9	13.7	16.6	17.9	12.63
01/3	7.15	15.2	17.3	11	13	12.4	15.3	15.9	12.3
05/3	19.30	11.5	12.5	6.4	7.4	6.6	9.6	11	6.26
10/3	12.30	10.9	12.8	8.6	12.7	10.5	12.9	13.3	6.68
14/3	17.15	15.5	19.7	13.8	15.8	14.7	17.3	18.8	7.14

In the table, the yellow series show the turned on fan periods, the others the natural ventilation. The red values are under the dew point and therefore the water contained in the air, condenses.

Measurement results on the climate conditions by mean of temperature distribution in

space and time and carbon dioxide in two given points inside the building are showed in terms of a temperature distribution graph (Fig. 12) in different ventilation conditions pointing out space-time variations. These data have been then related to CO<sub>2</sub> measurements in order to highlight not so good air mixing and renewing affecting wellness of animals housed inside. The forced ventilation system was automatically activated if the temperature went under the 22°C. The temperature was detected by a thermostat located near the central Hobo. The higher early-morning temperature is due to the closed doors during night time that don't allow the air change in the breeding, while the minimum temperature is due to the opened doors for the foods load and unloading.

Figure 12. Temperature in position F7.

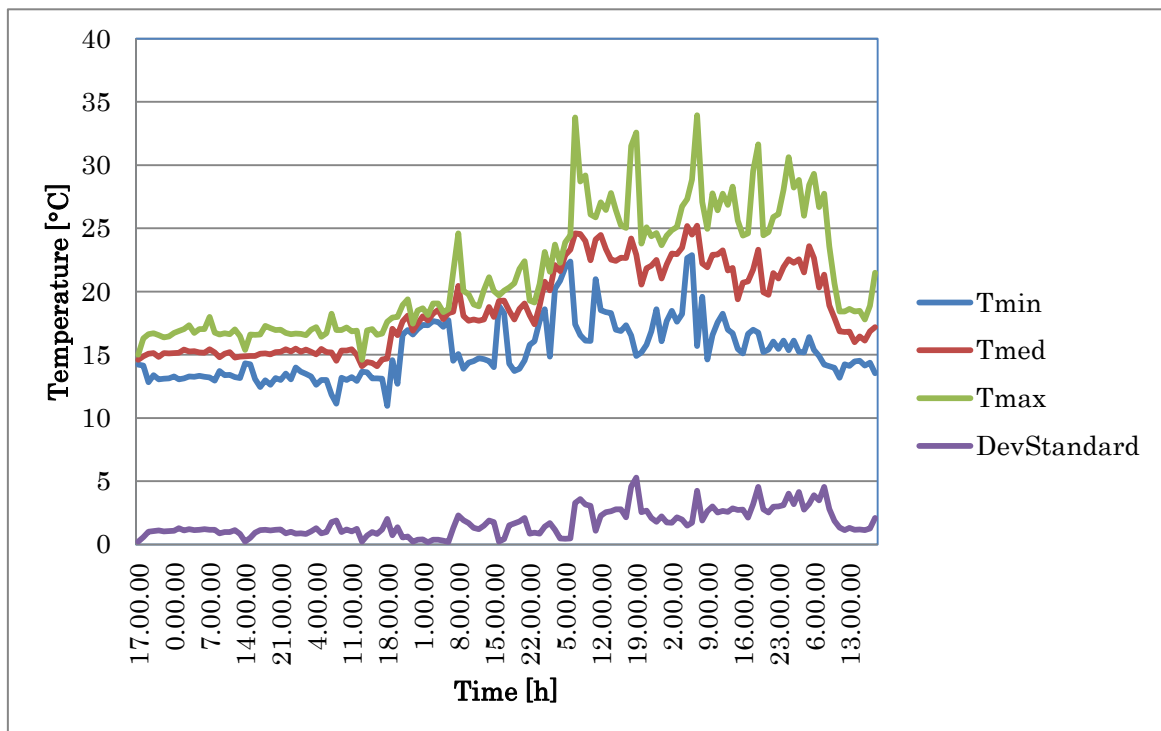


Figure 12 shows the temperature inside the breeding detected by the data logger Babuc

in position F7: sampling time was 1s and minimum, mean and maximum values are calculated during one minute and over the group of three thermo-resistors for each plotted value. During the first three days an almost constant temperature can be observed as forced ventilation was used, then very large variations occur as the ventilation system was stopped due to technical problems in fan equipment.

Figure 13. Carbon dioxide concentrations (Lateral position).

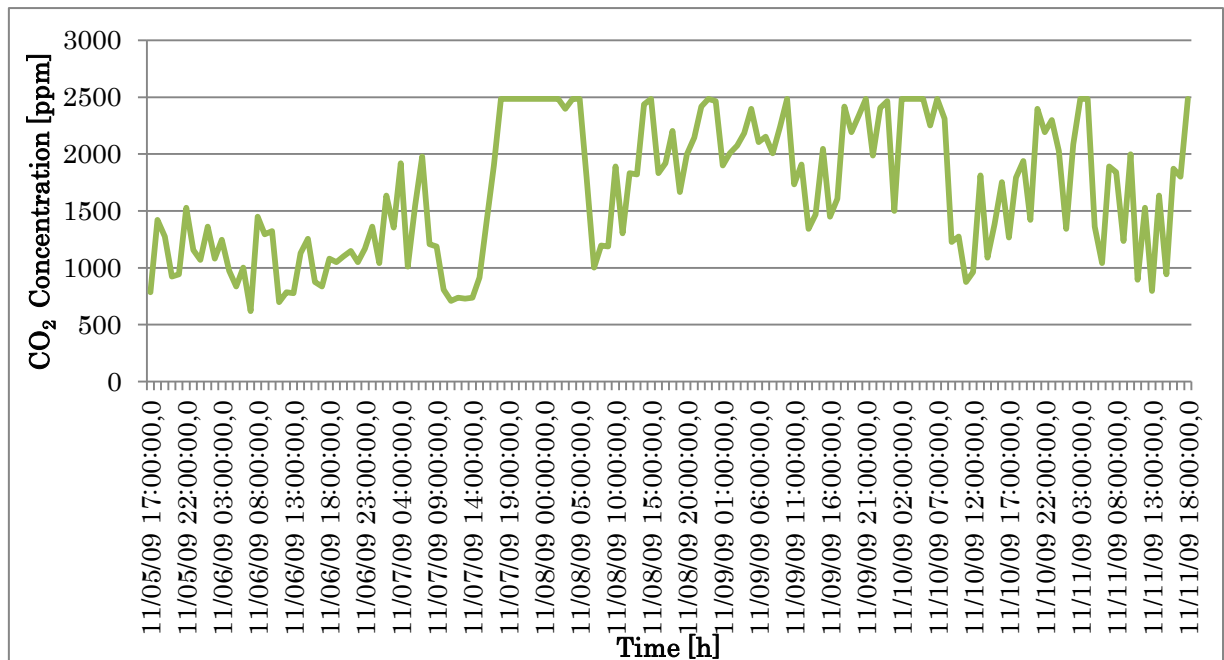
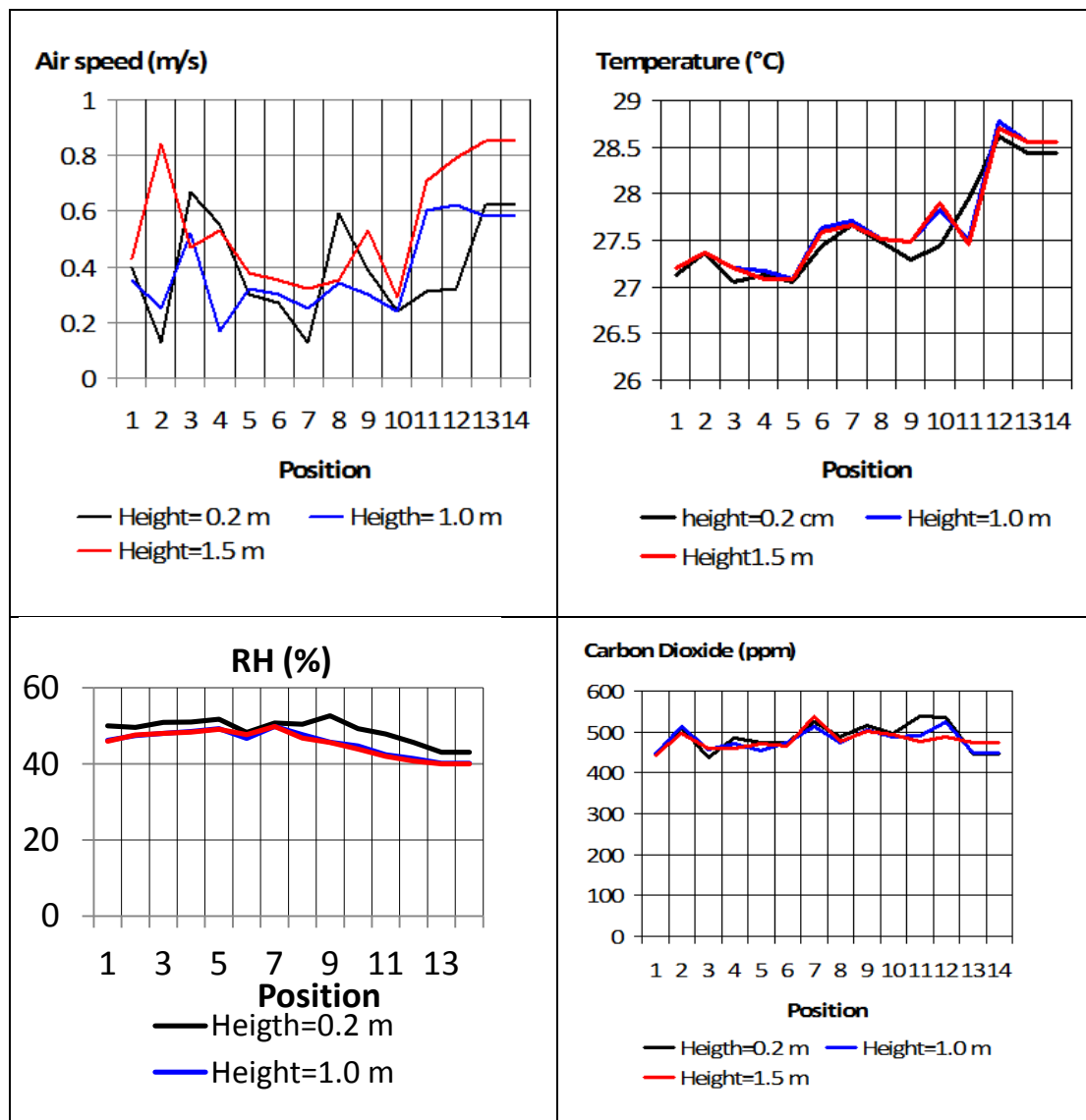


Fig. 13 shows the carbon dioxide concentration trend. It is clear that during the forced ventilation period (first three days), the values never exceed 2485 ppm which is the storing limit of the Onset Hobo. Greatest values (2485 ppm) can be observed after milking (20:00) and in the first hours of the morning (7:00) and in both cases only during the turning off fan period. This could even mean that the maximum level allowed for animals' health is likely to be exceeded in these conditions.

### 7.1.2 Broilers House

The measurements of the environmental parameters and also the number and the location of the fans have been registered in function of each test. The following graphs (Fig.14) obtained allows a first evaluation of the microclimate in the farm.

Figure 14 – Microclimate parameters measurements.



The graphs show the parameters trend considering the variation of height and length of the farm building. The air velocity mean value is higher at 150 cm from the floor with corresponding higher mean values of Humidity and Carbon Dioxide measured at 20 cm from the floor (animals height). The temperature values are higher at 100 and 150 cm from the floor respect to the values measured at 20 cm from the floor. The temperature values increase and the Relative Humidity values decrease moving towards the end of the building because of the presence of animals that heat the air. The Carbon Dioxide concentration was constant during the air flow. The Carbon Dioxide rate can be evaluated by mean of the following equation (rate of Carbon Dioxide which flows through a generic section in time unit):

$$\dot{m}_{CO_2} = \omega_{CO_2} \rho_a v_a A$$

where:

$\dot{m}_{CO_2}$  = Carbon Dioxide mass rate (mg/s),

$\omega_{CO_2}$  = Carbon Dioxide concentration (ppm: mg (CO<sub>2</sub>) /kg (dry air)),

$\rho_a$  = air density (kg/m<sup>3</sup>),

A (section) = area of the transverse section (m<sup>2</sup>) in the point of measure,

$v_a$  (air) = air velocity (m/s).

Figure 15 – Amount of carbon dioxide delivered across each measurement point

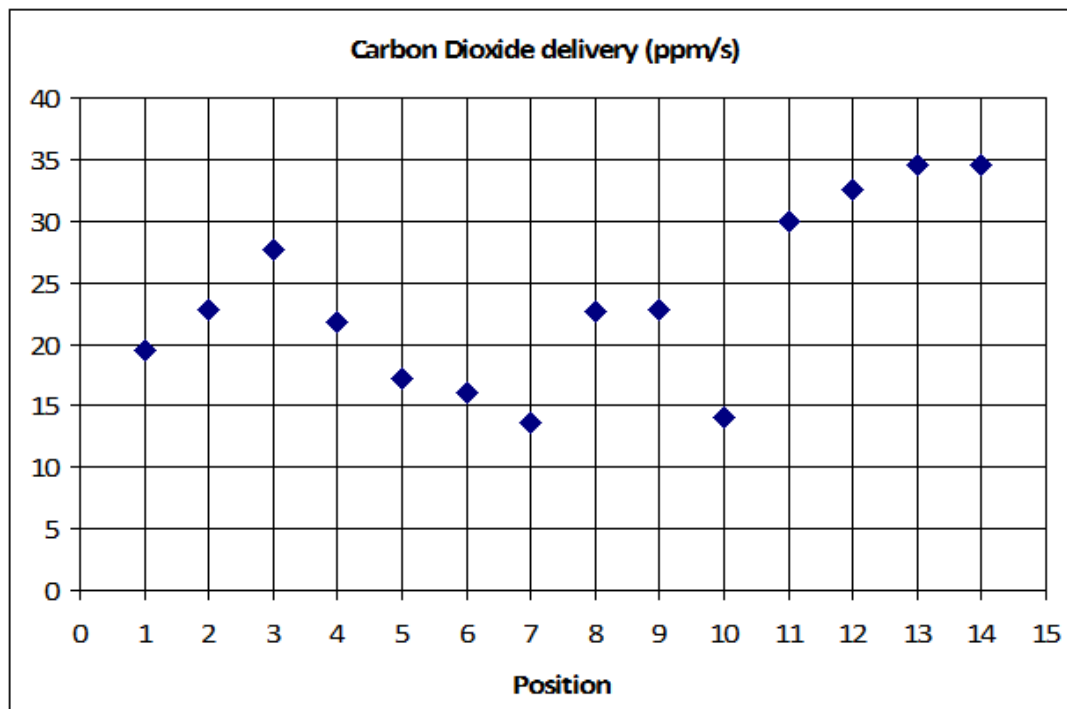


Figure 15 shows the variation of the Carbon Dioxide rate along the air flow in the farm. The values used for the Carbon Dioxide concentration and for the air velocity were obtained from the average of the corresponding values measured at three different heights. The graph is subdivided in three parts:

- a first phase of CO<sub>2</sub> increase, due to the animals presence without a further air change,
- a second phase of CO<sub>2</sub> rate decrease, during the air change and due to the cooling (in the first part of the farm(1/3)),
- a third phase of CO<sub>2</sub> increase (during the second inactive cooling).

The CO<sub>2</sub> increases linearly during the tests and shows a quite high gradient.

The carried out tests showed a good quality of the air in the farm related with the



Carbon Dioxide and the Relative Humidity. The fans put in are able to extract a high air rate causing, in some cases, a sudden variation of temperature. The values of the measured parameters, except for the temperature, are mainly included in the range considered as optimal for the welfare of the animals. The mean value of the CO<sub>2</sub> were calculated at three height of measure, to determine the CO<sub>2</sub> rate. Tests were carried out during summer when the worse conditions of microclimate are evaluated in the farm. In particular:

- The measured Carbon Dioxide never overcame the value of 800 ppm, also when the animals generated a higher amount of the gas. The low concentration of Carbon Dioxide and the low Relative Humidity, both due to good ventilation, make us to think that the concentration of other polluting substances in the farm is low also in absence of specific monitoring.
- The temperatures, before cooling, always were not higher than 3 °C respect to the outside temperature. The inside temperature, during cooling, lowered of 3 – 4 °C respect to the outside temperature. The temperature values measured during cooling tests ranged between 25 – 30°C, too high compared to that ones considered as optimal for the boiler growth up (range 20-21°C).
- The Relative Humidity values measured during the tests ranged between 40 and 60%. During the cooling some R.H. values are lower than that ones considered as optimal (range 60-70%) for animals. A low Humidity makes the temperature perceived by the animal not too high, partially compensating the highest tested temperature values.

## 7.2 Experimental device for pigs

First of all groups for which the tool was not used are examined. In particular in table 2 the time of the first animal exiting the pen is highlighted (bold character) for each of the four groups. As can be easily viewed pigs require similar times to begin to go out of pens, excluding those of group 2 that showed significant difference when compared to groups 1, 3 and 4. Animals of group 2, in fact, initially went in the dejections area and then stayed in the corner for some seconds only after 65 s they started to go out of pen; the others pigs moved without tool (groups 1, 3 and 4) required on average less time (about 38 s) to start to go out. The total time required by each group of animals moved without tool to leave the pen cover a wide range of values (from 21 to 125 s). Animals moved using the tool, excluding group 6, began to go out of pens more quickly than the others (Table 3, bold character as for table 2). Group 5 and 8 show similar behavior while group 6 and 7 were respectively slower and faster than previous. Anyway, all groups showed significant difference of the total time required by each group to go out of pen (between 10 and 17 s after the first animal goes out), when compared with pigs moved without tool. Pigs of group 6 required more time as they were quite scared and, at the start, they went all together in the dejections area of pen. Moreover, as detected times of animals of group 6 showed times to go out of pen similar to times required by pigs moved without tool, these values were compared with those of group 1,3 and 4; statistical analysis showed again significant difference ( $P<0.001$ ) between group 6 and groups 1, 3, 4. Group 7 showed the smallest values both for starting exit and total time required. Moreover, considering that the number of animals of group 7 was the same of animals of group 3, Times of these two groups can be compared highlighting the efficiency of tool.

Table 2– Time required by each animal moved without tool and divided in four groups.

Animal No.	Times of group 1 <sup>a</sup> (s)		Times of group 2 <sup>b</sup> (s)		Times of group 3 <sup>a</sup> (s)		Times of group 4 <sup>a</sup> (s)	
	Total	Relative	Total	Relative	Total	Relative	Total	Relative
1	<b>41</b>	0	<b>65</b>	0	<b>38</b>	0	<b>34</b>	0
2	42	1	66	1	40	2	35	1
3	45	4	81	16	41	3	39	5
4	45	4	88	23	42	4	39	5
5	45	4	88	23	51	13	40	6
6	46	5	92	27	58	20	45	11
7	47	6	97	32	59	21	46	12
8	47	6	106	41			47	13
9	48	7	106	41			59	25
10	48	7	118	53			60	26
11	49	8	118	53			74	40
12	49	8	120	55			91	57
13	56	15	155	90				
14	57	16	190	125				
15	76	35						

Table 3– Time required by each animal moved using the tool and divided in four groups.

Animal No.	Times of group 5 <sup>c</sup> (s)		Times of group 6 <sup>d</sup> (s)		Times of group 7 <sup>e</sup> (s)		Times of group 8 <sup>c</sup> (s)	
	Total	Relative	Total	Relative	Total	Relative	Total	Relative
1	<b>21</b>	0	<b>34</b>	0	<b>16</b>	0	<b>19</b>	0
2	22	1	34	0	16	0	19	0
3	22	1	35	1	17	1	20	1
4	23	2	36	2	17	1	21	2
5	23	2	36	2	18	2	22	3
6	23	2	37	3	20	4	27	8
7	25	4	37	3	26	10	28	9
8	25	4	39	5			28	9
9	26	5	40	6			29	10
10	26	5	40	6			33	14
11	38	17	43	9				
12			44	10				
13			46	12				

## **8. Conclusions**

### **8.1 Evaluation of ventilation in cattle and broilers houses**

#### **8.1.1 Cattle barn**

The carried out research has allowed to show the potential application of the calculation methodologies and of the ventilation systems plan for the micro-environmental conditioning of the refuges. The control of the real ventilation obtained through the detection of the carbonic dioxide concentration and the direct reading of the ventilation rate on the abacus is an applicable result to every livestock farm. In this specific case the data confirmed the validity of the calculation model. The work carried out gives the possibility to get information related to the trend of some parameters helping to determinate the assess of animals breeding conditions. By the analysis of environmental parameters it is possible to assert that with forced ventilation, during the autumn, the variability of inside temperatures is very low and their stratification in plant is homogeneous. At the opposite during the natural ventilation, in the autumn season, the inside temperature is higher with differences of over 5°C. Continuous monitoring of micro-environmental parameters could be a tool used by the breeders to improve cowshed management.

#### **8.1.2 Broilers house**

The research showed that some conditions in the farm, regarding the environmental control, could be improved trough a better control of the ventilation.

- A more homogeneous condition of temperature and R.H. in the farm could be

reached working on smoother ventilation and testing the cooling surface.

- The optimization of the ventilation system could be done changing the ON-OFF working with the VFD working. The VFD system, thanks to the opportunity to control the speed, guarantees a better ventilation control and a higher energy saving.

## **8.2 Experimental device for pigs**

In this study we have investigated an appropriate handling method that allowed us to plan and assemble a particular tool, to be used inside the pens, to support the pigs during the exit; we used the tool to close the corner opposite to the door, replacing it to the walls. If we want to better understand pigs behavior during transfers, first of all we have to see the way by pig's point of view; the observer looks at about 170 cm from ground while pigs look at about 45 cm, therefore the passageway, for example, for man is only a small construction inside the main building, but for animal is the main construction; on the other side the pen's door, when opened, is only a little different part of the wall and animals, during handling/transfer procedures, often do not consider it and, moreover, they go toward the angle where they felt more protected. The use of the tool during the trial showed a positive effect on the time requested by pigs to go out of pens; in fact, when the tool was used fewer stops were observed. Moreover, the tool requires the presence of one worker only in order to move the animals. Consequently, the animals are calmer and no squirrels/vocalizations have been recorded during the experimentation; that is why they did not require of any external stimuli for going on and, additionally, they were less dangerous for workers also. Finally, the need of one worker only is an important factor even for the economic efficiency.

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