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FIELD TEST INSTALLATIONS USING NH_3 SENSOR AND VENTILATION RATE SENSOR FOR CONTINUOUS MEASUREMENT OF TOTAL AMMONIA EMISSION FROM ANIMAL HOUSES

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ABSTRACT

Two field test installations are discussed. In the first one a new ammonia sensor and an accurate ventilation rate sensor are combined. They are installed in the exhaust chimney in a ventilated pig house. The relative humidity and the room temperature are measured as well. In the second one, an in situ $NH_3 \rightarrow NO$ converter with subsequent NO_x analyser is also being added for accurate ammonia measurement. In this way, the continuous measurement of the total NH_3 emission can be obtained, the performance of the NH_3 sensor can be evaluated, and the ammonia reduction techniques can be tested. The outputs of measurement are fed into a data acquisition system then to a PC in the laboratory. There has been realised the first test installation with which research on the new ammonia sensor is carried out. The primary research results are presented.

Key words: Environment, Air pollution, Pig house.

INTRODUCTION

The anthropogenic NH_3 emission in Europe is estimated to consists for 90% of the ammonia generated from animal wastes. In Belgium it is estimated that about 74,000 tons of NH_3 is emitted from animal wastes each year (Buijsman et al., 1987). A certain part of it is emitted from animal houses. High emission rate of NH_3 from animal house represents two kinds of problems: Inside the animal house the high concentration of NH_3 is a potential health hazard to humans and animals. Outside the animal houses the excess ammonia emitted into the atmosphere causes mal-odour, the loss of fertiliser value of the slurry, and the damage of ecosystem via the acidification of soil (Fig. 1). Because agriculture is the main source of anthropogenic ammonia emission, it is therefore natural that it has attracted more and more attention. In some of the European countries, e.g. the Netherlands, Belgium, Germany and the United Kingdom, there is strong concern to reduce ammonia emissions from agriculture. The Dutch Government has stated that the ammonia emission must be reduced in the year 2000 by 70% compared with 1980 (Verdoes, 1991).

The reduction of total NH_3 emission from agriculture depends on effective measuring, monitoring and controlling techniques. Most of the available techniques today for measuring the ammonia in animal houses use wet chemistry, gas chromatography, Gastec tubes. For the total ammonia emission from animal houses, although some researches in mechanically ventilated houses have been reported, no measurement techniques for naturally ventilated animal houses are ready for practical use (Monteny, 1993). For the mechanically ventilated animal houses, most of the measurement methods can only provide periodic results or with low accuracy. Table 1 provides some reported information of measurement accuracy. Furthermore, many accurate measurement instruments are expensive. Until now, although the techniques for accurate and continuous measurement of the total ammonia emission from livestock buildings are available, it is not yet in practical use.

A new ammonia sensor is being developed and evaluated by the IMEC (Inter-university Micro-Electronics Centre, Leuven) and the Catholic University of Leuven, Belgium, providing a possibility of low cost and continuous measurement of ammonia concentration. If reliable and low cost sensors for ammonia measurement are available, they can be integrated in the control system. For the evaluation of the performance of this ammonia sensor, a laboratory test installation is employed (Van Geloven, 1992). However, to make this sensor work in the animal houses, a hard field condition is confronted. Many fixed gases and chemical compounds, much dust and high relative humidity are presented in the animal buildings. They represent two kinds of problems for the solid state ammonia sensor, one is the interferences of the moisture and gases to the sensor output, and the other is their influence on the lifetime of the sensors. Field installations are therefore needed to evaluate the sensor. They are also useful tools for the measurement and the control of the NH_3 emissions from animal buildings .

OBJECTIVE

The research projects are combined and the objective of this work is: 1. To develop effective field installations for the continuous and accurate measurement of ammonia emission; 2. To evaluate and further develop a new ammonia sensor; 3. To evaluate two ammonia reduction techniques.

MATERIAL AND METHOD

The study of the ammonia sensor and ventilation rate sensor for continuous ammonia measurement from animal houses can be divided into three stages. In the first stage, a prototype of NH_3 sensor was developed and installed in a pig house together with an accurate ventilation rate sensor to test the possibility of total ammonia emission measurement. This work was finished in November 1990.

The second stage of work is an 18-month feasibility study project (VLIM/H/9032) funded by the administration of Flemish Impulse Program on Environmental Problems (VLIM) of the Flemish government in Belgium. It was started in September 1992 with improved NH_3 sensor and more measurement parameters including the ventilation rate, relative humidity and room temperature. A field test installation has been developed in a commercial fattening house in the Zoötechnisch Centrum of the Catholic University of Leuven, Belgium.

The third stage of experiment is supported by a 2-year research project started in April 1993. The project is funded by the Institute for Scientific Research in Industry and Agriculture (IWONL) in Belgium. In this research, the NH_3 sensor is evaluated with the reference NH_3 measurement using an $NH_3 \rightarrow NO$ converter with a subsequent ON_x analyser. Two ammonia reduction techniques are also to be studied: a biofilter and an additive to the manure. A second field test installation is being developed.

First field test installation for evaluation of an NH_3 sensor and to measure the NH_3 emission

The schema of the first field test installation is illustrated in Fig. 2. The animal building selected is one of the standard commercial fattening pig houses in Belgium equipped with mechanical ventilation system. The compartment is 12.05 m long, 6.20 m wide with a roof top height of 4.60 m, and with fully slatted floor. In the compartment there are 12 pens lined on two sides. Between the two rows of pens is the corridor. The ventilation chimney, with a diameter of 0.45 m, is installed above the corridor with the height of 3.5 m from the ground and with 1 m of horizontal distance from the entrance. There are in the compartment a total of 50 - 60 fattening pigs. The pigs are fed on commercial dry feed. The in-building climate in the pig house is controlled with temperature ranges between 15 - 22 °C. The estimated relative humidity as confirmed by first measurement is around 70% - 90% during winter time.

Measurement position, measurement parameters and sensors selected

The measurement position is chosen in the ventilation chimney where all the sensors are installed. The ventilation chimney is on the roof of the compartment. Four measurement parameters are decided:

1. Ventilation rate as measured through the exhaust chimney: The ventilation rate through the pig house is measured with an accurate ventilation rate sensor developed in the Laboratory for Agricultural Building Research, Catholic University of Leuven, Belgium. It is a new low-cost sensor (the price of each prototype was around US $ 220). The principle and the performance of this sensor have been discussed by Berckmans et al. (1991). Fig. 3 shows the representation of the principle of a free-running impeller (turbine) of this ventilation rate sensor.

2. Ammonia concentration: Ammonia concentration is measured with the ammonia sensor and the Dräger tubes. The ammonia sensor developed in IMEC is a thick film semiconducting metal oxide sensor. This type of sensors has been produced by a conventional screen printing technology on 96% alumina substrates. On these substrates a patterned multi layer structure has been realised consisting of a heater element, a contact layer, a dielectric layer and a gas sensitive semiconductive metal oxide layer. The conductivity of semiconducting metal oxide films at a certain temperature is influenced by the presence of reducing gases in the surrounding atmosphere. Fig. 4 gives the illustration of the ammonia sensor. In the field use the sensor is capped by a dust filter. The working temperature of the sensor is about 350 °C. The use of the Dräger tubes is periodically only for verifying the ammonia concentration in the compartment with seasonal intervals.

3. Relative humidity: A Rotronic Hygromer® I-200 transmitter is selected among several commercial hygrometers because of its accuracy, stability, and easiness for maintenance. The measurement range of this sensor is 0-100% RH with a calibration accuracy of ±1.5% as indicated by the manufacture.

4. Room temperature: The room temperature is measured with a Pt 100 incorporated in the Rotronic Hygromer® I-200 transmitter. Its indicated measurement range is 0-100 °C with the calibration accuracy of ±0.5°C.

Data acquisition and processing

The outputs of the sensors are acquired by an intelligent data acquisition card (DAP 800) that is plugged in a personal computer. The sensor outputs are sampled with the rate of 0.1 second and averaged from every 1 minute to several hours according to the requirement of the experiment.

Second field test installation for evaluation of the NH_3 sensor, accurate NH_3 measurement and NH_3 reduction technique test

The schematic drawing of the second field test installation is given in Fig. 5. The research with this test installation is to be carried out in a commercial pig house in Schriek, Belgium, in four compartments (No. 1 to No. 4) each with 80-100 pigs. Two of the compartments (No. 1 and No. 2) are used for the reference of ammonia emission measurement and the evaluation of the ammonia sensor. Two others (No. 3 and No. 4) are used to test the effectiveness of ammonia reduction methods: additives to the animal wastes and a bio-filter. With the combination of an accurate ventilation rate sensor (accuracy 3 % at 2000 m^3/h) and an accurate "in situ $NH_3 \rightarrow NO$ converter with subsequent NO_x analyser" (accuracy 2 %), this test installation allows us to measure NH_3 emission with an accuracy of 3-5 % (Coenegrachts, 1993). When the NO_x analyser monitors only one compartment instead of four, then the measurement is continuous, e.g. with a sample frequency of 60/min.

Measurement position, measurement parameters and sensors/instruments selected

The ventilation chimney is fixed on the wall in each compartment. The ammonia concentration, ventilation rate, relative humidity and temperature are measured in these exhaust chimneys as it is in the first test installation. At the outlet of the biofilter of the No. 4 compartment measurement of NH_3 concentration and air flow rate is also designed. Beside the measurement parameters and sensors selected for the first test installation, some other parameters and instruments are also to be used.

Accurate ammonia measurement of in situ $NH_3 \rightarrow NO$ converter with subsequent NO_x analyser: For the accurate ammonia measurement a Chemiluminescence NO_x Analyser (Thermo Instrument Systems, Model 42, measurement range 50ppm, Precision ±0.5ppb) is selected. Air samples are obtained in the same position where the ammonia sensor is installed. Through a short piece of teflon tubing and a dust filter, a continuous air stream is fed into an $NH_3 \rightarrow NO$ converter, then to the stream selector that regulates the air samples from five $NH_3 \rightarrow NO$ converters to the NO_x analyser. The air sample from one converter is connected to the NO_x analyser and measured continuously for 2 minutes then the stream selector switches to the next converter. Ten minutes are needed to analyse an air stream from five converters.

CO_2, ambient relative humidity and temperature measurement: The concentration of CO_2 in the animal house is measured in one of the compartments using a CO_2 analyser (Thermo Instrument Systems, Model: 2000, Measurement range: 0-0.3% or 0-2%, Accuracy: ± 2%). The CO_2 is monitored for the safety of the animals while some experiment with the reduction of ventilation rate is being performed. The ambient relative humidity and temperature measurement are using a Rotronic Hygromer® I-200 transmitter.

Data acquisition and processing

The outputs of the measurements are to be retrieved to an intelligent data acquisition system. Through two modems and public telephone line the data are transferred to the laboratory, about 40 km away from the animal house, to a personal computer connected to the computer centre through local network. After data processing and interpretation, commands can be fed back to control the ventilation rate, the stream selector, the NO_x analyser as well as the sampling rate of the sensors according to the test requirement.

PRIMARY RESULTS

Primary research results are now available for the first test installation. The calibration of the sensor in the laboratory and the measurement results in the field are presented as follows.

Ammonia sensor in laboratory and in field tests

The calibration of the sensor in laboratory conditions is performed in IMEC. Research activities at IMEC are oriented towards the development of semiconducting metal oxides with an improved selectivity ratio for ammonia to other major component of the atmosphere in stables. Preliminary results under laboratory conditions have been published (Berckmans et al., 1992). The sensor shows a good sensitivity towards ammonia in the concentration range as required for on site monitoring. It was also shown that in the air with relative humidity of 50% (50% RH) the sensitivity towards ammonia decreases. Within the range from 50 to 90% RH the sensitivity towards ammonia remains fairly constant.

In the field test, the sensor temperature is maintained at about 350 °C. A dust preventing cap is used to protest the sensor tip. After one month of using in the pig house, no change of the performance of the sensor caused by dust contamination was observed. The field test results of the ammonia sensor together with other sensors are presented in Fig. 9.

Ventilation rate sensor in laboratory test and in field use

The ventilation rate sensor used in the first test installation is a 2-blade impeller one. Its calibration was realised in a laboratory calibration installation before its using in the pig house. The calibration was done under the pressure differences of 0, 2, 4, 6, 8, 10 and 12 Pa. Berckmans et al (1991) has discussed the calibration test rig and the calibration of the sensor. The linear regression analysis of the calibration of this sensor is presented in Fig. 6 with R^2 = 0.998. Its accuracy is ±60 m^3/h (versus about ±600 m^3/h for previous sensors as used by other research teams measuring NH_3 emission) in a measurement range from 200-5000 m^3/h and for pressure differences from 0-120 Pa. In the field measurement, the sensor is proved sensitive and reliable, and no re-calibration is needed in normal conditions.

Relative humidity sensor and temperature sensor in laboratory calibration and in field use

The measurement of relative humidity in a hard environment like in the pig house often has the problems of maintenance and accuracy. To test the performance of the selected Rotronic transmitter, calibration of the transmitter in laboratory was done before its installation in the field and after its use for a certain time. The calibration installation is illustrated in Fig. 7. In this installation, a dew point hygrometer is adopted. The precision dew point hygrometer is accepted as a secondary standard for relative humidity calibration (Parkes, 1979). The calibration results are drawn in Fig. 8 from which it can be seen that the transmitter gives a good linear output. At the 63% reference RH, the maximum measurement difference of the transmitter among the three calibrations is 9.08 %. The response time of the relative humidity sensor with a wind protection is 40 seconds.

For the temperature sensor incorporated in the transmitter, no special problems are met.

Field measurement results of the sensors

Fig. 9 presents part of the field test results of the measurement. The measurement for which the results are shown in Fig. 9 was carried out in the first field test installation where there were 50 fattening pigs. During the 24 hours of test, the temperature and relative humidity in the exhaust chimney were quite stable (temperature range 16.8-17.6 °C, relative humidity range 66-76%). The ventilation rate controlled according to the normal requirements (room temperature, number of pigs etc.) varied between 1012-1867m³/h. The average output of the ammonia sensor as presented in Fig. 9 is 1.016 volts. In the laboratory calibration with dry air one volt of output of the sensor equals to 15 ppm of ammonia concentration. However, the conversion of this voltage into ammonia concentration needs to take into account the interferences resulted from the hard field conditions, namely relative humidity and other gases. Therefore calibration of the sensor and measurement of reference ammonia concentration in the field conditions are prepared.

CONCLUSION

The combination of ammonia sensor and an accurate ventilation rate sensor provides a possibility for low cost continuous measurement of the total ammonia emission from ventilated animal house. To test the ammonia sensor in hard field conditions, field test installations are needed. The first test installation shows that the principle of the combination of the sensors works well. For the interpretation of the ammonia sensor output, calibration of the sensor in field conditions is needed. The second field test installation with accurate measurement of ammonia by $NH_3 \rightarrow NO$ converter plus subsequent NO_x analyser can be a useful tool for such a purpose as well as for the test of the ammonia reduction techniques. This test installation allows us to measure NH_3 emission continuously with an accuracy of 3-5 %.

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Table 1. Some of the reported accuracy for total ammonia emission measurement in the animal houses

Ventilation rate measurement: Technique	Ventilation rate measurement: Accuracy	Ammonia measurement: Technique	Ammonia measurement: Accuracy	Combined accuracy*
Hot wire anemometer	25 %	Ammonia sensor	10 %	27-35 %
Hot wire anemometer	25 %	Gastec tube	10 %	27-35 %
Hot wire anemometer	25 %	Kitagawa ammonia tube	10 %	27-35 %
Hot wire anemometer	25 %	Dräger tube	20 %	32-45 %
Tracer gas	30 %	NH_3 -NO converter + NO_x analyser	2 %	30-32 %
Tracer gas	30 %	NDIR-spectrophotometer	5 %	31-35 %
Measuring turbine	30 % at $2000 m^3/h$	NH_3 -NO converter + NO_x analyser	2 %	30-32 % at $2000 m^3/h$
Measuring turbine (EMI type)	30 % at $2000 m^3/h$	Dräger sensor	15 %	34-45 %
Dräger gas tube for CO_2	40 %	Dräger gas tube for NH_3	20 %	45-60 %
Accurate ventilation rate sensor	3 %	NH_3 -NO converter + NO_x analyser	2 %	3-5 %

Extracted from Coenegrachts, 1993.
* Results from two formulas of accuracy calculation.

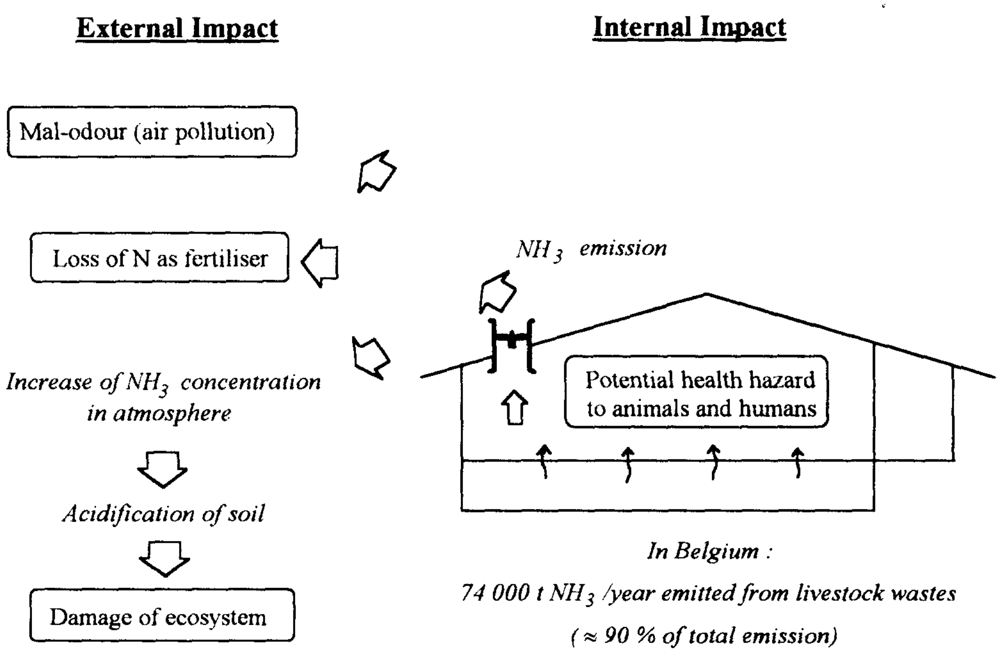

Fig. 1. Summary of the impacts of excess ammonia emission from animal houses

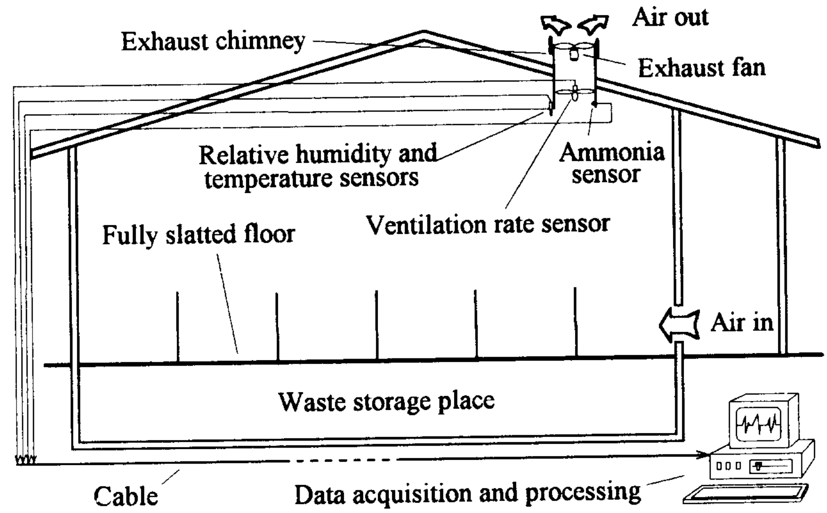

Fig. 2. Schematic drawing of the first field test installation for NH_3 sensor test and continuous total ammonia emission measurement

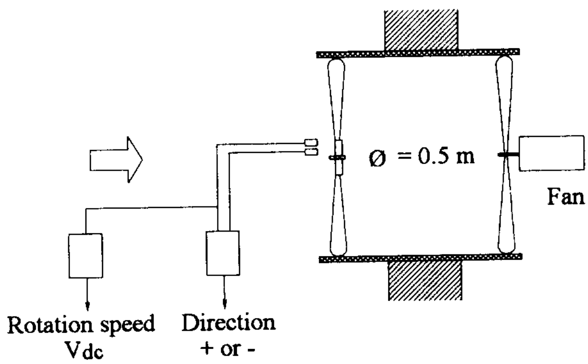

Fig. 3. Representation of the principle of a free-running impeller (turbine) as a ventilation rate sensor (From Berckmans et al., 1991)

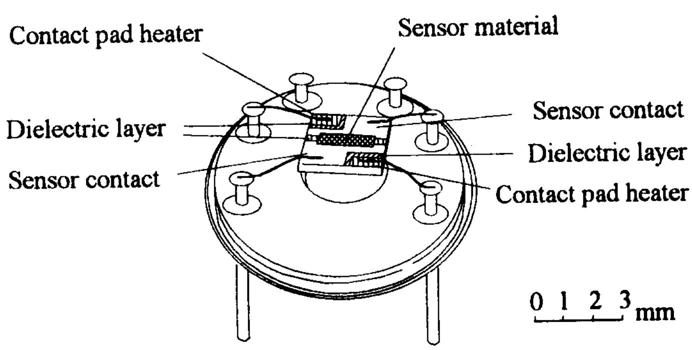

Fig. 4. The ammonia sensor under study

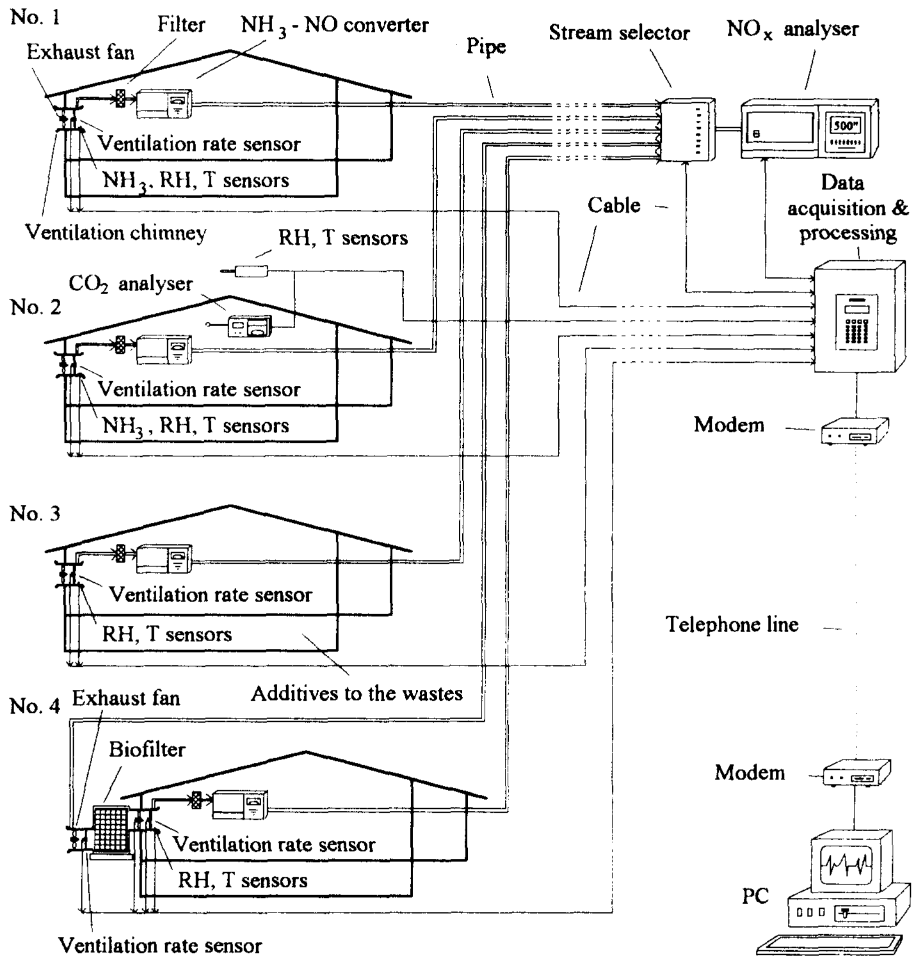

Fig. 5. Schematic drawing of the second field test installation for NH_3 sensor evaluation, accurate ammonia emission measurement and ammonia reduction technique test

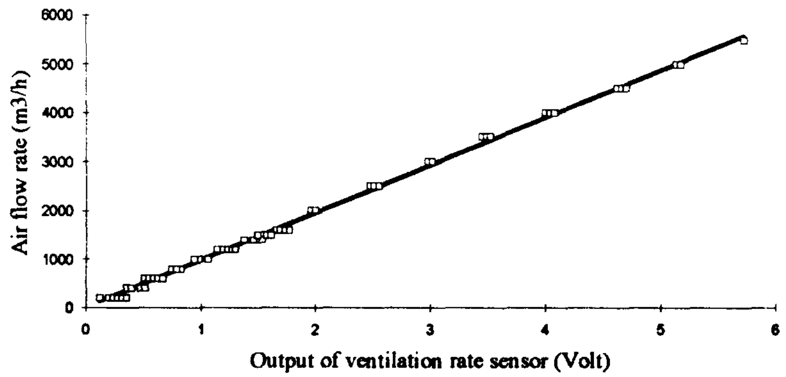

Fig. 6. Linear regression analysis of the ventilation rate sensor used in the first field test installation

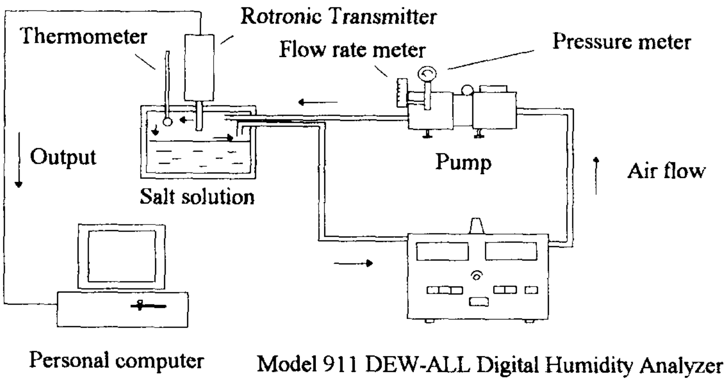

Fig. 7. Laboratory calibration installation of the relative humidity sensor

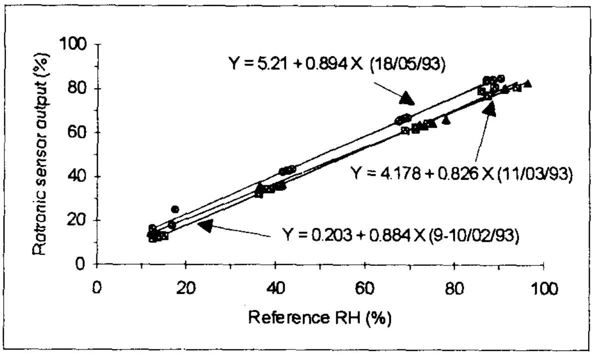

Fig. 8. Calibration results of the relative humidity sensor

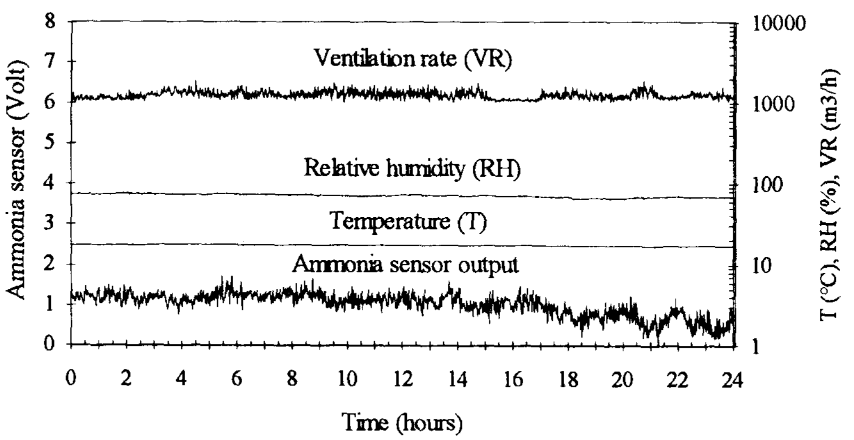

Fig. 9. Field test results of measurement (From 20/02/1993 11am to 21/02/1993 11am)