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TECHNICAL NOTE

EVALUATION OF PM_{10} EMISSION FROM FARROWING AND FATTENING SWINE ROOMS BY CONTINUOUS ON-LINE MEASUREMENTS

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1. Introduction

Agriculture and environment are closely connected and interacting: agriculture, in general, is a source of various materials which can affect all environmental compartments such as soil, water, air, plants and individuals [1]. In particular, dust concentrations in livestock houses and aerial dust emissions from animal husbandry, introduced into the environment by a ventilation system, may significantly damage the health and welfare of men and animals. These pollutants can affect the respiratory health of people living close to livestock enterprises. Such compounds as dust, micro organisms and endotoxins, also addressed as bio aerosols, are especially reputed to play an active role in the prevalence of respiratory affections in receptive humans as shown by occupational health reports on farm workers in animal houses [2]. The concentration of dust in animal houses is variable and depends mostly on the animal species, stocking density and behaviour [3]. Environmental enrichment and lighting strategy influence animal activity and consequently also dust concentrations and emissions.

Not all dust particles are equally harmful. Particle size is fundamentally important when considering dust harmfulness, irrespective of whether the inhaled particle is a grain of dust or bacterium [4].

Bio aerosols are defined as breathable, thoracic or respirable depending on their aerodynamic diameter which determines the depth of penetration in the respiratory tract [5] (ISO 7708). The smaller the particle diameter, the deeper it will be deposited in the respiratory tract .

In animal husbandry, dust particles, originating from the animal itself, fodder, litter and feed, contain up to 85 % of organic matter [6]. Inorganic material, gases, bacteria and viable endotoxins which are fixed to the surface of dust particles are potentially hazardous agents [7]. Because they are minute they remain suspended in the air for longer periods of time [4]. More than 80% of the airborne micro organisms found in cattle, pig, and poultry housing are staphylococci and streptococci, fungi, and moulds. Yeasts can exceed 1% and coli-type bacteria about 0.5% of the total aerobic count. Dust concentrations in animal buildings are significantly higher in pig and poultry housing than in cattle housing [8].

In animal buildings, feed contributes from 80 to 90% of total dust, litter from 55 to 68%, animal surface contact with the floor or other animals 2 to 12% and faeces from 2 to 8% [9]. In pig houses dry feeding dramatically increases dust levels and the amount of airborne dust fluctuates greatly both during the day and according to the type of animal [10]. All these particles are emitted to the external environment through outlets and ventilation exhaust systems.

A great amount of past literature is concerned with dust concentrations inside animal buildings, but little information is currently available on dust emission.

It is thus difficult, if not impossible, to evaluate dust emission into the atmosphere based on the reported dust concentration values, as there is no available information on many significant variables, like ventilation rates, microclimatic conditions, dust concentrations in the external environment etc.

Current studies conducted by the CEPMEIP Steering Group (Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance, [11].) now provide new information on dust emission into the environment.

For this purpose, we aimed to measure the emission factor of PM_{10} in a swine house in order to evaluate the real contribution of mechanically ventilated animal husbandries to PM_{10} environmental pollution in our region.

Moreover, this work had the aim to evaluate if the vacuum system, considered as a BAT (Best Available Technique) manure removal system, could improve dust emission containment as well as ammonia.

We began by investigating a fattening room and a farrowing room.

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2. Materials and methods

The study involved monitoring PM_{10} concentrations in a farrowing room and in a fattening room (first phase, from 30 to 100 kg of live weight) of a mechanically ventilated piggery, with vacuum system, in order to evaluate the contribution of two single piggery compartments to PM_{10} concentrations in dust emissions into the atmosphere.

PM_{10} was also monitored outside the room, to obtain an emission factor, "subtracting" the amount of dust coming from outside.

The selected piggery had a ventilation control system which used a free running impeller to continuously monitor environmental and management parameters in the real time, with an accuracy of 10 % [12], described below.

Accurate pollutant emission estimations depend on reliable and accurate measurements of the ventilation flow rate and pollutant concentrations. The field survey part of the trial involved monitoring ventilation using a full-size anemometer (Fancom, FMS).

This type of ventilation rate sensor consists of a free running impeller that receives energy from air movement and transforms it into rotational energy (Fig. 1 and 2).

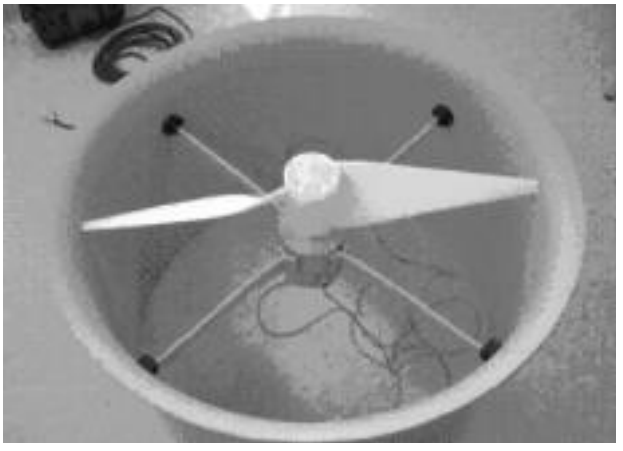

Fig. 1 - Photo of the anemometer.

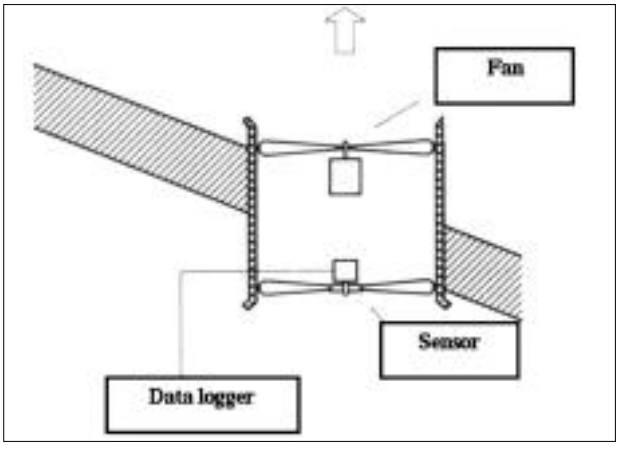

Fig. 2 - Scheme of the anemometer.

It was installed in the ventilation chimney and covered the whole exhaust section.

The relationship between the rotational speed and the flow rate for the newly developed turbinemeter is highly linear ($R^2 = 0.99$; [12]). This implies a satisfactorily accurate flow rate measurement which is almost independent of prevailing pressure differences [12]. The available diameters range from 35 to 81 cm.

As the instrument is highly accurate it only requires a single calibration. Its accuracy is less than 60 m^3h^{-1} in a measurement range from 200-5000 m^3h^{-1} and with a pressure difference of 0-120 Pa.

PM_{10} concentration was continuously monitored by a sampler (HAZ DUST- EPAM 5000, Fig. 3) which combines the traditional gravimetric technique with "near forward light scattering" technology (Fig. 4).

velocity, measured by a hot wire anemometer (LSI instruments, BSV 101) was less than 0.05 m s^{-1}.

Samplers were located inside the room, where air The Haz -Dust, based on the criterion of near-forward light scattering of infrared radiation, is able to instantly and continuously measure the concentration of airborne dust particles, in mgm^{-3}.

This principle uses an infrared light source positioned at a 90° angle to a photo detector.

As the airborne particles enter the infrared beam, they scatter the light. The amount of light received by the photo detector is directly proportional to the aerosol concentration. A unique signal processes internally and compensates for noise and drift, resulting in high resolution, low detection limits and excellent base line stability.

To sample PM_{10}, the inlet system of the instrument was configured and the relative PM_{10} impactor was placed on the instrument to pre-select particulate matter size.

The ventilation rate (air volumes extracted by ventilation system per unit of time), internal and external temperature and relative humidity, PM_{10} concentration both inside and outside the room (to monitor dust coming from the external environment) were all monitored in each room at one minute intervals.

Fig. 3 - The sampler EPAM-5000.

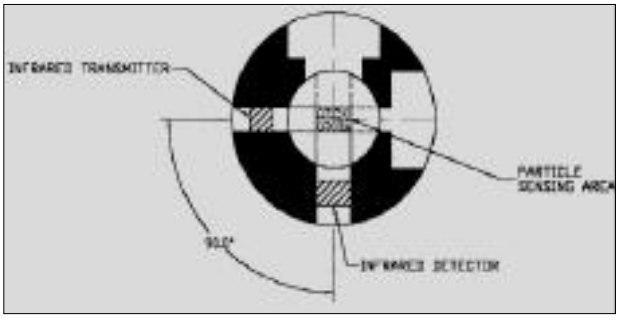

Fig. 4 - Diagram of "near-forward light scattering" principle utilized by Haz-Dust.EPAM 5000.

Variations in the weight and number of animals, the type of feed and feeding time were also collected. throughout the study.

Two rooms in a piggery 20 km West from Milan, North Italy, were used for the experiment.

Farrowing room

The farrowing room measured 10.95 by 17.30 metres (see Fig. 5). 30 sows were lodged in 3 -5 days before farrowing to 21 days after delivery.

Lateral walls were 3.75 m high with a 30% roof slope.

The maximum ventilation rate of air extraction from the two chimneys was respectively 7666 m^3 h^{-1} for chimney one and 7566 m^3 h^{-1} for chimney two (Fig. 5).

The room was relatively "closed": windows were totally closed to prevent direct air exchange with the external environment. Air entered the room from a tunnel under the building: the air initially spread into the corridor before entering the room from the upper side of the stable through a perforated PVC sheet ceiling. This method limited thermal variations and guaranteed both sows and piglets a comfortable and climatically controlled environment in the parturition period.

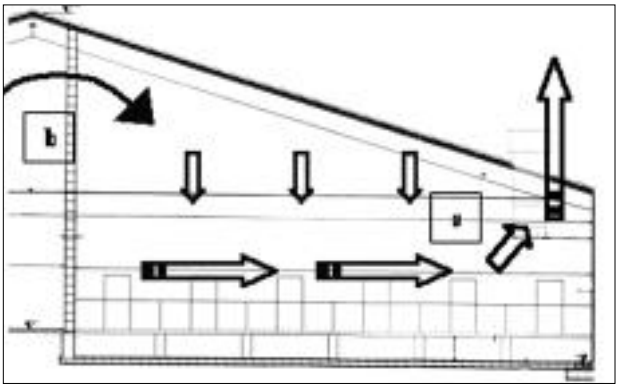

Fig. 6 - Cross section of the farrowing room.

Two sampling instruments were placed in the farrowing room, one inside the room near the exhaust chimney ("a" in Fig. 6), and the other in the corridor where the ventilation rate would not affect measurements (air velocity lesser than 0.05m/s; "b" in Fig. 6).

The adult animals were fed liquid feed (three times a day), while suckling piglets were fed with a dry feed (pre-starter) contained in portable fodder-troughs from the first week of life.

The reproduction cycle (28 days) was followed by the so-called "all-in all-out" period (15 days). In this period the room was totally cleaned (high pressure washing) and disinfected, from floor to ceiling (to eliminate any dust trapped in the PVC sheet). Two samplers were placed in the room, one where air velocity, measured by a hot wire anemometer (LSI instruments, BSV 101) was under 0.05 m s^{-1} and the other in the corridor to measure incoming dust.

Fattening room

349 pigs (initial mean LW= 26-30 kg and final LW= 90-100kg) were lodged in the fattening room at the beginning of May 2004: the fattening cycle ended

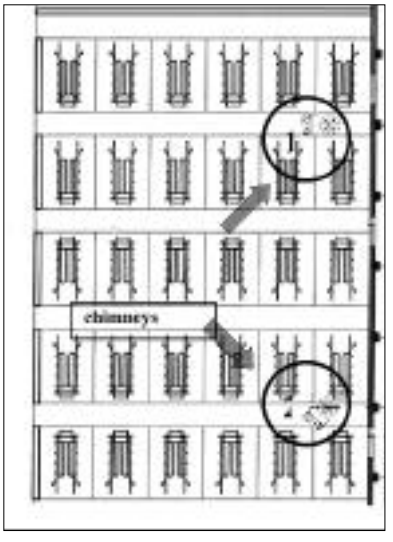

Fig. 5 - Top view of the farrowing room.

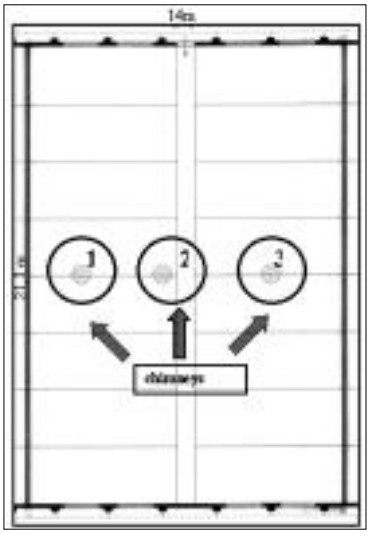

Fig. 7 - Top view of the fattening room.

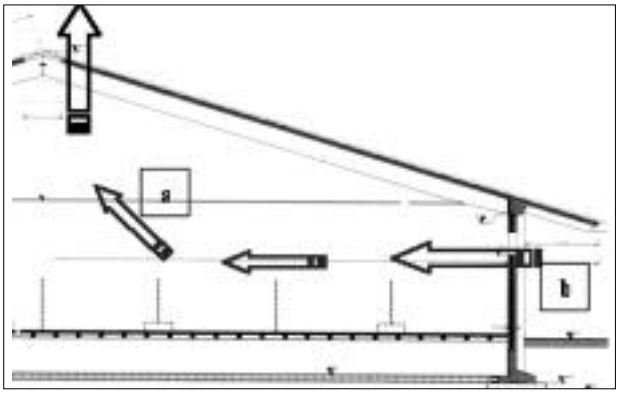

Fig. 8 - Cross section of the fattening room.

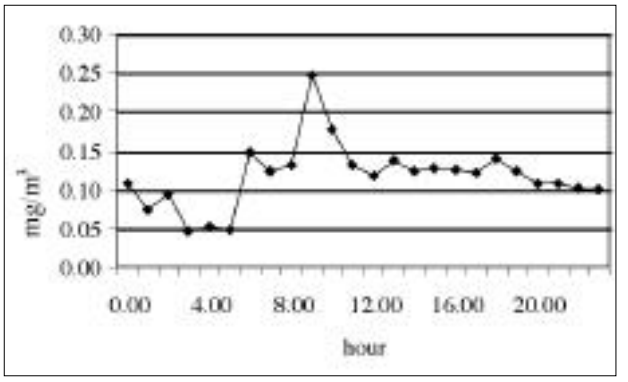

Fig. 9 - Example of diurnal pattern of PM_{10} mean concentration per hour in the farrowing room.

after 100 days. The room, measured 14 × 21.10 m and was divided into 16 boxes with a totally slatted floor (see Fig. 7).

Pigs were administered liquid feed 4 times a day. 30 minutes after feeding time and they were also supplied with drinking water, to flush out and clean the pipeline. The maximum ventilation rate for the three chimneys (see Fig. 7) was respectively 16352 m^3/h for chimney one and 16207 m^3/h for chimneys two and three. Two particulate matter sampling instruments were placed inside the building, one near the exhaust chimney, where the ventilation rate would not affect measurements (air velocity under 0.05m/s; "a" in Fig. 8) and the other outside the room, near the inlet, to measure incoming PM_{10} ("b" in Fig. 8).

3. Results and discussion

Farrowing room

Farrowing room measurements were taken in springtime 2004 and the mean values of recorded parameters throughout the experimental period are given in Table 1. The thirty sows delivered a total of 322, alive until weaning, piglets. The total live weight in the room was estimated as 6000 kg and 7300 kg at the end of the farrowing cycle.

The mean concentration of PM_{10} per hour during the day is given in Figure 9.

PM_{10} concentration in the facility reached a maximum at around 9.00 in the morning when the farm operators carried out inspections.

The mean PM_{10} concentration, subtracted from the PM_{10} coming from outside, was 85.8 $\mu m\ m^{-3}$. By multiplying the mean particulate matter concentration (85.8 $\mu m\ m^{-3}$) by the mean ventilation rate (5204 m^3h^{-1}) we can calculate that a mean value of 0.447 g/h of PM_{10}.was emitted from the two chimneys As far as animals are concerned, 6.8 mg $head^{-1}\ h^{-1}$ were emitted from the farrowing room (head=100 kg LW).

Fattening room

Table 2 gives the mean values, standard deviation, minimum and maximum values of variables throughout the observation period in the fattening room.

Figure 10 gives a graph of PM_{10} trends in the room for one trial day.

PM_{10} concentrations in the facility reached maximum values at feeding times, (at 09.30, around 12.00, 16.30, 19.30 and 23.30) and these peaks are particularly high in the afternoon, in correspondence more than with the effective feed release, with lights switched on. In fact it was observed that pigs usually began to move before actual feeding as they are aware

Parameter	Means	SD
External Temperature °C	13	4,8
External Relative Humidity %	61	15.9
Temperature of tunnel under the building °C	12	3.6
Room Temperature °C	23	1,4
Room Relative Humidity %	49	5,0
Air Volumes (m^3h^{-1}) extracted from the room	5204	1282

TABLE 1 - Mean values, standard deviation, minimum and maximum values of variables during observation period in the farrowing room.

Parameter	Means	SD
External Temperature °C	24	3.9
External Relative Humidity %	55	16.4
Angle of inlets opening	57	15.7
Room Temperature °C	27	1.9
Room Relative Humidity %	57	8.6
Air Volumes (m^3h^{-1}) extracted from the room	30691	2937

TABLE 2 - Mean values, standard deviation, minimum and maximum values of variables throughout the observation period in the fattening room

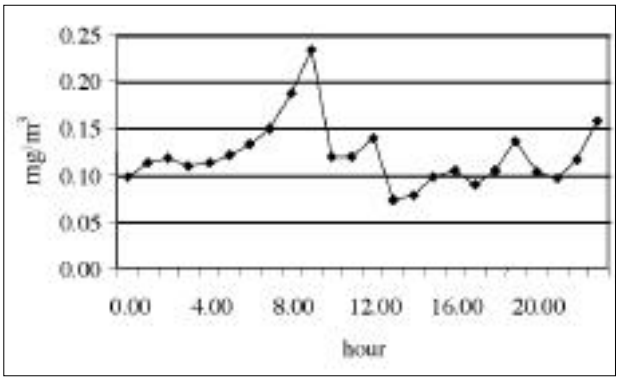

Fig. 10- Example of diurnal pattern of mean PM_{10} concentration/ hour in the fattening room.

of pipe vibration caused by feed circulating in the system and being administered in other rooms.

The mean PM_{10} concentration, subtracted from PM_{10} coming from outside, measured 82.1 _m/m^3.

By thus multiplying the mean particulate matter concentration (82.1 μm m^{-3}) by the mean ventilation rate (30691 m^3 h^{-1}) we get PM_{10} emission of 2.52 g/h or, in other words, of 12.03 mg $head^{-1}$ h^{-1}(head=100 kg LW).

There are considerable differences between the emission factors (PM_{10}) given for swine breeding of the same animal species in literature.

Moreover, available references related to particulate matter emission factors mainly result from studies carried out in Northern Europe.

Sometimes, comparisons with other studies cannot be made either due to the different measurement units used [13] or because of a lack of information on building ventilation rates.

It is thus clear that the reported emission factors are quite different: emission factors available for swine production from CEPMEIP and RAINS [14] inventories are similar, while data from Berdowsky [15] and RAINS [16] are plainly higher or lower.

In particular, Berdowsky et al. [15] estimated a high value of PM_{10} emission (251 mg $head^{-1}$ h^{-1}), while CEPMEIP [11], which bases its inventory on Dutch data, estimated a 40.41 mg $head^{-1}$ h^{-1} PM_{10} emission factor for swine husbandry.

Values from the studies conducted by ENEA ([17], 2002) with 13.69 mg $head^{-1}$ h^{-1}, by RAINS [15] with 4.91 mg $head^{-1}$ h^{-1}, and Fabbri et al. [18] with 7.38-57.2 mg $head^{-1}$ h^{-1} for pigs on slatted floor (no BAT) and 35.56-61.94 mg $head^{-1}$ h^{-1} for pigs on vacuum system (BAT) are more similar to those obtained in our study.

It has to be stressed that hardly any of the studies give indications on the piggery compartment studied, easily leading to inadequate emission factors in inventories. Such data does not consider the fact that dust concentration and emission into the atmosphere varies with many factors like different animal weight classes, the producing phase, feeding and housing type.

In particular, the experimental study that we carried out in collaboration with CRPA (Centro Ricerche Produzioni Animali di Reggio Emilia; [18] in 2004, showed that the manure removal system can also affect the amount of PM_{10} emitted from a swine building. This work highlights that the vacuum system, considered as a BAT (Best available Technique) thanks to low ammonia emissions, cannot be defined as a BAT for dust emission containment, whilst slatted flooring (not BAT) can lower PM_{10} emission.

4. Conclusions

It is clearly obvious that emission factors vary considerably from author to author. Moreover, comparison of particulate matter emission estimates is very difficult due to the different measurement units used or because of a lack of effective air volume extracted from the stable. For this reason we need to investigate all the other piggery compartments (weaning room, finishing room etc.) in order to collect data on all animal types and, above all, to assess seasonal effects on dust emission.

Investigation into the real contribution of swine production on particulate matter pollution in the atmosphere is increasingly important after Italy's adoption (Decree n. 372 of 04/09/99) of the 96/61/EC Directive, also known as IPPC (Integrated Prevention Pollution Control, [19]), concerning existing intensive animal housings, which obliges breeders to declare and compel the final destination of all waste produced, with the aim of strictly regulating all forms of emission into the atmosphere, water and soil. The directive is based on the concept of Best Available Technique (BAT), where farmers have to choose and adopt the most effective market technology for preventing or limiting emissions, and which are both sustainable and economically viable.

5. References

[1] Hinz T., *PM in and from agriculture. Introduction and overview,* Proc. PM in and from Agriculture. (2002) Braunschweig, 3-4 June 2002, p 1-6.

[2] Parry R.R., Schlenker E.H. and Feistner R. *Correlation of positive Farmer's Lung serologies, respiratory symptoms, and pulmonary function tests in nonsmoking workers involved in confinement raising of livestock*. American Review of Respiratory Disease. (1987) 135, A 451

[3] Liao C.M, Chen J.W., Huang M.Y., Chen J.S. and Chang T.J., *An inhalation dose model for assessing dust–borne Voc–odor exposure from feeding in swine buildings*. Trans. ASAE. (2001) 44(6): 1813-1824.

[4] Hartung J., *Effects of bioaerosol related particulate matter on animal health*. Proc. PM in and from Agriculture. (2002) Braunschweig, 3-4 June 2002, pp. 119-123.

[5] ISO 7708. Norma italiana. Qualità dell'aria. definizioni delle frazioni granulometriche per il campionamento relativo agli effetti sanitari. (1998) Ente Nazionale Italiano di Unificazione; Milano.

[6] AENGST C., *Zur Zusammensetzung des staubes in einem schweinemaststall*. Thesis. School of Veterinary medicine. (1984) Hanover.

[7] DONHAM K.J. *Relationships of air quality and productivity in intensive swine housing*. Agri-Practice. (1989) 10, 15-26.

[8] GUARINO M., NAVAROTTO P., VALLI L., SONZOGNI A., "*Particulate matter concentrations in two different buildings for laying hens: a first note"*. Proc. PM in and from Agriculture. (2002) Braunschweig, 3-4 June 2002, pp. 175-179.

[9] HARTUNG J., *Dust in livestock buildings as a carrier of odours*. In: Nielsen, VC., Voorburg, J.H. and LHermite, P. (eds), Odour Prevention and Control and Organic Sludge and Livestock Farming. (1986). Ed Elsevier, London, p.321-332.

[10] COSTA A., NAVAROTTO P., GUARINO M. e SAVOINI G., *Analisi di alcune caratteristiche fisiche di mangimi di origine commerciale per suini. LVI Convegno Nazionale* S.I.S.VET. Giardini Naxos 26-28 Settembre 2002. Pp. 425-426.

[11] CEPMEIP Co-ordinated European *Programme on Particulate Matter Emission Inventories, Projections and Guidance.* (2002). *Database presented on the Internet*: http://www.air.sk/tno/cepmeip/.

[12] BERCKMANS D., PH. VANDENBROECK & V. GOEDSEELS *Sensor for continuous ventilation rate measurement in livestock buildings - Integration in the control system*. ASAE paper (1991). 91-N° 4031, 21 pp.

[13] TAKAI H., PEDERSEN S., JOHNSEN J.O., METZ J.H.M., KOERKAMP P.W.G.G., UENK G.H., PHILLIPS V.R., HOLDEN M.R., SNEATH R.W., SHORT J.L., WHITE R.P., HARTUNG J., SEEDORF J., SCHRODER M., LINKERT K. H., WATHES C.M. TAKAI, *Concentrations and emissions of airborne dust in livestock buildings in Northern Europe.* Journal of Agricultural Engineering Research. (1998) 70 (1): 59-77.

[14] KLIMONT Z., COFALA J., BERTOK I., AMANN M., HEYES C., GYARFAS F., *Modelling Particulate Emissions in Europe: a framework to estimate reduction potential and control costs*, I.I.A.S.A. (2003). Interim Report IR-02-076.

[15] BERDOWSKI J.J.M., MULDER W., VELDT C., VISSCHEDIJK A.J.H., ZANDVELD P.Y.J., *Particulate matter emissions (PM_{10} - $PM_{2.5}$ - $PM_{0.1}$) in Europe in 1990 and 1993, 1997.* TNO report, TNO_MEP. (1997). R 96/472.

[16] LÜKEWILLE A., BERTOK I., AMANN M., COFALA J., GYARFAS F., HEYES C., KARVOSENOJA N., KLIMONT Z., SCHÖPP W., *A Framework to Estimate the Potential and Costs for the Control of Fine Particulate Emissions in Europe*, I.I.A.S.A.(2001). Interim Report IR-01-023 http://www.iiasa.ac.at/~rains/PM/

[17] ENEA. *Rapporto finale sul progetto: Misure di concentrazioni di materiale PM_{10} e $PM_{2.5}$ nell'aria ambiente dei ricoveri zootecnici (suinicoli ed avicoli) ed elaborazione dei risultati per la valutazione delle emissioni di particolato in relazione alle tecniche di abbattimento d'inquinanti atmosferici.* (2002). Roma.

[18] FABBRI C., GUARINO M., VALLI L., NAVAROTTO P., COSTA A., "*Emissioni di gas e particolato dai ricoveri. Risultati di un anno di monitoraggi*", Rivista di Suinicoltura. (2004), 2: 22-29.

[19] IPCC, 2005. *Report of the IPCC Expert Meeting on Emission Estimation of Aerosols Relevant to Climate Change.* 2-4 May, Geneva, Switzerland, 34 p.

SUMMARY

In this study, PM_{10} emission factors were studied in both the farrowing and fattening rooms of a piggery. The following climatic and managerial variables were monitored online, in both rooms, throughout the observation period; temperature and humidity (internal and external), ventilation rate, heating, number and weight of animals and type of feed administration. PM_{10} concentration was also measured continuously in both rooms, and also at the inlet level of the fattening room, to estimate dust coming from the external environment, using a Haz Dust EPAM 5000 (EDC) sampler which is based on the near-forward light scattering method. The emission factor of particulate matter (PM_{10}) was calculated by taking into account PM_{10} concentrations both inside and outside the building, and the ventilation rate (air volumes extracted from the stable). Correlations between PM_{10} concentration and the considered variables were studied. The PM_{10} emission was estimated at 6.8 mg $head^{-1}$ h^{-1} from the farrowing room, and at 12.03 mg $head^{-1}$ h^{-1} from the fattening room.

Key words: PM_{10}, concentration, emission, mechanically ventilated swine house.