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Comparison of atmospheres in new construction and retrofitted broiler houses

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To the Graduate Council:

I am submitting herewith a thesis written by Joseph M. Milner entitled "Comparison of atmospheres in new construction and retrofitted broiler houses." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Luther Wilhelm, Major Professor

We have read this thesis and recommend its acceptance:

William Hart, John Wilkerson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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We have read this dissertation
and recommend its acceptance:

John B. Wilkerson

Michael D. Smith

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

Comparison of Atmospheres in New Construction and Retrofitted Broiler Houses

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Joseph M. Milner
August 2000

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ABSTRACT

Atmospheric and environmental conditions inside a new chicken house and an adjacent older house that had been upgraded with equivalent environmental control mechanisms were compared. Continuous monitoring of oxygen, ammonia, hydrogen sulfide, carbon monoxide, and carbon dioxide was done during cool weather grow-outs. Averages of the continuous observations were recorded every thirty minutes. Other data collected were interior temperature and relative humidity, and exterior temperature, relative humidity, and solar radiation.

Statistical analysis was performed to test for differences between the houses for each gas. Differences between the houses were found for each gas that was measured in both houses.

An experiment to test the importance of sensor location within the broiler house was also conducted. Ammonia sensing was found to be affected by the sensors' proximity to the litter, while the oxygen sensor measured concentrations adequately at 5 feet and 1 foot above the floor.

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

FIGURE

LIST OF ABBREVIATIONS

ppm	parts per million

WEATHER AND NON-HOUSE DEPENDENT VARIABLES

Dg	Day of the grow-out
Day	Julian date
Time	24 hour time scale
Pyr	pyronometer
W107	outside temperature
W207	outside relative humidity

VARIABLES USED INSIDE THE CHICKEN HOUSES

HOUSE 1

GAS DATA

oO2	% oxygen concentration in old house
oNh3	ppm ammonia in old house
oH2s	ppm hydrogen sulfide in old house
oCo	ppm carbon monoxide in old house
oco2	ppm carbon dioxide in old house

ENVIRONMENTAL DATA

oInrt	inside temperature recorded by relative humidity sensor in the old house
oInrh	inside relative humidity in old house
oPvolt	panel voltage in old house
oPtemp	panel temperature in old house
oTcavg	thermocouple average in old house

HOUSE 2

GAS DATA

NInrt	inside temperature recorded by relative humidity sensor in the new house
NInrh	inside relative humidity in new house
NPvolt	panel voltage in new house
NPtemp	panel temperature in new house
NTcavg	thermocouple average in new house
nO2	% oxygen concentration in new house
nNh3	ppm ammonia in new house
nH2s	ppm hydrogen sulfide in new house
nCo	ppm carbon monoxide in new house

DATA ABBREVIATIONS AFTER SORTING BY HOUSE

GAS VARIABLES

O2	% oxygen concentration, after sorting by house
Nh3	ppm ammonia, after sorting by house
H2s	ppm hydrogen sulfide, after sorting by house
Co	ppm carbon monoxide, after sorting by house
Co2	ppm carbon dioxide, after sorting by house

WEATHER VARIABLES

Inrt	inside temperature from relative humidity sensor, after sorting by house
Inrh	inside relative humidity, after sorting by house
Pvolt	battery voltage, after sorting by house
Ptemp	data logger panel temperature, after sorting by house
Tcavg	thermocouple average, after sorting by house

CHAPTER I

INTRODUCTION

The need to keep the margin between broiler production cost and market values as large as possible has led to developments in genetic strains, diet formulations, house and equipment design, and the understanding of the effects of husbandry techniques. Part of maximizing the efficiency of poultry production is the optimal use of broiler housing space, energy, labor, and material input at the contract grower level. Motivation to cut costs at the grower level is necessarily tempered by the need to produce a uniform, healthy flock. Information about the environment within modern chicken houses is one of the tools available to integrators and contract growers alike to decrease losses due to mortality and low carcass quality while streamlining production. Development of new, effective environmental controls and management schemes is dependent on comprehension of the relationships between the components of atmospheres within chicken houses.

In a chicken house, the atmosphere is a product of inputs from the weather, management decisions, and the chicks. Chicks are a product of genetics, nutrition, environment, and management. The response of the chicken house atmosphere to management inputs and the chick's response to the environment are parts of a complex relationship that generates further inputs for the system. Relationships between the components of the broiler chicken house environment have been only partially explained because of the complexity of this environment.

Air quality parameters such as temperature, relative humidity, oxygen, carbon dioxide, carbon monoxide, ammonia, hydrogen sulfide and other gas concentrations can be observed using various types of monitoring equipment. Although available to producers, equipment used to detect air quality other than temperature and relative humidity is not commonly used. One reason for this is the high cost of some sensing devices. Another concern of producers may be the potential for such a device to add to the workload that producing broilers already presents. Increased costs and work load due to increased use of gas sensing equipment could be justified if profits from their use were significant; however, integrators and growers may be hesitant to invest in equipment or information that has not been proven profitable in commercial scale production.

Broiler house temperature and humidity can be altered by adjustment of ventilation and heating systems. Growers may be able to adjust environmental controls based on observations of chick behavior, or by using their own senses to adjust house controls and air quality. Factors like caking of litter, condensation of moisture in the air, olfactory sensing of ammonia, bird activity levels, and integrator requirements may be used as inputs to a manager's decision to adjust environmental control mechanisms. Evaluation of broiler house environments will vary by producer. The producer's ability to evaluate the environment is important to making management decisions. Adequate control of the broiler house environment is a contributing factor to the production efficiency of the farm.

Use of electronic and mechanical control mechanisms is limited in most cases to heaters, fans, ventilation openings, and in some modern houses the use of evaporative cooling pads and fogging systems. Many suppliers of broiler chicks in the southeast provide growers with guidelines for controlling the environments regarding temperature and relative humidity adjustments. Integrators use flock supervisors to assist growers with environmental management.

In Tennessee, the annual broiler production increased from about 100 million birds in 1990 to 160 million birds in 1998(Tennessee Agricultural Statistics, 1999). Increased and sustained chick production will necessitate construction of additional chicken houses as well as replacement or refitting of old houses. Current poultry management practices are facilitated by house design and environmental control mechanisms associated with the house. Costs of construction and air quality controls vary with house design and control mechanisms used (Overhults and Gates, 1994). Initial cost of these systems, maintenance and use cost, and cost of eventual replacement or upgrades are important considerations for the producer planning a new farm or maintaining an existing operation (Gempesaw and Bhargava, 1990).

OBJECTIVES

This study examines relationships between components of the chicken house environment. Measurements of the concentrations of several gasses, ammonia, carbon monoxide, oxygen, hydrogen sulfide and carbon dioxide, were made. Temperature and relative humidity data were collected inside and outside the house. This database allows the comparison of the internal environments of a new chicken house and an adjacent older house that had been upgraded to have the same environmental control mechanisms. There are three main objectives of this research.

1. Determine if growers can control the environments in retrofitted broiler production units as well as in newly constructed units.

2. Continue the collection of broiler production house environmental data.
3. Determine if a model to predict the levels of atmospheric components can be generated from the database.

CHAPTER II

LITERATURE REVIEW

Environmental air quality within an animal production system can be defined as a function of inert particles, viable particles, and toxic gases (Van Wicklen et al., 1986). Controlled studies of dust exposure with treatments emulating a mechanically ventilated broiler house indicate that dust levels found within production units do not affect overall production (Van Wicklen et al., 1994). Environmental quality indicators such as temperature, relative humidity, carbon dioxide, carbon monoxide, ammonia, hydrogen sulfide, and oxygen concentrations can be used to interpret the effectiveness of the house design and environmental controls. Of these air quality indicators, temperature and relative humidity are often used as the decision making criteria for air quality management (Van Wicklen et al., 1986).

Temperature, concentration of pollutant gases, relative humidity levels, air movement, litter conditions, and light schedules have been shown to affect performance of broiler chicks. Many of these components of the chicken house environment interact with each other, and can also be affected by management activities and inputs. In a study to determine the effects of a bronchodilating drug, it was established that cold stress and low oxygen concentrations contribute to the development of acites. During these tests it was also shown that temperature and oxygen levels affected the overall weight gains and feed conversion efficiency of the tested birds. It was concluded that brooding at lower temperatures caused increased heart mass, regardless of the two oxygen concentrations tested (Vanhooser et al., 1995). Deaton et al. (1996) found that the brooding temperature management affected causes and levels of mortality in broiler chicks, but feed conversion and final body weight were not affected by the temperature schemes tested.

Feed conversion rates are affected by ammonia concentrations within poultry production units. Concentrations as low as 50 PPM caused total body weights of chicks tested to lag behind the growth of control groups (Reece, 1979). Feed conversion rates and growth rates were found to be negatively affected by 25 ppm ammonia when exposure began early in a production cycle (Quarles and Kling, 1974). Lighting schedules and drinker design have also been shown to affect the early development of broiler chicks. Retarded growth has been observed when comparing nipple drinkers versus bell type drinkers (Elwinger and Svensson, 1996). Retarded growth was also an effect of limited first week lighting regimes as opposed to the standard 23 hours of light and one hour dark schedule (Buyse et al, 1996). In the lighting and drinker studies, the differences in early growth rates were at least partially recovered by chicks late in the grow-out cycle. Both studies found higher nitrogen retention rates and better feed conversion rates in the chicks that lagged behind control groups. Leaner birds, smaller breast fat pads, and less deposition of nitrogen in feces indicate that the maximum possible feed and water consumption is not optimum. Release of excess water and nitrogen to the litter provides nutrients for production of ammonia by uricolytic bacteria in the litter. Increased production of ammonia and high relative humidity in litter increase the incidence of carcasses with foot pad and breast damage due to ammonia burns (Weaver and Meijerhof, 1991).

Implications of diet, drinker, brooding temp, air quality, and lighting schedule studies are that early environmental quality affects chick growth. Control of mortality, carcass quality, breast fat pad deposition, and feed conversion rates are all linked to the environment and management inputs. This leads to the conclusion that environmental observation and control are critical to chicken production.

FACTORS AFFECTING THE ENVIRONMENT

The atmospheric conditions within chicken houses are important components of the environment. Scheduled light inputs, ventilation and temperature control, litter management, feed formula, genetic stock choices, and equipment selection and use are examples of manager controlled inputs that affect the atmosphere inside a chicken house. External factors influencing the internal atmosphere include weather inputs such as external temperature, relative humidity, wind velocities, and the amount of solar energy reaching the structures. External factors are most important to management decisions concerning ventilation and temperature control and may present challenges in maintaining desired temperature and air quality parameters, while controlling energy costs. Choices about house dimension, insulation, ventilation, heating, and cooling methods and capacities are commonly made for the contract growers by integrators. Watering, feeding, heating, and cooling systems are all purchased by the grower; however, integrators often require upgrades and specifications for new construction that lead to standardization within houses of similar age.

Equipment selection is important beyond being able to maintain adequate heating and cooling in the chicken house. The effect of nipple drinkers versus bell type drinkers on litter quality was shown during a test with varying levels of dietary protein (Elwinger and Svensson, 1996). This study demonstrated that chicks used more water, with less efficiency when drinking from bell style drinkers. The indication is that more water was deposited on the litter through feces and spillage than with the nipple drinkers. In the same study, protein level in the chick diets was shown to be positively related to the amount of nitrogen deposited on the litter in fecal material. Given uric acid and adequate levels of moisture, uricolytic bacteria produce ammonia in litter. Weaver and Meijerhof (1991) conducted experiments to determine the effects of temperature, relative humidity, and air movement on ammonia production. Analysis indicated a positive relationship between relative humidity and ammonia in the experimental grow-out chambers, until about day 30 of the trial. At the end of grow-outs, the measured values for ammonia in the atmosphere were lowest in chambers with the highest relative humidity settings. The indication is that litter quality, in this case caking and moisture content, affects the amount of ammonia that is produced and released into the chicken house atmosphere.

A common litter management practice is to reuse a portion of the litter over the course of several grow-outs. Only the caked surface of the litter is removed. Scraping the caked liter from the surface allows drying and air transfer that would be otherwise prevented by the caked layer. Top dressing of the litter with a layer of fresh material allows the new grow-out to begin with a dry, clean litter surface. However, while determining minimum ventilation rates for ammonia control, it was found that houses utilizing top dressed litter, as opposed to new litter, required an average of 9 times the volume of air exchange to keep the aerial ammonia in the range of 25 to 30 PPM. This exchange rate was well beyond rates needed to control the buildup of relative humidity levels (Xin et al., 1996).

RESEARCH TECHNIQUES USED IN OTHER STUDIES

Dew point and dry bulb data or thin film capacitance sensors have been used to record relative humidity information. Pollutant gas concentrations have been measured using paper tape indicators, indicator tubes filled with pH sensitive reagents, infrared gas analysis, metal oxide semiconductors, and electrochemical gas sensors. Challenges of collecting data during different periods of grow-outs have been dealt with by creating controlled situations, scheduled individual samples, brief periods of monitoring remotely, and continuous monitoring during several weeks of production inside commercial chicken houses.

Previous studies of chicken house environments have not yet established normal profiles for chicken house atmospheric cycles. Critical levels of ammonia and the effects of exposure have been demonstrated in several studies. Tested ammonia concentrations and results are shown in Table 1. The levels tested did affect the performance of chickens; however, ammonia concentrations were applied using experimental environmental enclosures. Because of this limitation, fluctuations of concentrations that occur due to the ventilation of a chicken house were not accounted for.

Table 1. Adverse Effects of Ammonia On Poultry Health Ross and Daley(1986).

AMMONIA LEVEL	EFFECT
20 ppm	Weight loss, anorexia, susceptibility to disease
25-50 ppm	Increased condemnations, reduced carcass grade
60 ppm	Tracheitis keratoconjunctivitis
100 ppm	Reduced feed intake reduced growth rate
50-200 ppm	Reduced feed conversion, reduce weight gain
100-200 ppm	Increased mortality

The environment inside a chicken house is dynamic. Unlike the controlled chambers of the previous studies, changes in pollutant concentrations and temperature characteristics can change quickly. Czaric and Lacy (1990) demonstrated the effect of reduced ventilation during the sixth week of a broiler grow-out in a naturally ventilated chicken house. Measurements were taken for 15 minutes while curtains were closed. Temperature, relative humidity, and to a lesser extent ammonia increased exponentially. Carbon dioxide concentration increased nearly linearly from 750 to 3600 ppm. Changes in environmental quality occur quickly with changes in ventilation. Cycling of pollutant concentrations is dependent on production rates within the house and the rate of exhausting those pollutants. Under variable ventilation, exposure to constant levels of a particular aerial pollutant is unlikely. There is a need to develop data that describes the maximums, minimums and normal pollutant concentrations inside commercial poultry houses.

Leonard et al., (1984) monitored the waste gasses produced in small broiler houses with a remote sampling system. Samples of the air from within the broiler houses were collected and pumped through heated tubes to a mobile laboratory. Ammonia and carbon dioxide concentrations were sampled 2 times per hour for a 24-hour period each week of the grow-outs tested. Hydrogen sulfide was sampled for 20 minutes each week. The resulting data enabled them to define a relationship between the amount of fecal material in the litter and the levels of ammonia observed. Ammonia data were fitted to the exponential equation ($R^2 = 0.87$): $Y = 0.81 \exp(0.078X)$ Where Y = ammonia production (micro $L/(h*m^2 *bird)$); and X = the age of bird in days.

Feddes et al., (1984) suggest using the carbon dioxide content of exhaust air to estimate ventilation rates in livestock structures. Carbon dioxide concentrations ranging from 1313-4001 ppm for two barns were observed. Production rates for carbon dioxide were defined by the equation: $C = 340-40.7A-5.59A^2 -0.0683A^3$ Where C = carbon dioxide production (L/h)/1000 birds; and A = age of birds (days).

CHAPTER III

METHODS AND PROCEEDURES

Two houses of different age were evaluated in this study. The atmospheres were monitored in two tunnel-ventilated houses built next to each other on a farm near Cleveland, TN. Concentrations of atmospheric components were continuously monitored during portions of 4 cool weather grow outs. The tunnel ventilation systems were not used during these grow-outs due to the low need for heat removal. Gas concentrations measured in both houses were carbon monoxide, oxygen, hydrogen sulfide, and ammonia. In the older house, the carbon dioxide concentration was also measured.

HOUSE DESCRIPTIONS

Both of the houses observed were located just east of Cleveland Tennessee. The houses were 40 x 500-ft tunnel ventilated houses with axis oriented south to north. Stocking was based on integrator need, but was similar between houses each grow-out. Stocking allowed approximately 0.75 ft^2/bird. One of the houses had been in use for 8 years prior to the construction of the new house. At the time of data collection, the new house had been used for production for 4 years. At the time of construction of the newer house, the old house was retrofitted so that both houses had similar environmental control systems. The south end of each house was equipped with evaporative cooling pads for use with negative pressure tunnel ventilation. Curtains for emergency ventilation lined both sides of each house. The north ends of both houses were fitted with exhaust fans for tunnel ventilation during hot weather. Tunnel ventilation was not utilized during these cool weather studies. Fans mounted to exhaust through the side walls were controlled by timers during times of moderate outside temperatures and during the first weeks of all grow-outs. Emergency high temperature controls were also in place to increase ventilation in the case of excessive heat accumulation during non tunnel ventilation periods. During cool fall and winter grow-outs, ventilation was controlled by timers with high temperature back-up switches. Ventilation timers were set to conserve energy used to heat the houses during early days of grow-outs. As the chicks grew and the need for high temperatures was reduced, exhaust schedules were increased. Adjustable air inlet openings were built into the wall of the chicken houses just below the eaves. The inlets had adjustable louvers to direct incoming air toward the ceiling at the center of the house. Inlet opening angles were fixed by the grower and his grow-out supervisor by manually adjusting the vents to maximize mixing of smoke used as an indicator. Half house brooding was used at the start of each grow-out. Only the south end of each house was equipped with propane brooders. The north ends of the houses were equipped with supplemental propane furnaces for heating after chicks were released throughout the house. Prior to the delivery of chicks, the litter was scraped to remove the crust from the previous production cycle. The remaining litter was then top dressed with pine shavings. The floor under feeder lines was covered with kraft paper and feed was dispensed into feed trays until it spilled out onto the paper. Nipple drinkers provided water for the birds and were adjusted upward as the chicks grew in size. Birds were exposed to 23hours of light and 1hour of dark schedule. Day old chicks were delivered to both houses on the same day for each grow-out period.

GAS MEASUREMENT

Both houses had similar sets of electrochemical sensors to measure carbon monoxide, oxygen, hydrogen sulfide, and ammonia, concentrations. Draeger Polytron SE brand sensors were used to measure most gas concentrations. Sensors for carbon monoxide, oxygen, hydrogen sulfide, and ammonia consisted of a sensing head with a reactive liquid containing cell that admitted atmospheric components through a permeable membrane. Chemical reactions between the specific atmospheric components and the cells created ionic changes that were interpreted by the sensing heads. The sensing heads produced an output electric current that was proportionate to the concentration of the target gas entering the sensor. The old house was also equipped with a chilled mirror infrared carbon dioxide sensor built by National Draeger Corporation (Pittsburgh, PA).

Except for the carbon dioxide sensor, each set of gas sensors was powered by a deep cycle 12 V battery. The output signal of all gas sensors was 4-20 milliamp. A voltage was measured across a 240 ohm precision shunt resistor by a Campbell Scientific 21X data logger set to measure in a 0±5000 millivolt range. The data logger was programmed to measure these signals as a single-ended voltage. The carbon dioxide sensor required a 24 V supply that was provided by an additional 12 V battery connected in series with the 12 V battery that provided power for the electrochemical sensors.

The gas sensors in each house were mounted under a 5-sided hood. The hoods were constructed from 0.25 inch PVC sheet. Length width and height for the hoods were 37 x 6 x 6.5 inches for the 4 sensor hood and 44 x 6 x 6.5 inches for the 5 sensor hood. The bottom of the hood and the upper 50% of each end were open to the atmosphere. Hood design allowed air to flow around the sensors while preventing accumulation of dust on the upper horizontal surfaces of the sensors. Dust settled on the upper horizontal surface of the hood during measurement periods with accumulations of 2 to 5 mm. In each house, the hood containing gas sensors was suspended so that the sensors were 5 feet above the floor and approximately 20 feet upstream of building center. During the final measurement period only, both sets of gas sensors were installed in one of the houses as shown in Figure 1. On set of sensors was installed as before, 5 feet above the floor. The other set was installed 1 foot above the floor.

GAS SENSOR CALIBRATION

All gas sensors were calibrated prior to data collection periods. Gas sensors were connected to the data logger and were powered for more than 24 hours prior to calibration. This warm-up period allowed the sensors to stabilize prior to exposure to calibration gasses. After a warm-up period greater than 24 hours, sensors were calibrated by adjusting both the zero and span potentiometers of the sensors in the presence of calibration gasses. The zero output was determined by exposing the sensor to ultra high purity nitrogen. In the presence of ultra high purity nitrogen the span potentiometer of the sensor was adjusted so that the indicated reading on the sensor's display was zero. After the span potentiometer was adjusted and the signal voltage for zero was recorded, the sensor was exposed to a known concentration of calibration gas (Table A-2). The span potentiometer of the sensor was adjusted so that the indicated reading on the sensor's display matched the concentration of the calibration gas. After the slope potentiometer was adjusted to indicate the known concentration of the

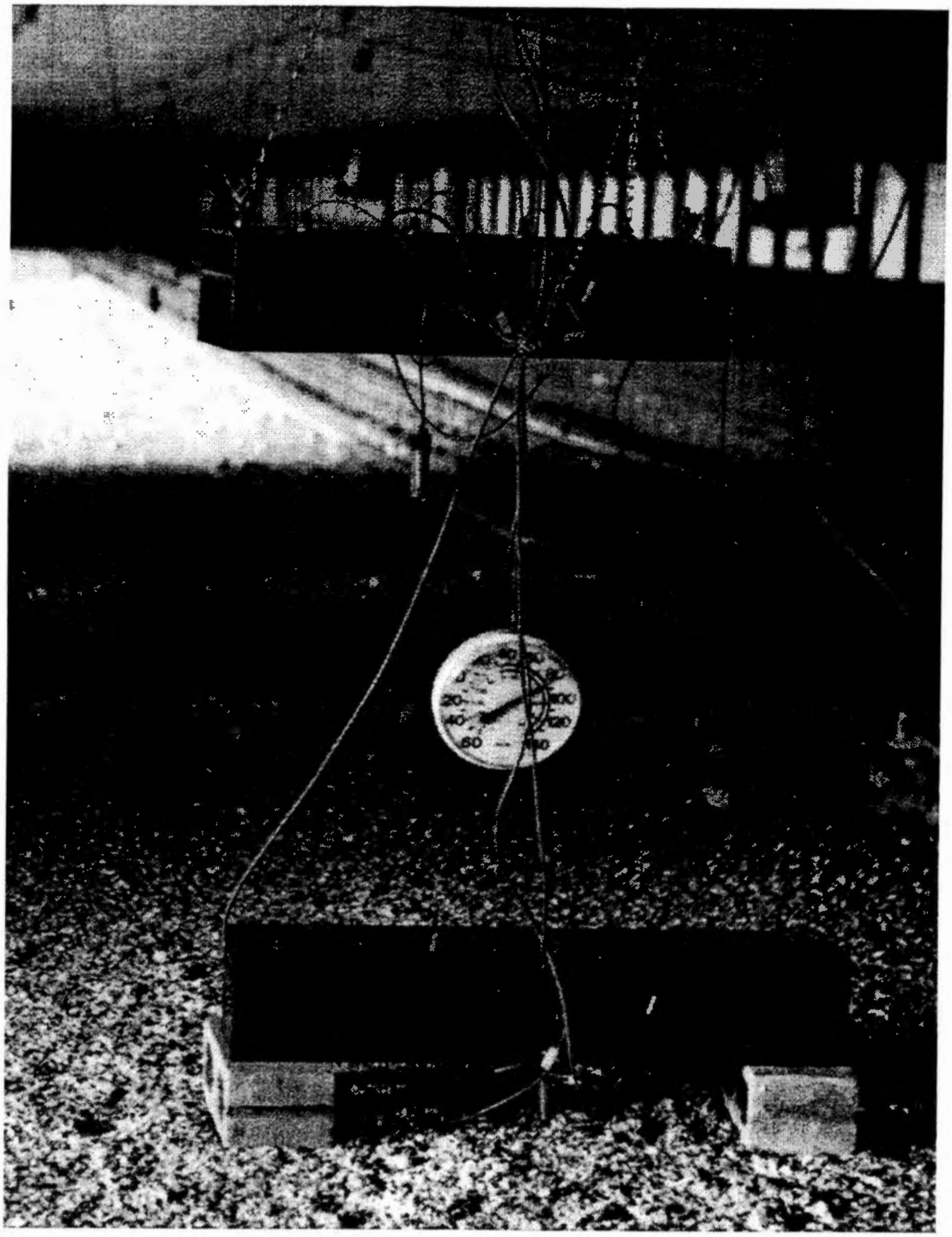

Figure 1. Photograph of gas sensors. Installation for high-low measurements. Locations are five feet and one foot above the floor.

calibration gas, the signal voltage indicated by the data logger for the span concentration was recorded. Sensors remained powered continuously during calibration, transport, installation, and data collection to prevent the need to recalibrate at the data collection site.

Linear regression was used to obtain a linear relationship for the output of each sensor according to the values recorded during calibration (Table A-1). Voltage signals recorded by the data logger were translated to gas concentration values using a spreadsheet and the appropriate calibration equations.

TEMPERATURE, HUMIDITY, AND RADIATION SENSORS

Campbell Scientific model 207 temperature and relative humidity probes were used to measure relative humidity under both hoods and outside. The inside sensors were suspended at the same elevation as the gas sensors under the hood. Outside temperature and relative humidity were observed by a sensor placed in a Campbell Scientific housing mounted on a tripod at 4 feet above ground level approximately 30 feet to the west of the new house structure. Signals from each of the model 207 sensors were read directly by the data logger.

One Licor LI-200SZ pyronometer was used to measure solar radiation outside the chicken houses. The pyronometer was mounted atop the tripod holding the outside relative humidity sensor, approximately 6 feet above ground level. The signal from the pyronometer was read directly by the data logger as a differential voltage.

Type T thermocouples were used to measure temperature inside the houses. A Campbell Scientific AM416 multplexer was used in each house to connect each of the signals from 9 thermocouples to the data logger. Thermocouples were hung from the ceiling in sets of three. Each set consisted of a thermocouple at 3 feet, 6 feet, and 9 feet above floor level. The sets of thermocouples were suspended at the hood, 100 feet upstream of the hood, and 100 feet downstream of the hood. Relative locations of all sensors is shown in Figure 2.

OBSERVATION PERIODS

Sensors were installed during 4 production cycles. For each grow-out, the sensors were installed after the chicks were placed and were removed prior to capture. Calibration and installation of instruments relative to chick age are shown in table A-3. Grow-outs starting in September, November, and December of 1996 were observed. During the 1996 grow-outs, observations were made in both houses simultaneously. An additional period of observation began in April 1997. Observations during the April 1997 production cycle were made using both sets of gas sensors placed at different elevations within the new house.

STATISTICAL ANALYSIS

General linear models (GLM), t-tests and correlation procedures were run on the data to compare gas concentrations within each house and between the houses. Comparisons of concentrations by house, week of production, and grow-out were made, comparisons are recorded in appendix D. The procedure general linear modeling was used to describe the relationships between gas concentrations within each house. General linear modeling was also used to determine how data could be used to estimate values for data missing in the database. Programs used for this analysis are shown in appendix C.

Data were arranged into groups based on the house, the month the grow-out started, and the age of the chicks. Each grouping was

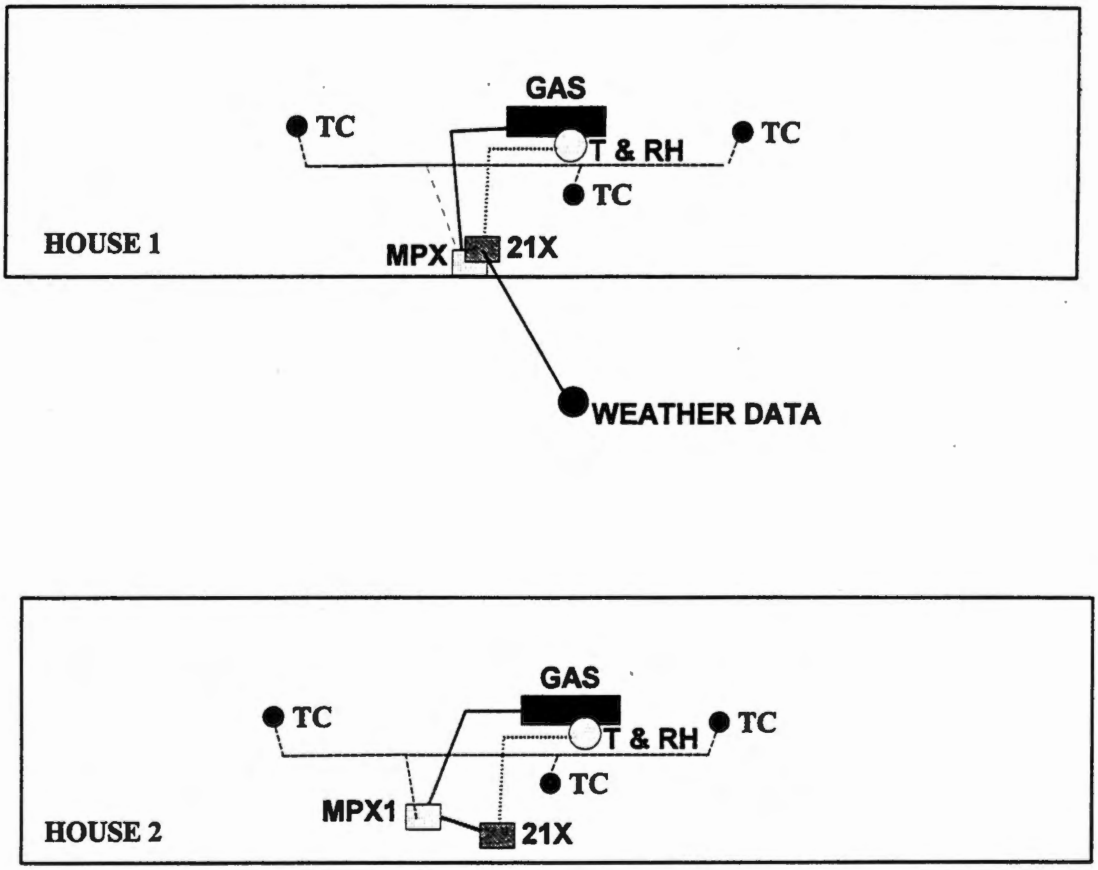

Figure 2. Diagram showing relative positions of data collection equipment.

used to make comparisons of the population means for the period observed. The houses were numbered in the order of construction. The old house was labeled house 1 and the new house was labeled house 2. Grow-outs starting in September, November, and December of 1996 were labeled with the name of the month in which they began. The final sets of observations were made during April 1997 with both sets of sensors placed in house 2. This data is labeled High-Low. The sensors for house 2 were in the same location as for previous observation periods. The sensors previously installed in house 1 were placed one foot above the floor, directly beneath the location of the house 2 sensors. Comparisons of the mean weekly values for all observations are recorded in appendix D.

CHAPTER IV

RESULTS AND DISCUSSION

This research was undertaken to determine if retrofitting a broiler production house with controls and systems similar to newly constructed houses would enable a grower to create an atmosphere in the retrofitted house similar to that of a newly constructed production unit. Regression formulas were created to predict values for oxygen and ammonia within each house using the observations of other gasses and environmental data. A comparison of gas concentrations measured at different heights within the same house was also conducted to determine if sensor location is critical to obtaining an accurate model of gas concentrations at chick level.

AMMONIA RESULTS

Concentrations of ammonia that have adverse effects on production have been established as shown in table 1. The greatest mean value for ammonia observed in either house did not exceed 17.5 ppm (table D-15). Neither house showed a consistently greater concentration of ammonia. House 1 had the higher ammonia concentrations during the November and December grow-outs, but had a mean that was 7 ppm less than house 2 during September. Concentrations of ammonia were statistically different by house ($p<0.0001$), but neither house had mean values great enough to warrant concern for the effects of exposure based on data in table 1. The houses were different, but the structures and control systems controlled ammonia concentrations adequately for known, exposure-related complications.

Models for predicting ammonia concentrations observed during the first 3 weeks of 1996 grow-outs were created using all of the weather and environmental data. The general linear model process was run several times for each house. Each time, variables with relatively low magnitude type III sums of squares f values were removed from the models. This process eliminated all except for the 3 most important variables. The most important variables are shown in table 2. T values are included to show the relative importance and direction of the relationships between the variables and the ammonia concentration. Ammonia in house 1 had an inverse relationship to relative humidity in the house and to outside temperature. These relationships are opposite to the results found in house 2. The houses show differences, but since mean concentrations are maintained at sub-critical levels, both houses are effective in managing ammonia levels during production.

Table 2. Models for ammonia First 3 weeks of production for all 1996 grow-outs

House	Variable	T Value	Probability > |t|
House 1 r2=0.76	Dg	46.28	<.0001
	W107	-11.50	<.0001
	Inrh	-5.69	<.0001
House 2 r2=0.41	W107	20.12	<.0001
	W207	-34.82	<.0001
	Inrh	8.05	<.0001

SENSOR LOCATION COMPARISON FOR AMMONIA

During the April grow-out, data were collected to investigate the importance of sensor location. All gas sensors were installed inside house 2. The sensors used in house two during previous data collection were suspended 5 feet above the floor, the same location as in previous observation periods. The sensors previously installed in house 1 were moved into house 2. These sensors were installed 1 foot above the floor, directly below the high level sensors. These sensor positions will be referred to as high and low.

Mean concentration of ammonia for the entire observation period at the low position was 3.6 ppm (table D-1). Mean ammonia concentrations measured in the high position was 0.9 ppm (table D-15).. The greater concentrations measured by the low sensor are likely due to the proximity of the sensor to the source of ammonia, uricolytic bacteria in the litter. The differences indicate the need to reconsider the location of ammonia sensors. To clarify the discrepancy between the high and low level observations, regression for the variance of the low sensor was run using only the high-level ammonia sensor data as a model. The resulting r^2 indicated that only 20% of the variance in the low-level readings could be explained by the high level ammonia sensor. Concentration of ammonia at chicken level during periods of low ventilation or mixing of the chicken house environment was not measured by the sensors hung 5 feet above the litter. Sensor position is important when measuring ammonia concentrations.

OXYGEN RESULTS

Mean oxygen concentrations for all grow-outs ranged from 19.7% to 20.7% (appendix D). The lowest mean was recorded in house 1 during the December grow-out(Table D-3). The highest mean was recorded in house 2 during the same period. The house 1 mean oxygen levels for both the September and November grow-outs were greater than the house 2 mean oxygen values for the same periods.

Regression models were produced for oxygen levels in each house. The r^2 for oxygen in house 2 using all in-house and weather data for all 1996 grow-outs is 0.77. The r^2 for oxygen in house 1 using in-house and weather data for all 1996 grow-outs is 0.72. In both houses the variable that contributed most to the explanation of the regression was the age of the chicks. The r^2 in these models indicate that the data collected in this study explain the concentrations of oxygen observed in the new house only slightly better than in the retrofitted house.

Regression models for oxygen concentrations during the first 3 weeks of the 1996 grow-outs were produced to eliminate some of the variation explained by the increased oxygen use by the chicks as they age. Eliminating the data from the end of the grow-outs reduced the effect that larger chicks had on the variance of the oxygen concentrations. These 3-week models initially included all of the weather and environmental data for each house for the period. The general linear model process was run several times for each house. Each time, variables with low magnitude type III sums of squares f values were removed from the models. This process eliminated all except for the two most important variables. The most important variables are shown in table 3.

The model for oxygen during the first three weeks of observation in house 1 produced a better explanation of the variance than the model for the entire grow-out data set. The importance of chick age was reduced in both the house 1 and house 2 three-week models. T values are included to show the relative importance and direction of the relationships of the variables to the oxygen concentration. Temperature data collected from the thermocouples in house two were on occasion excessively high. Attempts were made to filter apparently incorrect data. In the case of the thermocouple data in house 2, some values included in the statistical analysis may still be incorrect. If a factor other than temperature caused the variance in the thermocouple data for house two, then the model in table 3 for house 2 is incorrect and should not include the thermocouple variable. Day of grow-out is, however; still important to explaining the concentrations of oxygen in house 2.

Table 3. Models for oxygen First 3 weeks of production for all 1996 grow-outs

House	Variable	T Value	Probability > |t|
House 1 r2=0.81	W107	32.65	<.0001
	Inrh	-36.74	<.0001
House 2 r2=0.67	Dg	-31.39	<.0001
	Tcavg	67.69	<.0001

Trends in the oxygen concentrations apparently follow adjustments to the ventilation system controls. Figure 3 illustrates several issues relative to oxygen levels. The oxygen concentration in house 2 is higher than house 1 for the period shown. The inverse relationship between the house 2 oxygen concentration and day of grow-out is clearly demonstrated. The absence of the importance of day of grow-out to the house 1 model is also illustrated. At days 11, 23, and possibly 17, it appears that ventilation was increased in house 2 to remove moisture, heat, and waste gas. The curve for house 1 also indicates moderate evidence for such changes. After day 27 the gas levels in both houses are relatively close. The oxygen

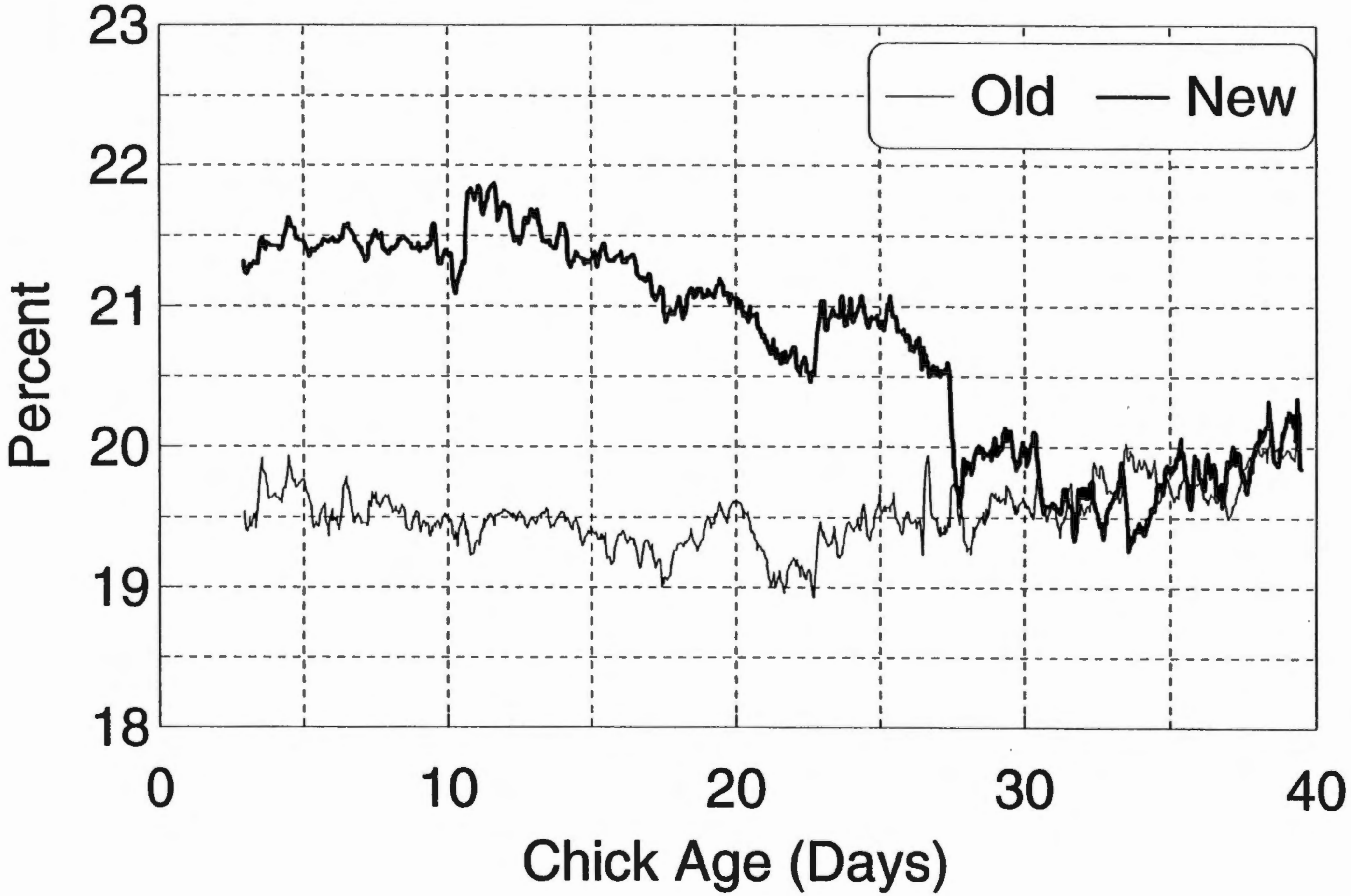

Figure 3. Oxygen concentrations during the December grow-out.

concentrations in both houses, for the remainder of the observation period, are much closer than when the houses are closed to retain heat.

Measurements of the concentrations of oxygen for the April grow-out allow a comparison of the concentrations of oxygen at 5 feet above the floor with concentrations measured at one foot above the floor in house 2. Mean oxygen concentration for April observations at the 5-foot elevation was 20.1%(table D-4). Mean concentration for April observations at the 1-foot elevation was the same. Correlation between the two sensors was 0.92 ($p<.0001$). This close relationship of the oxygen concentrations is illustrated in figure 4. Concentrations of oxygen at chicken level during periods of low ventilation or mixing of the chicken house environment were adequately measured by the sensors hung 5 feet above the litter. Either location, 5 feet above the floor or one foot above the floor will adequately measure oxygen concentrations for the chicken house.

Oxygen use, other than chick respiration, can be attributed to burning propane to heat the chicken house. Reduction in the rate of burning fuel to heat the house reduces the demand for oxygen by the brooders. Increased ventilation removes heat, waste gases, and moisture while it brings in oxygen. The reduction in consumption of oxygen by the brooders does not match the increase in demand by chicks as they grow. This relationship is confirmed in figure 3 where oxygen levels are the lowest near the end of the observation period.

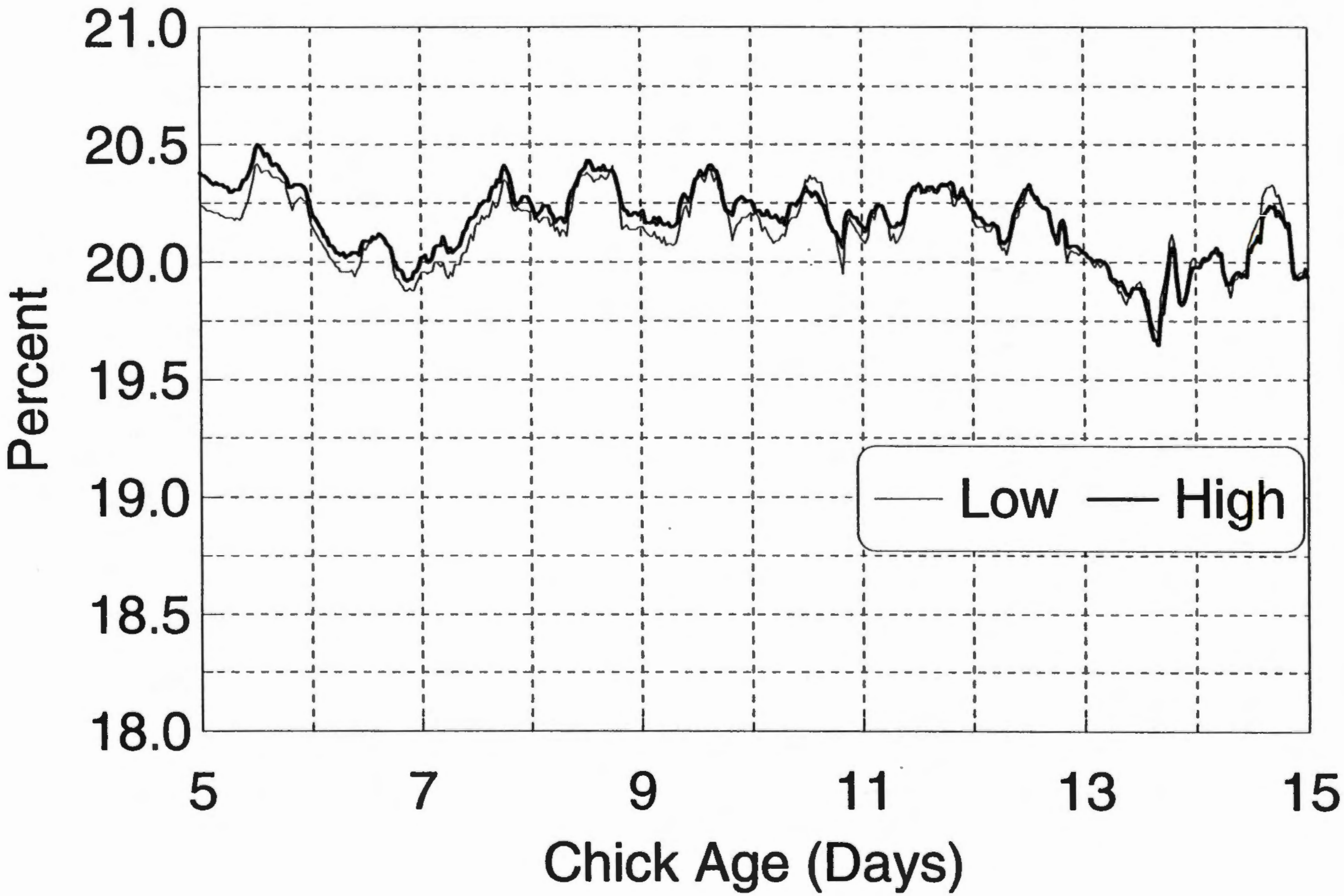

Figure 4. Oxygen concentrations for sensors placed 5 feet and one foot above the floor.

HYDROGEN SULFIDE RESULTS

Hydrogen sulfide was monitored during all measurement periods. Means for hydrogen sulfide in house 1 ranged from 0.48 ppm to 0.90. Means for hydrogen sulfide in house 2 ranged from 0.02 ppm to 7.87 ppm. The importance of hydrogen sulfide production in broiler house environments has not been established in the literature. Because hydrogen sulfide concentrations were monitored during earlier research with this equipment, observations were continued. The data collected during this study indicates a need to review the accuracy of the hydrogen sulfide sensors used. A specific problem appears to be the inability to adequately zero the sensors during calibration. This is especially critical for measuring low magnitudes of hydrogen sulfide concentrations. It also implies the need to consider use of a sensor that is designed to measure magnitudes that are expected in the environment being observed. The normal values for hydrogen sulfide in a broiler house environment will be near zero. A sensor with a range slightly greater than the expected normal concentrations would likely provide more accurate measurements than a device designed for ten times the normal expected during observations. The gas concentration sensors used in these observations were designed to measure up to 100 ppm. Because hydrogen sulfide is not an expected product of broiler house atmospheres, variance in the concentrations measured might indicate an introduced source of the gas. Some possibilities are that propane laced with hydrogen sulfide olfactory indicator leaked near the sensor, the sensors are unable to accurately measure concentrations at or near zero, or there was a source for the production of hydrogen sulfide in house 2.

CARBON MONOXIDE RESULTS

Carbon monoxide in the broiler house environment is a product of the incomplete burning of organic fuels. Low levels of carbon monoxide are produced by brooders that burn propane to keep chicks warm early during grow-outs. Weekly means for carbon monoxide were less than 11 ppm for all grow-out periods. While weekly means were different, the greatest difference was only 6 ppm (appendix D). Neither house stood out as having consistently higher concentrations of carbon monoxide. Figure 5 shows that the major changes in carbon monoxide concentrations in both houses happen in similar magnitude and timing. The tendency for similar changes indicates that the control mechanisms inside the houses are contributing to carbon monoxide levels similarly, or there is a factor that contributes greatly to the variation of carbon monoxide concentrations that is not controlled by either house. Adjustment of brooder thermostats is likely the major factor in carbon monoxide concentrations.

Carbon monoxide concentrations in the chicken houses were highest during times when the need to heat the houses was high. Figure 6 shows that the highest concentrations are present when the chicks are less than a week old. Brooders during this time were set to keep the chicks warmer than any other period during grow-outs. The concentrations dropped quickly as the grower reduced temperatures by about a degree each day.

CARBON DIOXIDE RESULTS

Carbon dioxide is a product of aerobic respiration and other combustion reactions. It is present in the atmosphere, normally.

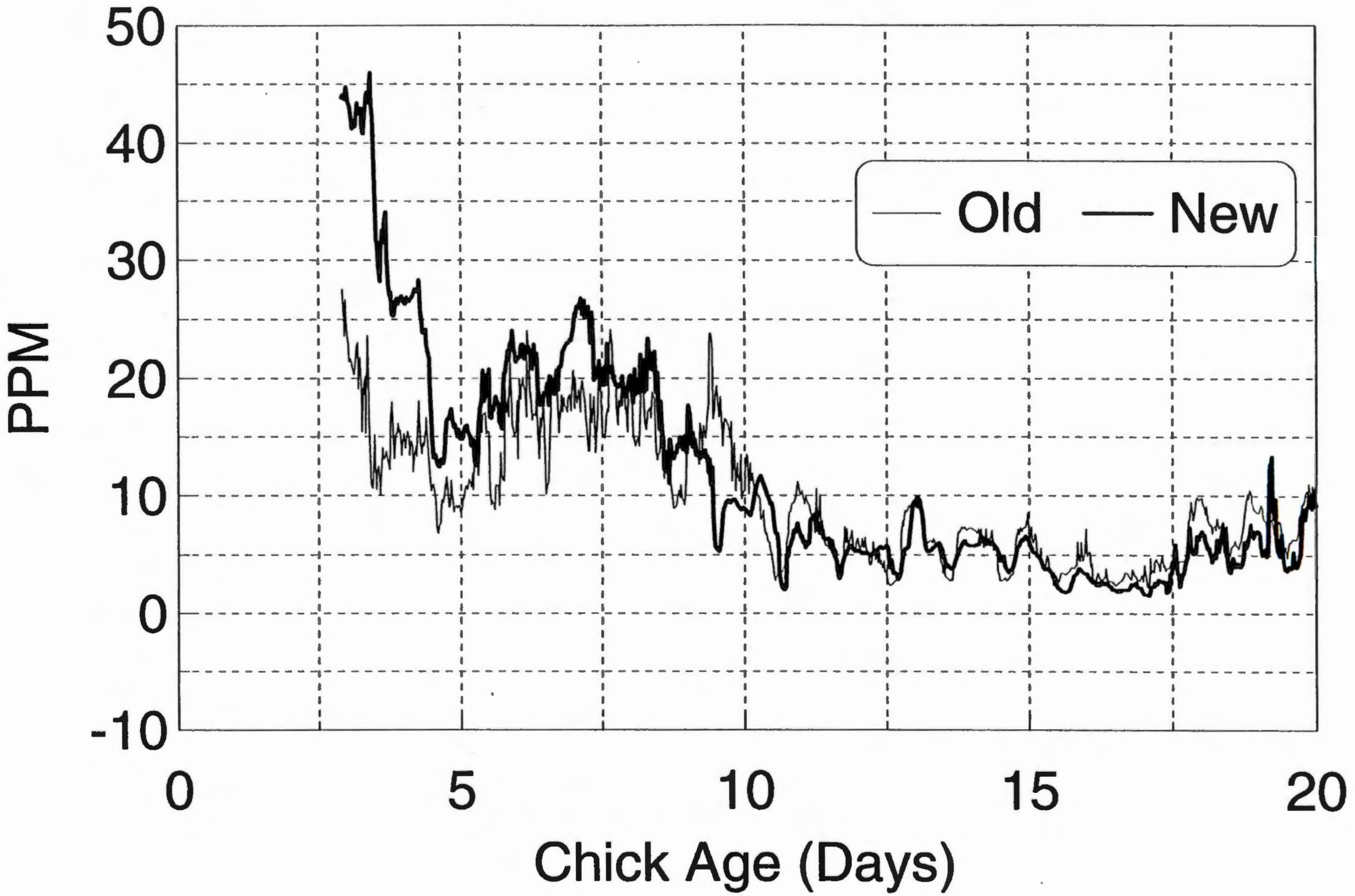

Figure 5. Carbon monoxide concentrations measured during the first half of the November grow-out.

Inside the broiler production unit the primary producers of carbon dioxide are brooders and the respiration of chickens. Mean carbon dioxide concentration for the first three weeks of all the 1996 data is 4775 ppm. As with oxygen, concentrations are affected by the age of the chicks. Three relationships were shown through correlation calculations. Correlation to the age of the chickens was 0.84 ($p<.0001$), correlation to carbon monoxide, another product of combustion, was 0.86 ($p<.0001$), and correlation to in-house relative humidity of 0.98 ($p<.0001$).

Only one carbon dioxide sensor was available for use of this study. Programming errors, equipment malfunction and lack of availability allowed only a small data set to be collected. Comparisons between houses and the high and low positions were not made.

PERSONAL OBSERVATIONS

During the time the author spent inside these houses, a difference in the way the inside environments of the houses felt was apparent. House 2 had a much tighter, quieter feel. Draftiness present in house 1 was absent from house 2. For the author, house 1 was more comfortable. The biggest comfort issue in house 1 was the influx of outside air even when powered ventilation was not happening. Neither house had temperature differences on the floor noticeable to the author, and both houses had tolerable levels of ammonia present at all times. Many hours were spent near the ceiling, standing on ladders, during the first days of grow-outs. There was a dramatic temperature gradient from floor to ceiling. Air close to the ceiling during early grow-out installations approached 50 C in house 2. The occasional light drafts in house 1 were welcome relief.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

SUMMARY

The purpose of this project was to continuously monitor the environment inside two similarly equipped broiler production houses of different age. The analysis showed differences between the houses and allowed description of relationships between atmospheric and weather components. Results show that there are differences between the atmospheric and environmental parameters that exist within each house. The differences appear to be of such a small magnitude that production of chickens would not be affected. The owner-grower was able to control the environment inside the houses so that chicken health should not have been affected. A large data set from several different grow-outs has allowed exploration into explanations of the complex relationships between the components of chicken house environments. The importance of instrument location has been shown, and the need to determine the actual precision of this instrumentation is noted.

RECOMMENDATIONS

Based on the lack of dramatic differences in the environmental conditions in the different aged houses, chicken producers can safely consider retrofitting older chicken houses as an alternative to new house construction. Growers can provide a satisfactory environment for growing broilers in older structures if control systems, and management are adequate.

Many of the models created to explain gas concentrations from this data explained most of the variance for the parameter being tested. There is a need to utilize the capacity of this equipment to further explain the relationships between environmental parameters. Collection and alignment of additional data such as power and fuel consumption, ventilation rates, specific stocking densities, periodic chick mass measurements, outside wind speed, and barometric pressure might contribute to explaining the variance that remains in models describing environmental parameters.

The data shows that early periods of grow-outs allow for better analysis of the environment because the factors affecting of the environment are the structure and control mechanisms of the house. This leads to the suggestion that an adequate model of a production unit could be made during a short period of time, which is strategically planned to observe the first two to three weeks of a grow-out.

BIBLIOGRAPHY

BIBLIOGRAPHY

Buyse, J., E.R. Kuhn, and E. Decuypere.1996. The use of intermittent lighting in broiler raising. Poultry Science 75(5):589-594.

Czarick, M., and M.P.Lacy.1990. Curtain machines and their effect upon broiler house environment. ASAE Paper No.90-4023. ASAE St. Joseph MI.

Deaton, J.W., S.L. Branton, J.D. Simmons,and B.D. Lott. 1996. The effect of brooding temperature on broiler performance. Poultry Science 75:(10) 1217-1220

Elwinger, K., and L. Svensson.1996. Effect of dietary protein content, litter and drinker type on ammonia emission from broiler houses. Journal of Agricultural Engineering Research 64:(3)197-208.

Feddes, Leonard and McQuitty.1984. Carbon dioxide concentration as a measure of air exchange in animal housing. Canadian Agricultural Engineering 26:(1) 53-64

Gempesaw, C.M.and S. Bhargava. 1990. Inter-regional profitability analysis of contract broiler grower investment decisions. Poultry Science. 69:2092-2101.

Leonard,J.J.,J. Feddes and J. B. McQuitty.1984. Air quality in commercial broiler housing. Canadian Agricultural Engineering 26:(1)65-71.

National Draeger, Incorporated. Pittsburgh, PA.

Overhults, D.G. and R.S. Gates. 1994. Energy use in tunnel ventilated broiler housing with different controls. ASAE paper No. 94-4561. ASAE St. Joseph MI.

Quarles, C.L. and H. F. Kling. 1974. Evaluation of ammonia and infectious bronchitis vaccination stress on broiler performance and carcass quality. Poultry Science. 53:1592-1596.

Reece, F.N.1979. The effect of ammonia on the performance of broiler chickens. ASAE Paper No. 79-4004. ASAE St. Joseph MI.

Ross, C.C. and W,D. Daley.1986. Ammonia sensing in broiler house environments ASAE Paper No.86-4044. ASAE St. Joseph MI.

SAS 8.0. 1999. SAS Institute, Incorporated. Cary, NC

Snyder, S.D. 1996. Evaluation of broiler house management systems in East Tennessee: A case study. Masters Th University of Tennessee.

Tennessee Agriculture Statistics, 1999. Tennessee Agriculture Statistics Service

Vanhooser, S.L., A. Beker, and R.G.Teeter.1995. Bronchodilator, oxygen level, and temperature effe incidence in brolier chickens. Poultry Science. 7

Van Wicklen, G.L. and J.M. Allison. 1989. Aerosol and ammonia concentrations in broiler houses using mechanical and natural ventilation. The Journal of Agricultural Engineering Research 42, 97-109.

Van Wicklen, G.L., M. F. Yoder, M. Czarick III. 1986. Respirable particle concentrations in Georgia broiler houses. ASAE Paper No. 86-4046. ASAE St. Joseph MI.

Van Wicklen, G.L., T.L. Foutz, G.N. Rowland, and M.G. Powell. 1994. Determining harmful respirable particle concentrations for broiler chickens. ASAE Paper No.94-4025. ASAE St. Joseph MI.

Weaver W.D. and R. Meijerhof. 1991. The effect of different levels of relative-humidity and air movement on litter conditions, ammonia levels, growth, and carcass quality for broiler-chickens. Poultry Science 70:(4) 746-755.

Xin, H.,. I. L. Berry, and G. T. Tabler.1996. Minimum ventilation requirement and associated energy cost for aerial ammonia control in broiler houses.Transactions of the ASAE 39(2):645-653.

APPENDICES

APPENDIX A

Table A-1 Calibration equations for gas sensors.

Date	Sensor	Refit house	New House
09/02/96	CO	(signal - 958)/12.71	(signal - 1003)/12.85
09/02/96	O_2	(signal - 960)/153.68	(signal - 996)/151.33
09/02/96	H_2S	(signal - 958)/77.05	(signal - 963)/76.54
09/02/96	NH_3	(signal - 986)/37.88	(signal - 974)/14.06
09/02/96	CO_2	No calibration performed	No CO_2 sensor used
11-06-96	CO	(signal - 956)/12.73	(signal - 1006)/12.96
11-06-96	O_2	(signal - 960)/153.64	(signal - 966)/153.92
11-06-96	H_2S	(signal - 965)/76.33	(signal - 969)/76.88
11-06-96	NH_3	(signal - 980)/38.46	(signal - 957)/12.88
11-06-96	CO_2	(signal - 803)/.51158	No CO_2 sensor used
12-20-96	CO	(signal - 960)/12.72	(signal - 1004)/12.80
12-20-96	O_2	(signal - 968)/153.79	(signal - 972)/153.69
12-20-96	H_2S	(signal - 965)/76.33	(signal - 950)/77.59
12-20-96	NH_3	(signal - 968)/38.29	(signal - 1014)/12.54
12-20-96	CO_2	(signal - 950)/.58947	No CO_2 sensor used
3-12-97	CO	(signal - 961)/12.669	(signal - 1005)/12.890
3-12-97	O_2	(signal - 964)/153.97	(signal - 969)/153.88
3-12-97	H_2S	(signal - 962)/76.371	(signal - 965)/76.835
3-12-97	NH_3	(signal - 986)/37.971	(signal - 965)/38.363
3-12-97	CO_2	(signal - 950)/.5938	No CO_2 sensor used
5-21-97	CO	(signal - 956)/12.244	(signal - 1002)/12.89
5-21-97	O_2	(signal - 965)/No span data	(signal - 975)/153.35
5-21-97	H_2S	(signal - 956)/72.743	(signal - 961)/76.456
5-21-97	NH_3	(signal - 1048)/37.61	(signal - 1011)/37.797
5-21-97	CO_2	No calibration performed	No CO_2 sensor used

Table A-2 Calibration gas concentrations.

Sensor	Calibration gas concentration
CO	209 ppm
O_2	Room atmosphere
H_2S	23.7 ppm
NH_3	69 ppm
CO_2	5004 ppm

Table A-3 Calibration and installation dates.

Month of grow-out	Action	Date	Julian Date	Age of chicks in days
September	calibration	09/02/96	246	
	Chick delivery	09/03/96	247	1
	Installation	09/06/96	250	4
	Removal	09/28/96	272	25
November	Calibration	11/06/96	311	
	Chick delivery	10/21/96	294	1
	Installation	11/07/96	312	16
	Removal	12/01/96	336	40
December	Calibration	12/20/96	355	
	Chick delivery	12/26/96	361	1
	Installation	12/27/96	362	2
	Removal	01/28/97	028	39
April	Calibration	03/12/97	71	
	Chick delivery	04/07/97	97	1
	Installation	04/09/97	99	3
	Removal	04/30/97	120	24

APPENDIX B

Table B-1 Data logger program for house 1.

```
};21X
;A:AGCO2.DLD
;$
;:BATT V    :PANEL T   :SIGNAL #1:SIGNAL #2:SIGNAL #3
;:SIGNAL #4:CO2 MV    :ProbeT #2:TEMP107   :ProbRH #1
;:Pyronomet:TC #1     :TC #2     :TC #3     :TC #4
;:TC #5     :TC #6     :TC #7     :TC #8     :TC #9
;:TC #10    :TC #11    :TC #12
;$

MODE 1
SCAN RATE 60

1:P10 Battery voltage
1:1   Location

2:P17 Panel Temperature
1:2   Location

3:P1  Volt (SE)
1:4   Reps
2:5   5000 mV slow range
3:1   IN Chan
4:3   Location
5:1   Multiplier
6:0.0000    offset

4:P2  Volt (Diff)
1:2   Rep
2:5   5000 mV slow range
3:6   IN Chan
4:7   Location
5:1   Multiplier
6:0.0000    offset

5:P11 Temp 107 probe
1:1   Reps
2:8   IN Chan
3:2   Excite all reps Exchan 2
4:9   Location
5:1   Multiplier
6:0.0000    offset

6:P12 RH 207 probe
1:1   Reps
2:9   IN Chan
3:2   Excite all reps Exchan 2
4:9   Temperature Location
5:10  Location
```

```
6:1   Multiplier
7:0.0000    offset

7:P86 Do
1:41  Set high Port 1

8:P87 Beginning of Loop
1:0000  Delay
2:15    Loop count

9:P86 Do
1:72  Pulse Port 2

10:P22   Excitation with Delay
1:1   EX Chan
2:1   Delay w/EX (units=.01s)
3:1   Delay after EX
4:5000   mV Excitation

11:P14 Thermocouple Temp (Diff)
1:1   Rep
2:1   5 mV slow Range
3:3   IN Chan
4:1   Type T
5:2   Ref Temp Loc Panel T
6:12--      Location
7:1   Multiplier
8:0.0000    offset

12:P95      End

13:P20     Set port
1:0   Set low
2:1   port number

14:P92   If time is
1:0000  minutes into a
2:30  minute interval
3:10  set high flag 0 (output)

15:P77   Real Time
1:0110      Day,Hour-Minute

16:P71      Average
1:20  Reps
2:1   Location

MODE 2
SCAN RATE 0.0000

MODE 3

MODE 4
1:00
2:00

MODE 10
```

```
1:35   Input Locations
2:70   Intermediate Locations

MODE 12
1:00   security option
2:0000 security code
```

Table B-2 Data logger program for house 2.

```
};21X
;A:AGWETH.DLD
;$
;:BATT V   :PANEL T  :SIGNAL #1:SIGNAL #2:SIGNAL #3
;:SIGNAL #4:ProbeT #1:ProbeT #2:ProbRH #1:ProbRH #2
;:Pyronomet:TC #1    :TC #2    :TC #3    :TC #4
;:TC #5    :TC #6    :TC #7    :TC #8    :TC #9
;:TC #10   :TC #11   :TC #12
;$

MODE 1
SCAN RATE 60

1:P10 Battery voltage
1:1   Location

2:P17 Panel Temperature
1:2   Location

3:P1  Volt (SE)
1:4   Reps
2:5   5000 mV slow range
3:1   IN Chan
4:3   Location
5:1   Multiplier
6:0.0000    offset

4:P11 Temp 107 probe
1:1 Reps
2:7 IN Chan
3:2 Excite all reps Exchan 2
4:7 Location
5:1 Multiplier
6:0.0000 offset

5:P12 RH 207 probe
1:1 Reps
2:8 IN Chan
3:2 Excite all reps Exchan 2
4:7 Temperature Location
5:8 Location
6:1 multiplier
7:0.0000 offset

6:P11 Temp 107 probe
1:1 Reps
2:9 IN Chan
3:2 Excite all reps Exchan 2
4:9 Location
5:1 Multiplier
6:0.0000 offset
```

```
7:P12 RH 207 probe
1:1 Reps
2:10 IN Chan
3:2 Excite all reps Exchan 2
4:9 Temperature Location
5:10 Location
6:1 multiplier
7:0.0000 offset

8:P2 Volt (Diff)
1:1   Reps
2:2   15 mV slow Range
3:8   IN Chan
4:11  Location
5:.09434    Multiplier
6:0.0000    offset

9:P86 Do
1:41  Set high port 1

10:P87      Beginning of loop
1:0000      Delay
2:10        Loop count

11:P86      Do
1:72        Pulse port 2

12:P22 Excitation with Delay
1:1 EX Chan
2:1 Delay w/EX (units=.01s)
3:1 Delay after EX
4:5000 mV Excitation

13:P14 Thermocouple Temp (Diff)
1:1 Rep
2:15 mV slow Range
3:3 IN Chan
4:1 Type T
5:2 Ref Temp Loc Panel T
6:12-- Location
7:1 Multiplier
8:0.0000 offset

14:P95      End

15:P20      Set Port
1:0         Set Low
2:1         Port Number

16:P92 If time is
1:0000 minutes into a
2:30 minute interval
3:10 set high flag 0 (output)

17:P77 Real Time
1:0110 Day,Hour-Minute
```

```
18:P71 Average
1:20 Reps
2:1 Location


MODE 2
SCAN RATE 0.0000

MODE 3

MODE 4
1:00
2:00

MODE 10
1:28 Input Locations
2:64 Intermediate Locations

MODE 12
1:00 security option
2:0000 security code
```

APPENDIX C

Table C-1. SAS program for data analysis.

```
data one;
infile 'd:\joe milner\sidebyside.csv' dlm=',';
input Dg DAY TIME PYR w107 w207 oINrt oINrh nINrt nINrH oTCAVG nTCAVG
oPVolt
nPVolt oPtemp nPtemp oCO nCO oO2 nO2 oH2S nH2S  oNH3 nNH3 oCO2;

run;
*proc contents data=one;run;

data Jan;set one;

/*input DAY   TIME   nPVolt nPtemp  nCO  nO2  nNH3  nH2S  nINrt
nINrH  Ot  OrH  PYR  nTCAVG


 oPVolt  oPtemp  oCO  oO2  oNH3  oH2S  oCO2  oINrt  oINrh  oTCAVG ;*/


Array Jan Dg DAY TIME PYR w107 w207 oINrt oINrh nINrt nINrH oTCAVG
nTCAVG oPVolt
nPVolt oPtemp nPtemp oCO nCO oO2 nO2 oH2S nH2S  oNH3 nNH3 oCO2;
do over  Jan; if jan=-6999.0 then jan =.; end;
 *if day <240 then temp=day+366; *else temp=day;
 *daytim=temp*10000+time;

 if day ge 250 and day le 263 then growout='sept';
 if day ge 311 and day le 335 then growout='nov';
 if day ge 356 and day le 366 then growout='jan';
 if day ge 0 and day le 34 then growout='jan';

 if dg ge 0 and dg le 6 then ageweek=1;
 if dg ge 7 and dg le 13 then ageweek=2;
 if dg ge 14 and dg le 20 then ageweek=3;
 if dg ge 21 and dg le 27 then ageweek=4;
 if dg ge 28 and dg le 34 then ageweek=5;
 if dg ge 35 and dg le 41 then ageweek=6;

 /* paste this into the high low porgram too    */

 if ageweek le 3;
 if ntcavg lt 0 or ntcavg gt 60 then ntcavg=.;
  if otcavg lt 0 or otcavg gt 60 then otcavg=.;
if oo2 lt 19 then oo2=.;
if no2 lt 19 then no2=.;
 run;


/*
proc corr;
var  DAY TIME nPVolt nPtemp nCO nO2 nNH3 nH2S nINrt nINrH Ot OrH PYR
nTCAVG
 oPVolt oPtemp oCO oO2 oNH3 oH2S oCO2 oINrt oINrh oTCAVG;
run;
```

```
proc corr;  var  DAY TIME nPVolt nPtemp nCO nO2 nNH3 nH2S nINrt nINrH
Ot OrH
PYR nTCAVG
 oPVolt oPtemp oCO oO2 oNH3 oH2S oCO2 oINrt oINrh oTCAVG;
with Day Time PYR OrH;
run;
    */


data long; set jan;
 drop  nPVolt nPtemp  nCO  nO2  nNH3  nH2S       nINrt  nINrH
nTCAVG
       oPVolt oPtemp  oCO  oO2  oNH3  oH2S  oCO2  oINrt  oINrh
oTCAVG ;
house=2;
PV     = nPVolt   ;
Pt     = nPtemp   ;
CO     = nCO      ;
O2     =  nO2     ;
NH3    =  nNH3    ;
H2S    =  nH2S    ;
INrH   =  nINrH   ;
TCavg  =  nTCAVG  ;
output;


house=1;
PV     =  oPVolt  ;
Pt     =  oPtemp  ;
CO     =  oCO     ;
O2     =  oO2     ;
co2    =  oco2    ;
NH3    =  oNH3    ;
H2S    =  oH2S    ;
INrH   =  oINrH   ;
TCavg  = oTCAVG   ;
output;
run;
  /*
proc sort data=long; by house;
proc means data=long; by house;
proc means data=jan;
run;
*/
/*
proc glm;
class house;
model Dg DAY TIME PYR pv pt co o2 nh3 h2s inrh tcavg =house    ;
means house/lsd;
run;


proc reg; where house=1 and nh3>1200;
model  NH3=  CO O2 H2S INrH TCAVG  Day Time PYR OrH /
selection = stepwise slentry=.05 slstay=.05;
model  NH3=  CO O2 H2S INrH TCAVG  Day Time PYR OrH /
```

```
selection = rsquare;

run;

proc reg; where house=1 and nh3>1200;
 model nh3 = day pyr orh;
 output out=rrr r=rnh3;
run;
proc univariate plot normal;
 var rnh3;
run;
proc plot data=long; where house=1;
plot nh3*daytim; run;
*/

/*
proc gplot data=long;plot o2*day=house;
symbol1 i=join;
symbol2 i=join;
run;
*/
/*

proc sort;by growout;
proc corr data=jan;by growout;
var nCO nO2 nNH3 nH2S;
with oCO oO2 oNH3 oH2S;
run;
proc corr data=jan;by growout;
var nCO nO2 nNH3 nH2S;

proc corr data=jan;by growout;
var oCO oO2 oNH3 oH2S;
proc corr data=jan;by growout;where pyr=0;title 'night';
var nCO nO2 nNH3 nH2S;

proc corr data=jan;by growout;where pyr=0;
var oCO oO2 oNH3 oH2S;

proc sort data=long;by growout;title;

proc ttest;by growout;
class house;
var co o2 nh3 h2s;
run;
*/

/*  new stuff july 5
proc sort;by house;
proc glm;where house=1;title 'old house';
model o2=dg  day pt co co2 nh3 h2s tcavg pyr w107 w207  inrh;
run;
proc glm;where house=1;
model nh3=dg day pt co o2 co2 h2s tcavg pyr w107 w207  inrh;
run;
proc glm;by where house=1;
model co2=dg day pt o2 co nh3 h2s tcavg pyr w107 w207  inrh;
```

```
run;

proc glm;where house=2;title 'new house';
model o2=dg day pt co nh3 h2s tcavg pyr w107 w207  inrh;
run;
proc glm;where house=2;
model nh3=dg day pt co o2 h2s tcavg pyr w107 w207  inrh;
run;
title ;
proc sort;by ageweek;

proc ttest;by ageweek;
class house;
var co o2 nh3 h2s;
run;

*/

/* july  20  stuff  here    */

/*  edit, run, save as sasJul20 and email to milner@internetpro.net
and milner@yahoo.com  */
/*  add a stipulation that we only use data when ageweek=1 2 and 3
*/


proc corr data=jan;
var dg DAY TIME nPVolt nPtemp nCO nO2 nNH3 nH2S nINrt nINrH w107 w207
PYR nTCAVG
 oPVolt oPtemp oCO oO2 oNH3 oH2S oCO2 oINrt oINrh oTCAVG;
run;

proc corr data=jan;  var dg  DAY TIME nPVolt nPtemp nCO nO2 nNH3 nH2S
nINrt nINrH w107 w207
PYR nTCAVG
 oPVolt oPtemp oCO oO2 oNH3 oH2S oCO2 oINrt oINrh oTCAVG;
with Day Time PYR OrH;
run;


/*probable interactions
oo2  no2 * nnh3 * h2s * nco  and dg * nco * nnh3   */

/* Additional definitions for ntcavg and otcavg if  they <0 then =.
and if >60 then =.*/

/* if oo2 and no2 are less than 19 then =.  */

/*  Run this model first for old house O2  */

/*  add a stipulation that we only use data when ageweek=1 2 and 3
*/

proc sort data=long;by house;
proc glm data=long;where house=1;title 'OLD HOUSE Oxygen Regression';
model o2=/*dg*/ day pt co nh3 h2s tcavg /*pyr*/ w107 w207  inrh time;
run;
```

```
proc glm data=long;where house=1;title 'OLD HOUSE Ammonia
Regression';
model nh3=dg day pt co o2 co2 h2s tcavg pyr /*w107 w207*/  inrh
/*time*/;
run;

proc glm data=long; where house=1;title 'OLD HOUSE Carbon Dioxide
Regression';
model co2=dg day /*pt o2*/ co nh3 h2s tcavg pyr w107 w207  /*inrh*/
time;
run;

proc glm data=long;where house=2;title 'NEW HOUSE OXYGEN Regression';
model o2=dg day pt /*co*/ nh3 h2s tcavg pyr w107 w207  inrh;
run;

proc glm data=long;where house=2;title 'NEW HOUSE AMMONIA
Regression';
model nh3=dg day pt co o2 h2s /*tcavg*/ pyr w107 w207  inrh;
run;

proc glm data=long; where house=1;title 'OLD HOUSE Carbon monoxide
Regression';
model co=/*dg*/ day pt o2 /*co2*/ nh3 h2s tcavg pyr w107 w207  inrh
/*time*/;
run;

proc glm data=long;where house=2;title 'NEW HOUSE carbon monoxide
Regression';
model co=dg day pt /*o2*/ nh3 h2s /*tcavg*/ pyr w107 /*w207*/  inrh;
run;
title ;
```

APPENDIX D

Table D-1. September grow-out mean gas concentrations.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	20.55	0.06
O_2	%	House 2	20.22	0.14
Difference between means			.33	
NH^3	ppm	House 1	9.93	1.71
NH^3	ppm	House 2	17.23	17.34
Difference between means			-7.30	
H_2S	ppm	House 1	0.48	0.10
H_2S	ppm	House 2	0.02	0.08
Difference between means			.46	
CO	ppm	House 1	-0.41	0.13
CO	ppm	House 2	-2.25	1.17
Difference between means			1.84	

Table D-2. November grow-out mean gas concentrations.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	20.28	0.18
O_2	%	House 2	20.21	0.16
Difference between means			0.07	
NH^3	ppm	House 1	9.42	2.08
NH^3	ppm	House 2	3.49	0.78
Difference between means			5.92	
H_2S	ppm	House 1	0.73	0.17
H_2S	ppm	House 2	4.59	1.06
Difference between means			-3.86	
CO	ppm	House 1	1.43	1.41
CO	ppm	House 2	2.86	1.84
Difference between means			-1.43	

Table D-3. December grow-out mean gas concentrations.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	19.54	0.50
O_2	%	House 2	20.75	0.73
Difference between means			-1.21	
NH^3	ppm	House 1	7.70	3.43
NH^3	ppm	House 2	-1.08	1.30
Difference between means			8.78	
H_2S	ppm	House 1	0.90	0.50
H_2S	ppm	House 2	7.87	1.50
Difference between means			-6.98	
CO	ppm	House 1	7.20	5.25
CO	ppm	House 2	7.81	7.94
Difference between means			-0.61	

Table D-4. April grow-out mean gas concentrations.

Gas	unit	House 2 Sensor Position	Mean	Standard Deviation
O_2	%	Low	19.70	1.39
O_2	%	High	20.04	0.24
Difference between means			-0.35	
NH^3	ppm	Low	3.63	4.39
NH^3	ppm	High	0.91	0.19
Difference between means			2.73	
H_2S	ppm	Low	0.95	1.83
H_2S	ppm	High	3.30	1.86
Difference between means			-2.34	
CO	ppm	Low	6.80	4.55
CO	ppm	High		
Difference between means				

Table D-5. Mean gas concentration summary, week 1 All 1996 grow-outs.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	20.09	0.54
O_2	%	House 2	20.83	0.57
Difference between means			-0.74	
NH^3	ppm	House 1	6.38	3.53
NH^3	ppm	House 2	14.48	21.48
Difference between means			-8.11	
H_2S	ppm	House 1	0.92	0.54
H_2S	ppm	House 2	3.74	4.24
Difference between means			-2.81	
CO	ppm	House 1	8.00	8.27
CO	ppm	House 2	9.40	14.53
Difference between means			-1.40	

Table D-6. Mean gas concentration summary, week 2 All 1996 grow-outs.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	19.46	0.50
O_2	%	House 2	20.84	0.71
Difference between means			-1.37	
NH^3	ppm	House 1	4.07	1.10
NH^3	ppm	House 2	5.38	5.98
Difference between means			-1.32	
H_2S	ppm	House 1	1.26	0.22
H_2S	ppm	House 2	3.49	3.49
Difference between means			-2.23	
CO	ppm	House 1	10.52	5.47
CO	ppm	House 2	4.41	8.00
Difference between means			6.11	

Table D-7. Mean gas concentration summary, week 3 All 1996 grow-outs.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	19.53	.56
O_2	%	House 2	20.76	0.56
Difference between means			-1.23	
NH^3	ppm	House 1	8.58	1.63
NH^3	ppm	House 2	1.04	2.74
Difference between means			7.54	
H_2S	ppm	House 1	1.01	0.20
H_2S	ppm	House 2	6.97	1.61
Difference between means			-5.96	
CO	ppm	House 1	4.55	3.17
CO	ppm	House 2	4.81	2.17
Difference between means			-0.27	

Table D-8. Mean gas concentration summary, week 4 All 1996 grow-outs.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	19.84	0.64
O_2	%	House 2	20.54	0.50
Difference between means			-0.69	
NH^3	ppm	House 1	11.63	1.89
NH^3	ppm	House 2	1.39	2.36
Difference between means			10.24	
H_2S	ppm	House 1	0.98	0.24
H_2S	ppm	House 2	7.57	2.17
Difference between means			-6.59	
CO	ppm	House 1	5.04	3.42
CO	ppm	House 2	4.72	2.34
Difference between means			0.33	

Table D-9. Mean gas concentration summary, week 5 All 1996 grow-outs.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	20.01	0.31
O_2	%	House 2	19.94	0.27
Difference between means			0.07	
NH^3	ppm	House 1	9.23	1.81
NH^3	ppm	House 2	0.31	2.62
Difference between means			8.92	
H_2S	ppm	House 1	0.55	0.21
H_2S	ppm	House 2	5.89	2.19
Difference between means			-5.35	
CO	ppm	House 1	2.33	2.22
CO	ppm	House 2	3.13	2.76
Difference between means			-0.80	

Table D-10. Mean gas concentration summary, week 6 All 1996 grow-outs.

Gas	unit	House	Mean	Standard Deviation
O_2	%	House 1	20.18	0.19
O_2	%	House 2	20.06	0.18
Difference between means			0.12	
NH^3	ppm	House 1	7.46	1.91
NH^3	ppm	House 2	0.49	2.98
Difference between means			6.98	
H_2S	ppm	House 1	0.36	0.26
H_2S	ppm	House 2	4.86	1.23
Difference between means			-4.50	
CO	ppm	House 1	0.95	0.72
CO	ppm	House 2	1.70	1.18
Difference between means			-0.75	

Table D-11. Mean gas concentration summary, week 1 April grow-out.

Gas	unit	House 2 Sensor Position	Mean	Standard Deviation
O_2	%	Low	20.20	0.15
O_2	%	High	20.28	0.17
Difference between means			-0.09	
NH^3	ppm	Low	2.08	0.77
NH^3	ppm	High	1.06	0.19
Difference between means			1.02	
H_2S	ppm	Low	0.71	0.14
H_2S	ppm	High	1.97	0.23
Difference between means			-1.30	
CO	ppm	Low	10.06	4.97
CO	ppm	High		
Difference between means				

Table D-12. Mean gas concentration summary, week 2 April grow-out.

Gas	unit	House 2 Sensor Position	Mean	Standard Deviation
O_2	%	Low	20.15	0.14
O_2	%	High	20.18	0.15
Difference between means			-0.03	
NH^3	ppm	Low	2.15	0.63
NH^3	ppm	High	0.98	0.16
Difference between means			1.16	
H_2S	ppm	Low	1.05	1.65
H_2S	ppm	High	1.71	0.23
Difference between means			0.48	
CO	ppm	Low	8.84	4.62
CO	ppm	High		
Difference between means				

Table D-13. Mean gas concentration summary, week 3 April grow-out.

Gas	unit	House 2 Sensor Position	Mean	Standard Deviation
O_2	%	Low	19.98	0.20
O_2	%	High	19.90	0.19
Difference between means			0.03	
NH^3	ppm	Low	3.65	1.14
NH^3	ppm	High	0.84	0.14
Difference between means			2.81	
H_2S	ppm	Low	1.10	2.56
H_2S	ppm	High	4.28	1.66
Difference between means			-3.50	
CO	ppm	Low	4.70	3.14
CO	ppm	High		
Difference between means				

Table D-14. Mean gas concentration summary, week 4 April grow-out.

Gas	unit	House 2 Sensor Position	Mean	Standard Deviation
O_2	%	Low	17.77	2.62
O_2	%	High	19.82	0.12
Difference between means			-2.05	
NH^3	ppm	Low	8.01	9.24
NH^3	ppm	High	0.73	0.07
Difference between means			7.28	
H_2S	ppm	Low	0.56	0.07
H_2S	ppm	High	5.74	0.55
Difference between means			-5.18	
CO	ppm	Low	4.00	1.75
CO	ppm	High		
Difference between means				

Table D-15. Mean gas concentration summary, All 1996 grow-outs.

Gas	unit	House	Mean
O_2	%	House 1	19.54
O_2	%	House 2	20.88
NH^3	ppm	House 1	7.98
NH^3	ppm	House 2	3.15
H_2S	ppm	House 1	None calculated
H_2S	ppm	House 2	
CO	ppm	House 1	8.34
CO	ppm	House 2	10.87
CO_2	ppm	House 1	4775.2

APPENDIX E

Table E-1. Correlation coefficients for first 3 weeks of all 1996 grow-outs house 1

Coefficient Prob > |r|	Nh3	H2s	co	Co2
O2	0.3414 <.0001	-0.690 <.0001	-0.536 <.0001	0.288 <.0001
Nh3	1	-0.447 <.0001	-0.684 <.0001	0.646 <.0001
H2s		1	0.712 <.0001	0.878 <.0001
Co2			1	0.861 <.0001

Table E-2. Correlation coefficients for first 3 weeks of all 1996 grow-outs house 2

Coefficient Prob > |r|	Nh3	h2s	co
O2	-0.236 <.0001	0.684 <.0001	0.612 <.0001
Nh3	1	-0.459 <.0001	-0.366 <.0001
h2s		1	0.688 <.0001

Table E-3. Correlation coefficients for low sensors April 1997

Coefficient Prob > |r|	Onh3	Oh2s	Oco
Oo2	-0.208 <.0001	-0.122 0.0004	0.048 0.1661
Onh3	1	-0.078 0.025	-0.572 <.0001
Oh2s		1	0.046 0.1872

Table E-4. Correlation coefficients for High sensors April 1997

Coefficient Prob > |r|	Nnh3	nh2s	nco
No2	0.140 <.0001	-0.466 <.0001	No data
Nnh3	1	-0.252 <.0001	No data
Oh2s		1	No data

Table E-5. Model for House 1 oxygen First 3 weeks of production for all 1996 grow-outs r2=0.81.

Variable	t Value	Probability > |t|
W107	32.65	<.0001
Inrh	-36.74	<.0001

Table E-6. Model for House 1 ammonia First 3 weeks of production for all 1996 grow-outs r2=0.76.

Variable	T Value	Probability > |t|
Dg	46.28	<.0001
W107	-11.50	<.0001
Inrh	-5.69	<.0001

Table E-7. Model for House 1 hydrogen sulfide First 3 weeks of production for all 1996 grow-outs r2=0.01.

Variable	T Value	Probability > |t|
Dg	2.10	0.0361
Inrh	-3.59	0.0001

Table E-8. Model for House 1 carbon monoxide First 3 weeks of production for all 1996 grow-outs r2=0.73.

Variable	T Value	Probability > |t|
Dg	-31.98	<.0001
Pt	-19.31	<.0001
W107	-23.56	<.0001

Table E-9. Model for House 1 carbon dioxide First 3 weeks of production for all 1996 grow-outs r2=0.84.

Variable	T Value	Probability > |t|
pt	-31.51	<.0001

Table E-10. Model for House 2 oxygen First 3 weeks of production for all 1996 grow-outs r2=0.67.

Variable	T Value	Probability > |t|
Dg	-31.39	<.0001
tcavg	67.69	<.0001

Table E-11. Model for House 2 ammonia First 3 weeks of production for all 1996 grow-outs r2=0.41.

Variable	T Value	Probability > |t|
W107	20.12	<.0001
W207	-34.82	<.0001
inrh	8.05	<.0001

Table E-12. Model for House 2 hydrogen sulfide First 3 weeks of production for all 1996 grow-outs r2=0.55.

Variable	T Value	Probability > |t|
Dg	15.33	<.0001
Tcavg	46.23	<.0001
Inrh	-20.07	<.0001

Table E-13. Model for House 2 carbon monoxide First 3 weeks of production for all 1996 grow-outs r2=0.50.

Variable	T Value	Probability > |t|
Dg	-6.61	<.0001
W107	-23.54	<.0001
inrh	-27.09	<.0001

VITA

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