EVALUATION OF ECONOMIC GAINS TO BROILER PRODUCERS BY MODULATING VENTILATION AND USING ALUM FOR AMMONIA CONTROL

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TABLE OF CONTENTS

Chapter Page

Chapter Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

In recent years, the environmental effects of agriculture, especially livestock production, have become the focus of both regulation and litigation. Liability rules that apply to agricultural producers come in part from federal and state environmental laws and regulations. The federal Clean Water Act and Clean Air Act, among other laws, include provisions that apply to livestock producers.

> "*Having completed substantial revisions of regulations intended to reduce water pollution from animal production facilities, the EPA is now taking a closer look at the impact of the livestock industry on air quality. One of the things that agriculture is facing is being brought under the Clean Air Act, as you're already under the Clean Water Act with the CAFO (Concentrated Animal Feeding Operations) rules. We've got more people in this country, we've got more and larger livestock operations, and to be blunt about it, when you have houses right next door to livestock operations, you have people complaining about odor. Stricter regulation is, inevitable within a few years*." (Gray, 2004).

AFO (Animal Feeding Operations): A Public Health Hazard?

The increasing concentration of food production from animals in very large feeding operations has focused public attention on associated environmental issues. These include the effects of air emissions, especially those that come from the large quantities of manure produced by the animals.

Past research has identified a range of potential problems from confined animal agriculture. These include emissions of odors and ammonia from animal production facilities, runoff of nutrients and other manure constituents from farmsteads, degradation of surface and ground water quality due to the runoff and leaching of nutrients, trace metals, pathogens, and hormones when animal manures are applied to crop land. (Sims et al., 2002).

Among other gases and odors a major pollutant from CAFOs is Ammonia (NH_3). Although ammonia is not a criteria pollutant, state and local air agencies are required to collect and report emissions as per EPA rules because it is a precursor for secondary $PM_{2.5}$, which is a criteria pollutant under the Clean Air Act (EPA Fact sheet, 2002). Particulate matter has been linked to a variety of adverse health effects including premature mortality, asthma, and chronic bronchitis. Large poultry layer houses emitting significant quantities of NH_3 into the atmosphere are potentially at risk if they are identified as point sources for emission of ammonia.

Sources of Ammonia

Typical sources of ammonia include livestock, fertilizer, soils, forest fires, slash burning, industry, vehicles, the oceans, humans, pets, wild animals, and waste disposal and recycling activities. Livestock is the largest source category of ammonia in the United States. Waste from livestock was responsible for about $3x10^9$ kg (approx. 6.6 $x10^9$ lb) of ammonia in 1995(Anderson et al., 2003). McCubbin et al. (2002) suggest that a 10 percent reduction in livestock ammonia emissions can lead to savings of over 4 billion United States dollars annually in particulate related health benefits.

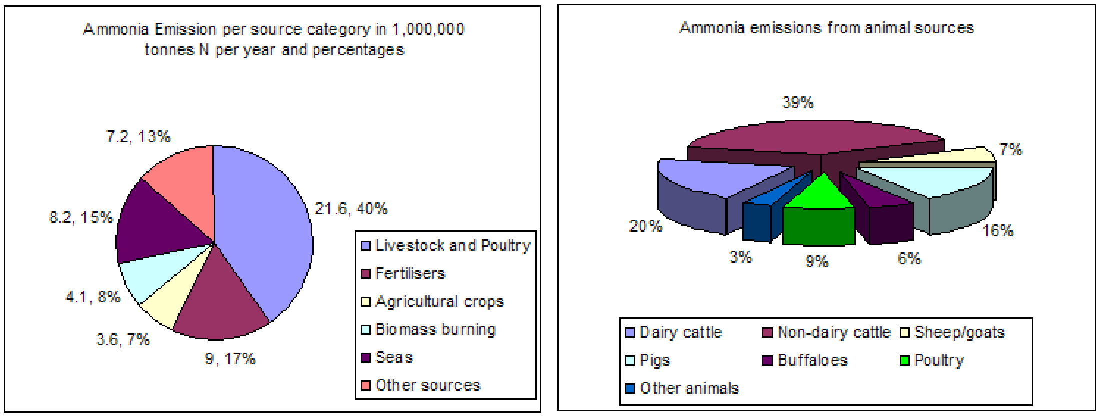


Figure 1. Global distribution of ammonia emissions from various sources.
Source: Global emission inventory for ammonia, with emphasis on livestock and poultry, American Dairy Science Association Website, adapted from a report by the Danish Institute of Agricultural Sciences.

Problems caused by current trends in poultry industry

- The system of poultry broiler production consists of a system with a bedding material such as straw, rice hulls, wood shavings added to the floor of the poultry house. The litter accumulates on this bedding and after the broiler growth cycle ends, it is stripped off from the floor and land applied as fertilizer. This mixture of litter and manure is effectively a nitrogen and phosphorus storehouse. Traditional litter materials, wood shavings and saw dust have become more expensive as they are being diverted to more profitable uses. Economic reasons dictate that broiler growers accumulate litter over 5 to 6 flocks or even longer before stripping the bed forcing the cleanout frequency to once a year. Decomposition of the uric acid leading to ammonia volatilization is a process, which commences almost immediately after excretion.
- Increased per capita consumption of broiler meat and increased interest costs have caused a shortage in broiler housing areas. The industry has increased the

packing density of birds and reduced the layout time between batches to less than a week (Ralph et al., 1985). This leads to a higher concentration of fecal matter in an already crowded poultry house.

- Increased energy costs have led growers to adopt practices like partial house brooding. A lower ventilation rate in winter can conserve fuel for supplemental heating and lower production costs since as much as 80 percent of total heat loss from a typical livestock facility is due to heat exhausted by ventilation air (Xin et al., 1986). Since the building will be warmer due to lower ventilation the maintenance energy for the birds will be reduced and feed efficiency is expected to improve. The flipside is, the air quality is compromised because reduced rates of ventilation during brooding will allow ammonia concentrations to build up (Xin et al., 1986). This allows the exposure of very young birds during brooding to high concentrations of ammonia.
- A typical broiler house with capacity for 22,000 birds at a time will produce 120 tons of litter per year (NCC, 1999). With increasing production, specialization, and confinement, disposal of the waste is problematic. Animal production facilities may not have enough land to incorporate all of the waste as fertilizer, and it may not be economical to transport it to locations needing fertilizer. Thus extensive land application is not the answer.

Problems Caused By Ammonia

Decrease In Poultry Performance

Charles and Payne (1966) showed that feed intake was reduced when broiler chickens were reared in atmospheres containing high concentrations of ammonia after 28 days of age. Body weights and feed efficiencies at 8 weeks were reduced when broilers were exposed to up to 50 ppm ammonia in the 4 to 8 week grow out period (Quarles and Kling, 1974, cited by Reece, Lott and Deaton, 1980a). Exposure of broilers to ammonia at concentrations of up to 50 ppm of ammonia during the 0 to 28 days period decreased feed efficiency (Reece, Lott and Deaton, 1980a cited Caveny and Quarles, 1978). Even after exposure to ammonia was stopped after 28 days, weight of birds at market age was significantly less than unexposed birds (Reece, Lott and Deaton, 1980a). Reece et al. (1980b) found that exposing broiler chickens to different levels of ammonia reduced weight gain by 10 percent at 50 ppm exposure and by 25 percent at 200 ppm after 4 weeks as compared to unexposed batches. Along with the aforementioned instances of “performance loss” and decreased egg production (Deaton et al., 1984), broilers exposed to ammonia are also found to be more disease prone. Ammonia concentrations of just 5 ppm, although undetectable by the human nose have been shown to irritate and injure the protective lining of the chick's respiratory system. Other studies report an increased susceptibility to Newcastle Disease (Anderson et al., 1964), increased incidences of airsaculitis (Kling and Quarles, 1974) along with higher incidences of keratoconjunctivitis (Bullis et al., 1950). Other ailments related to chronic ammonia exposure are mycoplasma gallisepticum (Sato et al., 1973) and immunosuppression (Nagaraja et al., 1983).

Health Risks To Workers

The human nose can detect ammonia at levels of around 20 ppm but prolonged exposure to this level of ammonia causes them to lose this sensitivity. The Occupational Safety and Health Administration (OSHA)'s ammonia exposure limit for general industry is 50 ppm exposed as an 8-hour Time Weighted Average (TWA). The National Institute for Occupational Safety and Health (NIOSH) recommends an exposure limit of 25 ppm. (US Dept. of Labor, OSHA).

Table 1. Physiological effects of ammonia exposure at different concentrations

Atmospheric concentration Of Ammonia	Physiological effect
20 ppm	First perceptible odor
40 ppm	A few individuals may suffer slight eye irritation
100 ppm	Noticeable irritation of eyes and nasal passages after a few minutes exposure
400 ppm	Severe irritation on the throat, nasal passages, and upper respiratory tract
700 ppm	Severe eye irritation. No permanent effect if the exposure is limited to less than one half hour
1700 ppm	Serious coughing bronchial spasms, less than half hour of exposure may be fatal
5000 ppm	Serious edema, strangulation, asphyxia, fatal almost immediately

Source: Adapted from "Broiler response to three ventilation rates", Carr and Nicholson, 1980b

Exposure to ammonia can cause lacrimation, burning sensation, swelling of larynx, spasm of glottis, asphyxia, conjunctivitis, laryngitis, severe pulmonary and gastrointestinal irritation, nausea, vomiting, abdominal pains, pulmonary edema, dyspnea, bronchospasm, chest pain, vesiculation, wheezing, cold and clammy skin, convulsions, collapse, coma, and even death from acute laryngeal edema. Milder exposure may predispose to bronchopneumonia following a chemical pneumonitis (National Safety Council). The physiological effect by level of ammonia concentration are shown in table 1.

- Ammonia increases the efficiency of sulfur dioxide wet deposition and therefore increases the local impact of SO_2 emissions.
- Sulfuric and nitric acids react with ammonia to produce ammonium sulfate and nitrate particles, which are deposited more slowly than the parent acids and can be transported over greater distances.
- Soil micro-organisms convert ammonia to nitrate releasing hydrogen ions, which increase the acidity of the soil.

This process of acidification can be linked to acid rain. Atmospheric ammonia deposition in fresh water is also responsible for eutrophication. Nitrate content in streams can be linked to nitrogen fallout from atmospheric nitrogen loading. Another problem of note is the generation of PM_{10} pollutants or particulate matter less than 10μ in size whose source is ammonium nitrate formed when atmospheric ammonia reacts with NOx. Particulates are of concern for human health and are regulated under the Clean Air Act. Animal manures represent one of the more dominant sources of ammonia in the atmosphere. Control of the ammonia flux from poultry houses deserves a great deal of attention. Atmospheric ammonia concentration is also thought to contribute to global warming. (Wathes et al., 1997).

Lowered Fertilizer Value Of Litter Due To Nitrogen Loss

Ammonia volatilization lowers the nitrogen content of poultry litter. Not only does a reduced nitrogen level decrease the fertilizer value of litter but it reduces the N : P ratio of litter. The nitrogen to phosphorus ratio in poultry litter is around 2 and less whereas crops require this ratio to be around 8. On application of litter with a low N : P ratio, plants utilize the plant available N but not the P. This results in a net surplus of phosphorus in or on the soil. This in turn leads to increased P runoff and an increased possibility of it leaching into the ground water. This is said to a potential "time bomb", pointing to the significant time delay between P enriched litter application and adverse environmental impacts like eutrophication.

It is evident that ammonia in excessive quantities is not only a matter of immediate concern to a grower and to the quality of his produce but a concern to the environment as an externality as well.

Rationale Behind The Study

The identification of the key problems linked to ammonia emission encouraged an exploration of the methods of ammonia control. The methods by which ammonia can be controlled can be classed into a few broad management practices which depend on where and how ammonia is eliminated. They are:

1. Minimization "at source" by diet modifications
2. Confinement of production areas by minimization of emitting surface area and ventilation adjustments

3. Treatment of manure by chemical precipitation, biological nitrification, and acidifying additives
4. Land application by injection into soil

A need to explore chemical amendments and ventilation management as a viable method of ammonia control was believed necessary due to the following claims:

Claim1. Increased ventilation will solve most of the problems associated with ammonia volatilization. Though this is true in summer, it is an expensive solution in the winter due to increased energy costs required to heat the higher volume of air. Elliot and Collins (1982) stated that maintaining a safe ammonia level of less than 25 ppm during the first week for flocks grown on old litter requires ventilation of rates 10 times as high as normal rates. Xin et al. (1996) calculated minimum ventilation requirements to control ammonia between 25 and 30 ppm. They found the ventilation required, largely exceeded normal minimum ventilation rates needed for moisture control during the first week of brooding.

Increased ventilation exhausts the ammonia out of the system, however it does not address the externality problem. The exhausted ammonia is released to the atmosphere. The grower contributes to pollution and could be liable under air pollution legislation if identified as a point source. Higher ventilation rates in the building also exacerbate dust problems from dry litter.

Claim2. The addition of certain chemicals may stop the generation of ammonia gas by changing the pH of the litter. Some chemicals especially alum have shown promise in reducing phosphorus related pollution related problems. This is because reducing phosphorus runoff from fields receiving poultry litter can reduce eutrophication in the watersheds (Moore et al., 1995).

Objectives Of This Study

The overall objective of this study is to determine the costs and benefits of using aluminum sulfate (alum) to reduce ammonia in broiler houses. Specific objectives are to:

- Develop a scalable and dynamic ventilation model that is based on the increasing weight of a broiler and the ammonia it generates.
- Determine the economic gains a poultry grower will get by adopting alum as a means of ammonia control.

Regulatory Overview

Concentration in the livestock industry has resulted in large facilities, often with accompanying increases in emissions to water and air. Regulatory changes have imposed additional obligations on producers and may increase production costs. Livestock producers can avoid legal controversy by following legal requirements. Legislation specific to livestock produces and facilities described below is from Grossman (2002)

Clean Water Act *(Us Code: Title 33, Chapter 26)*

The federal Clean Water Act (CWA) was designed to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters". The CWA protects water quality through regulatory measures, including ambient water quality standards, limits on effluents, and permits (USEPA, Clean Water Act).

Under the CWA, concentrated animal feeding operations (CAFOs) are defined as "point sources" of water pollution. Therefore, they are subject to requirements of the National Pollutant Discharge Elimination System (NPDES) and may discharge pollutants only in compliance with an NPDES permit. Animal feeding operations that are not regulated as point sources are considered nonpoint sources. Non point sources are only subject to less rigid state planning programs under the CWA. Some nonpoint sources will also be regulated through state Total Maximum Daily Load (TMDL) programs required by the CWA (adapted from Grossman, 2002).

New federal CAFO regulations

The EPA first enacted regulations for CAFOs in the 1970s, Effluent Limitations Guidelines and Standards (ELGs) in 1974, and NPDES permit requirements in 1976. Consolidation of the livestock industry has led to a review of the CAFO regulations, beginning in 1992. In 1998, the US Clean Water Action Plan identified polluted runoff from agriculture as one of the serious water quality problems facing the United States and recommended that EPA and USDA develop a national strategy to minimize environmental and public health impacts of livestock production. After publishing preliminary documents, USDA and EPA cooperated to prepare the Unified National Strategy for Animal Feeding Operations. This strategy, established a national goal to minimize water pollution from confinement facilities and land application of manure. It indicated that CAFOs would be expected to develop and apply comprehensive nutrient management plans. In January 2001, EPA proposed regulations that would revise the NPDES provisions that define CAFOs and require permits and the ELGs (Effluent

Limitation Guidelines) that set technology-based standards for effluent limitations from CAFOs. Complying with the new regulations, especially the nutrient management plan is likely to increase costs for livestock producers (Grossman, 2002).

Clean Air Act *(US Code: Title 42, Chapter 85)*

Air emissions produced by livestock facilities include several pollutants regulated under the federal Clean Air Act, which governs air quality in the United States. Important "substances of concern" emitted by livestock facilities are ammonia, hydrogen sulfide, particulate matter, nitrous oxide, nitric oxide, methane, volatile organic compounds, and odor. Criteria pollutants and the hazardous air pollutants are a major focus of regulation. To regulate criteria pollutants, the national ambient air quality standards (NAAQS) program is central. EPA has established primary NAAQS for six criteria pollutants: sulfur dioxide, nitrogen dioxide, particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide, ozone, and lead. Under the CAA, the livestock producer who plans to construct a new livestock facility may have to obtain an air pollution permit prior to construction or operation, if the facility is large enough to be considered a "major" source. Generally, a major source is a stationary source that emits, or has potential to emit, 100 tons per year or more of any air pollutant (USEPA, Clean Air Act, and Grossman, 2002).

CERCLA and EPCRA

The Comprehensive Environmental Response, Compensation and Liability Act *(US Code: Title 42, Chapter 103)* and Emergency Planning and Community Right-to-

Know Act *(US Code: Title 42, Chapter 116)* requires, facilities that release pollutants above set minimum reportable quantities of certain hazardous pollutants may require to report these emissions. For livestock facilities the reportable level for substances like hydrogen sulfide and ammonia is 100 lbs/day. Although the EPA has rarely enforced the reporting requirement for livestock facilities, large livestock operations are still vulnerable to citizen suits for failure to report (Grossman, 2002).

Safe Harbor Agreement Proposal

An October 2003 draft of the industry lobbyists proposed safe harbor agreement indicates an intention "to address emissions of air pollutants and hazardous substances and to ensure that participating AFOs (eventually) comply with provisions of the CAA and CERCLA. This would be accomplished by applying emission-estimating methodologies developed in a monitoring program funded by participating AFOs". Under the draft agreement, each participating AFO will pay a civil penalty of $500 and contribute $2,500 to implement a nationwide monitoring program for AFOs. Each facility must make their facility available for monitoring, and submit regular monitoring (conducted by independent contractors) reports to the EPA for pollutants like particulates, ammonia, hydrogen sulfide, volatile organic compounds, and nitrogen oxides. In exchange for participation, the EPA will agree not to sue facilities for failure to comply with certain CAA permit requirements. These include CAA obligations triggered by emission thresholds, and required reporting under CERCLA. The safe harbor proposal has been met with strong objections from the members of the environmental community and state and local air pollution administrators (Grossman, 2002).

Common-Law, Torts

Livestock producers also face liability under common-law tort principles. These are usually based on state law. Under the common law producers are liable when their actions cause environmental or other damage to the person or property of others. Tort claims associated with livestock facilities often result from the presence of odors. However manure spills and improper manure applications have also led to lawsuits against producers. Remedies available in tort cases include monetary damage awards and, less often, injunctions against defendant's behavior (Grossman, 2002).

CHAPTER II

LITERATURE REVIEW

Physics of Ventilation

Ventilation is a system of air exchange which accomplishes one or more of the following (Oderkirk, 2001):

- Provision of adequate fresh air at all times,
- Distribution of fresh air uniformly without causing drafts,
- Regulation of temperature,
- Exhaustion of the respired moisture, and
- Removal of odors and gases.

A ventilation rate that can moderate summer temperature fluctuations and limit winter moisture buildup is sufficient for most needs. Though this rate suffices for ideal design conditions, for poultry grown on manure require more ventilation to manage the high levels of ammonia.

Ventilating Systems For Livestock

Natural

The effectiveness of natural ventilation systems depend on the heat production of the birds, the solar heat, the shed design, the configuration and operational state of various openings, the ambient wind speed and the orientation of the shed relative to the wind. These systems operate without fans, and as a result have minimal or no ventilation cost. Thermal transport arises where temperature varies between locations. Air near the floor is warmed by the bird bodies and gently rises to the shed ceiling. The upper air is cooled by conduction through the roof ceiling and moves downward towards the bird and litter surface. In addition there is a superimposed slow movement of the air above the birds along the longitudinal axis of the shed driven by the net result of differential temperature and leakage effects arising from ambient wind speed and other factors such as bird movement. This method is not very effective for modulating temperatures when there are severe fluctuations. Therefore their application is limited to housing supporting mature animals whose performance is not adversely affected by large variations in temperature.

Mechanical

Mechanical ventilation systems unlike natural systems, force air movement by using large fans. These systems can better control the air flow rate to match the varying needs of livestock in the building. Mechanical ventilation systems can be of three types:

Negative Pressure (the most common type and the one on which this model is based)

This system forces air out of the system, causing a reduced pressure in the system which causes fresh air from the outside to get sucked in through the inlets. This system along with recirculation is especially suited to remodeled buildings where leaks interfere with ventilation. This system can provide good distribution even at lower ventilation rates (MidWest Plan Service - 32, 1990).

Positive Pressure

This system forces air into the system through fans, while forcing the exhaust air out through outlets due to the higher pressure inside the system. These systems work well with “below floor manure storage”. A disadvantage of this system is that warm, moist air under pressure moves into all the cracks in the building walls and ceiling seeking openings to the lower pressure outside. In winter due to condensation on the surface of the walls the insulation capacity is impaired along with the integrity of the insulation material.

Neutral Pressure

Fans force air into and out of this system, the pressure being the same as the outside pressure. One fan pushes air into the system through a duct while an exhaust fan pulls stale air out of the room. The two fans create a near neutral pressure inside the room which reduces the effect of leaks (MidWest Plan Service, 1990).

Ventilation Design Concepts

Ventilation rates are designed to balance sensible heat gains and losses, as well as latent heat gains and losses. Sources of sensible heat gain in poultry and livestock shelters include body heat, mechanical heat from lights, motors, supplemental heat from furnaces or lamps, and solar heat gain. Sensible heat losses include heat removed with ventilating air, heat losses through doors, walls, and sensible heat used to evaporate water. Sources of latent heat gain are from animal respiration, animal waste, water vapor from wash water, flush water, spilled water, and water vapor in incoming air. Latent heat is removed through ventilation (Porter, 1998).

Animal Heat Loss

Poultry like most farm animals try to maintain a constant body temperature by either losing metabolic heat to their surroundings or by modulating their body temperature. If an animal cannot lose heat fast enough it overheats. Similarly it chills if it cannot trap its body heat in colder temperatures.

The modes by which heat loss occur are:

- Conduction,
- Thermal Radiation,
- Convection, and
- Evaporation.

Among the above modes, conduction, radiation, and convection are sensible heat losses while evaporation is a latent heat loss (MidWest Plan Service, 1990).

Principles of Moisture Balance

The modes of entry for water or water vapor into the system are through evaporation from surfaces, from manure, from respiration of the animals, and through inlet air. The amount of moisture to be removed varies with species. A ventilation system has to work to remove excess moisture from the livestock house environment. However the amount to be removed depends on the kind of animal housed. MidWest Plan Service - 34, (1990) suggests ventilating the room to maintain the air between 40 percent and 60 percent relative humidity. This is because higher humidities tend to increase condensation where as lower levels aggravate dust problems. The low humidity zone is the least favorable to the growth of airborne bacteria found in livestock buildings.

Heat Balance Principles

Ventilation systems function on the principle of heat balance. Heat balance means:

$$HEAT\ LOSS = HEAT\ GAIN.$$

For the maintenance of a constant room temperature, heat produced by livestock or poultry has to equal heat lost through building walls, floor, the roof, and ventilation. It must also be added that "the value of sufficient insulation cannot be over emphasized as it plays such an important role in achieving a good heat balance year round" (Oderkirk, 2001). The equation for ventilation heat loss is:

$$VHL = cfm_c * 1.1 * (T_{IN} - T_{OUT}),$$

Where VHL = Heat loss by ventilation air in Btu/hr, cfm_c = cold weather ventilation air in cu.ft./min and T_{IN}, T_{OUT} being internal and external temperatures in °F.

Air Volume Requirements

Requirements for airflow, like humidity requirements, vary with the animal species and with their size. The system should be designed with three temperature conditions in mind: cold, mild, and warm weather. Ideally, ventilating air must vary from "just enough air to maintain air quality" during very cold weather up to a "maximum rate to prevent heat stress" during hot weather according to MidWest Plan Service - 34, (1990) ventilation guidelines.

MidWest Plan Service - 34, (1990) suggests that ventilating rates should be based on animal numbers or body weight so as to eliminate the animal density in ventilation calculations. This is because ventilation rates based exclusively on building air changes per hour neglect the heat and moisture produced by different stocking densities of animals.

Cold Weather Ventilation

A properly designed cold weather ventilation (CWV) system conserves energy through utilization of heat generated by the livestock adding to the profitability of running a poultry business. The main targets of CWV are providing oxygen and removing moisture. This is accomplished by drawing outside air through the building to absorb this moisture and by exhausting the moisture-laden air from the building. Retaining body heat in a cold temperature is of prime importance for maintenance of body temperature and evaporation of excess moisture. This again emphasizes the virtues of effective insulation (MidWest Plan Service – 32, 1990).

Supplemental Heating

During winter months the relative humidity of the outside air is quite high (80 percent to 90 percent often reaching 100 percent). Unless this incoming air is heated, little or no additional moisture can be added to it. As this incoming air mixes with inside air, it is warmed to room temperature and is capable of holding much more moisture to exhaust out of the system.

Supplemental heating is necessary when the heat produced by animals is not enough to maintain the desired warm indoor temperature in cold weather. As discussed earlier heat can be lost through the walls and roof and ventilation. MidWest Plan Service - 34 (1990) states that, up to 90 percent of the heat produced in the building is used to heat ventilating air and remove moisture. CWV reduces relative humidity which reduces fogging and condensation on building surfaces. Moisture control requires a higher volume of air than temperature control. Adding to an already high volume of air, more ventilation is needed to remove odors and ammonia. Consequently this higher volume of air cools and lowers the poultry house temperature further. This creates the need for additional supplemental heating.

At warmer temperatures this is not a problem because the higher rate and volume of air flow keeps moisture in control without the need for heating. Open flame, non vented natural gas or propane heaters with metal brooders are common choices for poultry house supplemental heating. Younger animals often need more additional heat than grown broilers.

Mild Weather Ventilation

MWV (Mild Weather Ventilation) attempts to modify temperature and control moisture. Fans are switched on by thermostats when additional ventilation is needed.

Hot Weather Ventilation

Heat reduction and increased air velocity are the characteristics of this mode of ventilation. Not unlike MWV, HWV (Hot Weather Ventilation) also uses thermostat controlled fans that are switched on when the indoor ambient temperature rises above a certain level. HWV rates suggested by MidWest Plan Service - 34 keep the internal temperature within a few degrees of the external temperature. Temperature can be lowered further by deploying evaporative cooling.

Cooling for Hot weather

Warmer climates of southeastern United States make it necessary to cool ventilation air during the hotter months. The more commonly used methods are evaporative pad cooling and fogging, both of which effect cooling by conversion of sensible to latent heat. Evaporative pad cooling can be used in conjunction with mechanical ventilation wherein all incoming air is pulled through wetted pads. Such a system can provide a reduction in temperature by 20°F in humid climates with pads operating at 80 percent evaporative efficiency states MidWest Plan Service - 34, (1990). Fogging on the other hand is more applicable to natural ventilated houses. While fogging is cheaper than evaporative cooling it has comparatively lower effective cooling capacity.

Agricultural Fans

Fans are a mechanical means to force the exchange of air that is necessary to create a healthy environment for animals and associated farm workers. Proper fan selection for a livestock building is important if ventilating goals are to be met at least cost. Testing and experience have shown that energy efficient fans can generate savings that amount to more than the price of the fans alone. Good quality fans are essential for proper performance of mechanically ventilated livestock facilities. Inefficient fans move less air than expected, allowing air quality to diminish which stresses animals. Inefficient fans erode the bottom line for producers through wasted energy and depressed poultry performance owing to stressed animals from impaired air quality.

Selection Criteria for Agricultural Fans

The following factors must be considered when selecting a fan or system of fans:

- Quantity of air delivered at different static pressures,
- Energy efficiency,
- Reliability and life,
- Suitability for application,
- Purchase Cost,
- Operating Cost, and
- Quality of dealer service and support.

Based on the above factors and ventilation criteria the objective is to select the system of fans that give the lowest annual cost.

Selection Procedure for Agricultural Fans

The selection of a fan system for an animal production facility follows the methodology and guidelines given below.

- Most agricultural fans operate against a static pressure of 0.125 or 1/8th inches of water. The range of static pressures in which the fan will operate can be determined from the static pressure table.
- Fan selection should be based on the fan operation data published by the Air Movement Control Association (AMCA) or Bioenvironmental Engineering Structure Systems Lab (BESS). As a measure of safety a system that exceeds the design values should be selected.
- "It is much more important to be concerned with reliable airflow from winter fans than it is to calculate energy consumption" according to MidWest Plan Service - 32, (1990). Winter ventilation requires the maintenance of air quality and continuous air flow.
- Maximum summer ventilation capacity will be based on the criteria of "one air change per minute". This ventilation rate gets rid of house heat and the high velocity generates a wind chill cooling effect on birds.
- Rated capacity for each 48 inch diameter fan will be assumed as 20,000 cfm at 0.05-inch static pressure difference with an energy efficiency rating of at least 20 cfm/W at 0.05-inch and 10,000 cfm airflow with 15cfm/watt efficiency at similar conditions for 36 inch diameter fans for energy calculations.

Cold Weather Fans

These fans are sized by calculating a required quantity of air to ensure proper air quality. These fans cater to minimum ventilation requirements and run continuously. A flat performance curve is desirable for cold weather fans in livestock buildings. This is to prevent substandard ventilation during windy winter conditions. In a fan with a flat performance curve the amount of air removed for a fan remains approximately constant as the pressure varies from 0 to 0.25 inches of water column. The "typical resistances" are shown in Table 2.

Table 2. Typical Resistances to Air Movement.

Category	Condition	Static Pressure in inches of water
Properly sized and managed inlet		0.04
Shutter	clean	0.02 – 0.10
	dirty	0.05 – 0.20
Exhausting against wind	5 mph	0.02
(no wind shielding)	10 mph	0.05
	15 mph	0.1
	20 mph	0.2
Fan guards, clean	wire mesh	0.05 – 0.15
	round ring	0.01 – 0.02

Source: MidWest Plan Service - 32, 1990.

When the wind is blowing in the same direction as the direction the fan moves the air, the suction effect produced can cause static pressure to drop to 0 inches of water. Conversely a 25 mph wind (Static pressure Table 2.) in the opposite direction can raise the static pressure to 0.28 inches of water. Irregular cleaning of the blades and inlets also contributes to a higher static pressure. This fluctuation in the operating static pressures leads to the demand for a fan that will perform well over a wide range of static pressures.

36 inch diameter fans that run continuously are preferred for minimum ventilation (MidWest Plan Service - 32, 1990 and ASAE, 2001).

Hot and Mild Weather Fans

For hot and mild weather fans energy efficiency is a more important because ventilation in warm weather can be controlled by on/off variable controls without the need to rely on a flat curve. Furthermore the volume of air needed in warmer weather is higher justifying the need for an efficient fan. Forty eight inch diameter fans are preferred for HWV and MWV.

Requirements For Broiler Growth And Maintenance

Livestock and poultry produce best when the environment is within an optimum zone. The ventilation or environmental control system should be designed and operated to achieve these optimal conditions. A description of “ideal” preferred conditions for “maximum” growth for broilers is given below.

Air Velocity

Speeds greater than 60 ft/min are not recommended for broilers under 2 weeks of age. Increasing air speeds from 40 to 500 ft/min has been shown to improve weight gain in broilers weighing around 1.4 kg when temperature was cycled diurnally from 70°F to 96°F (MidWest Plan Service - 32, 1990).

Ventilating Rates

MidWest Plan Service - 32 mechanical ventilating rates should be followed for a close estimation of air volume requirements for poultry. These are shown in table 3.

Table 3. Recommended mechanical ventilating rates for Broilers.

		Cold weather	Mild weather	Hot weather
Age	Unit	cfm/unit		
0-7 days	head	0.04	0.2	0.4
over 7days	lb	0.1	0.5	1

Source: Based on MidWest Plan Service – 32, 1990.

Temperature

For the first 3 to 7 days house temperature should be kept at 85 °F, followed by 80 °F for the second week and 75 °F for the third week (MidWest Plan Service - 34, 1990).

Humidity

Air relative humidity should be maintained between 50 and 70 p ercent. This will control litter moisture between 20 and 30 percent (MidWest Plan Service - 32, 1990). During first 2 to 3 weeks, brooding chickens may need relative humidities of more than 60 percent. But during grow out phase, the performance of broilers is only slightly affected if relative humidities are between 30 and 80 percent as long as the dry bulb temperature is below 85 °F (ASAE, 2001).

Air Quality Requirements

Air composition is altered by livestock living in the building. Breathing uses oxygen and releases carbon dioxide. An oxygen content of less than 16 percent in the air causes discomfiture while an oxygen content of less than 10 percent is dangerous. Anaerobic decomposition of manure releases odors and other noxious gases including ammonia, methane (a highly flammable gas), and hydrogen sulfide (a toxic gas). All harmful gases and dust should be removed to maintain a healthy environment for broiler chickens and workers. In well designed systems the concentrations of these gases do not reach lethal concentrations. However care still needs to be exercised because even low levels of these pollutants can cause chronic disease (MidWest Plan Service - 32, 1990).

Broiler Performance Modeling

The indoor climate of poultry houses is of importance for the well being and health of animals and their production performance. The performance of farm animals is a result of the genotype of the animals and parameters like nutrition, hygiene livestock management as well as their abiotic environment.

The equations below describing body weight and feed conversion change with respect to age and environmental temperature. The specific equations developed by Reece and Lott, (1982) show the relationship between body weight, feed conversion and age for different temperatures between 35 to 55 days:

$$\begin{gathered} W = 57.9D - 833; FC = 1.191 + 0.0163D @ T = 15.6C, \\ W = 55.8D - 747; FC = 1.143 + 0.0160D @ T = 21.1C, and \\ W = 50.0D - 623; FC = 1.164 + 0.0147D @ T = 26.7C. \end{gathered}$$

In the above equations W is Body weight in grams, FC = feed to gain ratio and T is temperature in Celsius and D is time in days.

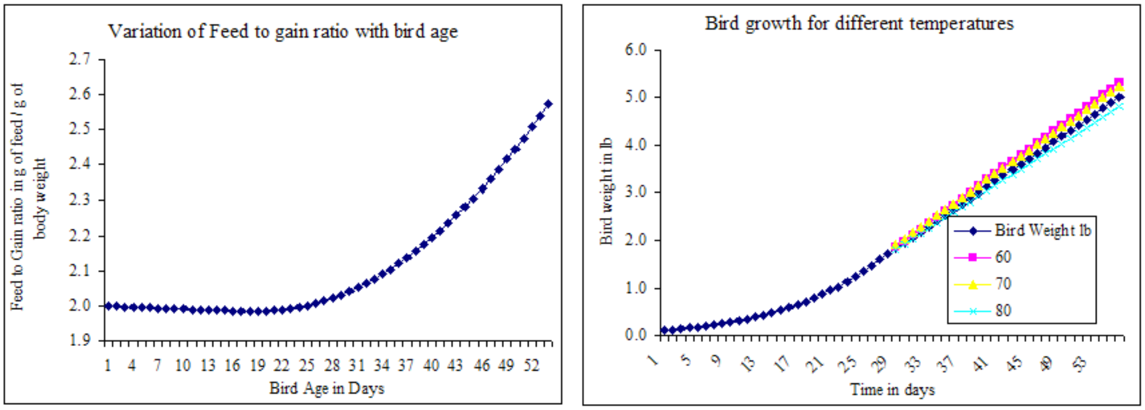


Figure 2. Comparison of Growth and Bird weight with bird age.
Source: Adapted from Reece and Lott, (1981).

<u>Growth Rate And Climate</u>

Charles et al. (1998) suggested that high environmental temperatures are detrimental to the feed to gain ratio and growth of broilers. Growers need to balance the cost of obtaining a viable temperature against the gain obtained in broiler performance due to that viable temperature. Maintenance of a broiler house at an ideal temperatures reduces feed consumption but increases utility cost. Electricity is required for ventilation and water is required for evaporative cooling.

Broilers like most birds are homeotherms, meaning they maintain a relatively constant body temperature regardless of the environmental temperature. Birds perform best when there is a minimal variation in house temperature over a 24 hour period of time (Vest, 1999).

In cooler temperatures, broilers will consume more feed but many of the calories they obtain from this feed will be used to sustain normal body temperature. When the calories are used for warmth, they are not converted to meat. Optimum temperatures allow maximum feed conversion meaning a greater part of the nutrition goes into growth rather than temperature regulation (Vest, 1999).

Broiler Growth Rates

Most published broiler growth rates are fragmented and need to be modified or combined with other data to be of use. To keep this model as generic as possible growth rates of typical mixed sex broilers were obtained during brooding and grow-out. The brooding phase growth rate exhibits a nonlinear function with a linear growth rate during grow-out.

The brooding phase, (weeks one through four) growth rate equation derived from Reece et al., (1981) is,

$$W = (.04 + 6.91 * 10^{-3} * D + 1.27 * 10^{-4} * D^2 + 2.04 * 10^{-5} * D^3) * 2.204.$$

The grow-out phase, (weeks five through eight) growth rate equation derived from Reece et al., (1981) is,

$$W = (- .71 + .0532 * D) * 2.204.$$

where W is weight in lb and D is chick age in days.

Ventilation Modeling

A typical livestock ventilation model has equations that reflect the size and type on livestock, the insulation of the building and the characteristics of the ventilation system. The physical environment of farm animals inside livestock buildings is primarily characterized by hygrothermal parameters and air quality. These parameters are influenced by interactions with the outdoor environment, the types of livestock, the ventilation system and the building. Ventilation systems for livestock buildings are mainly designed as temperature-controlled variable volume flow systems.

Steady-State Balance Models

Schauberger et al. (1998) developed a climate simulation model that uses a steady-state model for the sensible and latent heat fluxes, CO_2 and odor mass flows to calculate the indoor climate of a mechanically ventilated livestock building. Most of the data are for Austrian climatic conditions, the methodology however is exportable. This model used a pig fattening unit with 1000 animal units. The model works on the basis of half hour inputs of meteorological parameters like temperature, wind speed, wind direction and humidity collected over a two year period generate indoor climate and odor emissions. The inside environment was evaluated according to a comparison with recommended values for animals. This model can be used as design tool for renovation of existing ventilations systems in its prognostic mode or in its diagnostic mode it works as a comparison for real world performance with respect to model calculations.

In this model the minimum volume of airflow for the winter period is calculated on the basis of the air quality requirements. These calculations consider the CO_2 release of the animals relative to their total heat production and the maximum accepted CO_2 concentration inside the livestock building. The maximum air flow for the summer period depends on the sensible heat production by animals and the necessary difference between indoor and outdoor temperature to avoid heat stress. Schauberger et al. (1998) found that with a constant volume of air flow the change in the indoor temperature is proportional to the change in the outdoor temperature.

Kic et al. (1998) developed a simulation program VENTOLA to study the behavior of the microclimatic situation inside of buildings housing domestic animals. This model has the ability to consider many parameters including species, category and characteristics of animals, structure of building, local climatic data, ventilation rate, heating, and heat recovery systems. The model was programmed in Excel 5.0 and can be used to design ventilation systems, to predict the microclimate conditions in building, and to study the effect which various parameters have on the inside microclimatic conditions.

The main parts of the VENTOLA algorithm are:

- calculation of ventilation parameters for winter period,
- calculation of ventilation parameters for summer period,
- calculation of winter heat balance,
- selection of a suitable simulation method, and
- simulation of air conditions inside the building.

The minimum ventilation capacity for winter conditions was calculated according to the ventilation needed for the moisture balance and for the CO_2 balance. The determination of the maximum ventilation capacity for summer conditions was based on practical experience. The relationship between the outside climatic conditions, building construction, and parameters of the inside air quality was estimated by the use of physical and mathematical models which described the steady or dynamic states and time behaviour of studied phenomenon.

Energy Modeling

Energy Plus®, EP is a building energy simulation program for modeling building heating, cooling, lighting, ventilating, and other energy flows developed by the U.S. Dept. of Energy and released for public use in 2001. Energy Plus works with a user's description of a building from the perspective of the building's physical make-up and associated mechanical systems, Energy Plus will calculate the heating and cooling loads necessary to maintain thermal control set points, conditions throughout a secondary HVAC (Heating, Ventilation and Air Conditioning) system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would (US, Dept. of Energy, Energy Plus Simulation Software Website).

EP has its roots in the BLAST (Building Loads Analysis and System Thermodynamics) program. BLAST was developed and released in the early 1980s by the U.S. Dept. of Energy as an energy and load simulation tool. It is intended for a design engineer or architect who wishes to size appropriate HVAC equipment, develop retrofit studies for life cycling cost analyses, and optimize energy performance. In spite of the versatility of EnergyPlus it was not used in its entirety for this thesis because of two main reasons:

1. Energy Plus is more suited to human comfort air systems. Human HVAC systems are technologically more sophisticated as compared to simple livestock building ventilation systems.

2. Livestock houses have a dynamic indoor temperature regime that changes weekly over their period of growth from brooding to grow out unlike HVAC systems for humans or industries which have simpler seasonal variations.

However, EP was used to get climate data for a typical year for the study area locations: Tulsa, OK; Oklahoma City, OK; Little Rock, AR; Fayetteville, AR; and Wichita, KS. Energy Plus uses an ASCII format weather data. This is a text-based format derived from the Typical Meteorological Year (TMY) weather format. The period of record for these weather data is typically 30 years (Energy Plus Help files).

Ammonia Chemistry

Ammonium (NH_4^+) is the predominant form of inorganic N in manure. Ammonium is converted to ammonia (NH_3) as the conditions become more alkaline. Ammonia is in equilibrium with ammonia gas, which diffuses from the litter into the surrounding air. This process is known as “ammonia volatilization” and is responsible for the high concentrations of ammonia in poultry houses.

The amount of ammonia that volatilizes depends on factors such as the amount of nitrogen in the food source, size and species of the animal, housing conditions of the animal, humidity, temperature, and animal waste handling practices or

$$\text{Ammonia Volatilization} = f\,(N, A, EC, M).$$

In the eqaution N is the Nitrogen content of the feed, A is the genotype of the animal, EC is the environmental conditions like humidity, temperature, air velocity, house type and M is management, like waste removal ventilation etc.

Chemical Process of Ammonia Volatilization

Nitrogen in livestock food sources that does not end up in products or in body absorption is usually excreted by the animal. Nitrogen in the waste is usually in the form of uric acid. Degradation of uric acid to ammonia is a two step process with urea being an intermediate product. The process is microbially mediated with aerobic organisms decomposing the uric acid. The microbes that are responsible for the conversion thrive under high pH (alkaline) conditions. Urea, $CO(NH_2)_2$, can rapidly hydrolyze by enzymatic conversion to form ammonium carbonate. Decomposition of ammonium carbonate frees up ammonium ions that can volatilize as gaseous ammonia (Anderson et al., 2003). This process is explained in the following equations,

$$CO(NH_2)_2 + 3H_2O \text{ ----------> } (NH_4)_2CO_3 + H_2O,$$

$$(NH_4)_2CO_3 + H_2O \text{ ----------> } 2NH_4^+ + HCO_3^- + OH^-, \text{ and}$$

$$NH_4^+ \text{ ----------> } NH_3 + H^+.$$

The pH of litter is an important property which affects the ammonia volatilization process. Uric acid degradation produces ammonia, thus litter pH rises with litter use. pH of the litter depends strongly on the age and number of flocks. Typically new bedding litter has a pH ranging from 5 to 6.5. Once the litter has accumulated a lot of droppings over several flocks the pH remains fairly constant and alkaline at 8.5.

Elliott and Collins (1982) proposed a pH model relating with age of birds as follows:

$$pH = \frac{2.7\,(0.0357 * AGE)^8}{1 + (0.0357 * AGE)^8} + 5.8.$$

At lower pH (acidic or neutral conditions) nitrogen released from litter exists as ammonium whereas at higher pH ammonia is abundant.

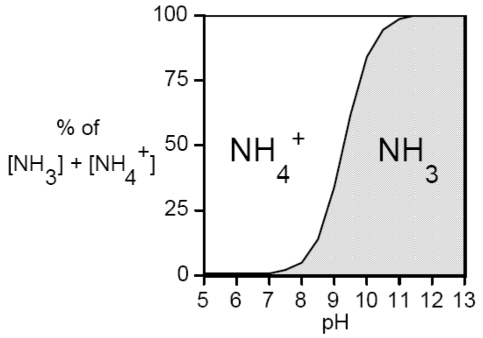


Figure 3. Relationship of ammonia (*NH_3*) and ammonium (*NH_4^+*) as a function of pH. *Source: Adapted from USDA "Ammonia Emissions and Agriculture".*

Ammonia Emission Modeling

Models are important for estimating emissions over a wide range of situations and for forecasting the effects of changes in the factors that affect NH_3 emissions. Existing models are either empirical or mechanistic. Most empirical models use statistics to obtain correlations and relationships between factors that affect NH_3 emission. Mechanistic models that base the emissions processes on the NH_3 source and NH_3 transfer to the atmosphere have been constructed (Arogo et al).

Horne, Brake and Williams (1998) proposed an ammonia model pertaining to commercial layer farms. Its target was to demonstrate the effects of different strategies for reducing ammonia emissions and how much it would cost to deploy different combinations of these measures. To effectively model ammonia it is important to understand its production at the various stages during egg production. Ammonia is released during deposition in layer houses, during storage of manure, and during manure application. The main premise for this model is that nitrogen input minus nitrogen deposition for growth and egg production results in nitrogen excretion as explained in the schematic diagram of N flows in the laying process below:

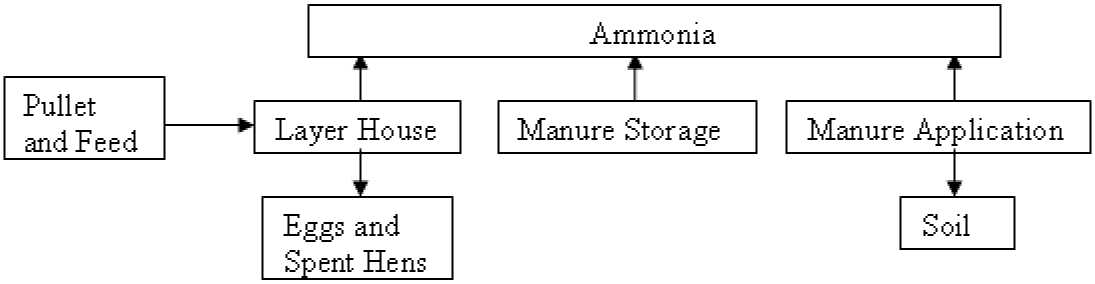


Figure 4. Nitrogen flow through a layer house
Source: Adapted from Horne, Brake and Williams et al, (1998).

The nitrogen emission in the layer house is characterized as:

$$EH = \sum_{i=1}^{n} (N * Hi * Ei)$$

Where EH is the emission in grams if nitrogen, i is the housing system, N is excretion per layer EX, Hi is percentage of hens in each housing system in the area (i) and Ei is emission coefficient for areai.

Ammonia emission during storage:

$$ES = \sum_{i=1}^{n} (N * Hi * Ei)$$

Where ES is the emission in grams of nitrogen during storage, i is storage system, N is nitrogen in manure (EX-EH), Hi is percentage of hens for which the manure is stored in system (i) and Ei is emission coefficient for areai.

Ammonia emission during application:

$$EA = \sum_{i=1}^{n} (N * Hi * Ei)$$

Where EA is the emission in grams of nitrogen during application, i is the application system, N is the nitrogen in manure after storage (EX-EH-ES), H is the percentage of hens for which the manure is applied by system (i) and E is the emission coefficient.

$$\text{Total Ammonia Emissions } ET = EH+ES+EA$$

After running different management scenarios, Horne, Brake and Williams et al, (1998) found that the cheapest method to reduce ammonia emission was to improve the land application technique. On arable land this can be done by plowing under manure slurry or dried manure directly after application. It was also found that ammonia emissions from high rise houses are 10 fold greater than from houses with manure belts. It was also found that improved manure application methods when combined with low protein feed and change to manure belt systems would reduce ammonia emissions by 50 percent.

The model described above was based on studies conducted in the Netherlands. Adopting these regulations for ammonia control in the United States (as implemented in Netherlands) would increase costs for the United States poultry producers because there are no direct revenues from lowering ammonia emissions. However if the value of ammonia damages avoided were included the net social benefit could be positive.

Broiler Litter NH_3 Modeling

Carr et al. (1990) developed an empirical regression model to relate ammonia concentrations from broiler litter to relative humidity, litter moisture, pH, ventilation rate, and the air temperature in the house. Three models were developed in his study and designated as pH, ammonia concentration without pH, ammonia concentration with pH. These equations are described below,

pH Model

This model included a relative humidity and temperature interaction term since the two do not vary independently. Also a litter moisture and temperature interaction term was included because the dryness of litter depends on evaporation which is a function of temperature and humidity. The model for pH is,

$$pH = -0.001 * LM^2 + 0.373 * LM + 1.156 * T + 0.305 * RH - 0.011 * T * RH - 0.01 * T * LM - 25.932,$$

where LM is litter moisture in percentage, RH is relative humidity in percentage, and T is temperature in °Celsius.

Ammonia Concentration Model Without pH

A response surface was developed to relate ammonia to all other variables apart from pH. In an effort to simplify the model and reduce variation, a logarithmic transformation was performed on the ammonia variable. The equation is,

$$Log_{10} (NH_3) = 0.623 * T - 0.042 * AC + 0.443 * LM - 0.015 * T * LM - 15.503,$$

where NH_3 ammonia in µL/L (ppm), LM is litter moisture in percent, AC is air changes per hour or the ventilation rate, and T is temperature in °Celsius.

When the model was plotted to visualize effects of ammonium concentration on varying temperature, litter moisture and ventilation rate it was clearly seen that ammonia concentration increases with an increase in temperature and litter moisture and decreases with increasing air changes. An increase in temperature above 25 °C (77 °F) or litter moisture above 30 percent causes an exponential increase in ammonia concentrations.

This was attributed to the fact that higher litter moisture would enhance the capillary effect and diffusion rate of ammonia. However at a very high temperature and moisture, ammonia release was suppressed due to the growth of aerobic bacteria and the decomposition of uric acid.

Ammonia Concentration Model With pH

The pH has been shown to be an important variable in control of ammonia release from broiler litter (Carr and Nicholson, 1980a). Thus the development of an ammonia model having a linear variation with pH was felt to be justifiable because the previous pH model included interactive and quadratic terms. The equations are,

$$Log_{10}\,(NH_3) = 1.089 * pH + 0.056 * T - 0.035 * AC - 7.811,$$

where NH_3 is ammonia in µL/L (ppm), AC is air changes per hour or the ventilation rate, and T is temperature in °Celsius.

Plotting the above equation shows that ammonia concentration increases with increasing pH and temperature and decreases with increasing ventilation rate. Also the plot suggested that keeping pH values below 7.5 will ensure very low levels of ammonia production.

Emission Abatement Economics Modeling

Cowell et al. (1999) UK modeled the economic consequences of different ammonia abatement approaches using a specially developed mathematical model called

SALAAM (Sectoral Analysis of Livestock Ammonia Abatement Model). This model uses a process based approach characterizing livestock waste management as a cascading system in which TAN (Total Available Nitrogen) through different systems and stages are linked into an overall flow network. Livestock were divided into seven classes namely, dairy cows, other cattle, sows, fattening pigs, weaning pigs, laying hens, and other poultry. SALAAM was used to determine the economic value of individual abatement measures, calculation of the maximum feasible reductions and estimation of potential abatements in relation to the sector livestock values.

For poultry it was found the unit cost, of NH_3 abated followed an exponential curve, the overall range of unit cost, in the above units, being from zero to many hundreds of dollars for near total ammonia abated. The approaches of dietary manipulation, individual feeding, industrial scale processing, fixing with acid and animal breeding had low unit costs in each of several sectors. Maximum feasible ammonia reduction was around 70 percent. The cost of abatement close to the maximum feasible reduction was achievable at an expenditure of not more than 10 percent of the annual value. The animal value for laying hens and other unspecified poultry were £10.00 (\$19.26) and £13.00 (\$25.03) respectively and the cost of Maximum feasible reduction (MFR) per animal was £1.66 (\$3.20) and £3.51 (\$6.76). The cost effectiveness of ammonia abatement for poultry was less than that required for non dairy cattle. It is however on the higher extreme and swine is the most cost effective for abatement strategies.

Chemistry of Alum Use

The gaseous emission of NH_3 can be inhibited if ammonia is converted to NH_4^+ (ammonium). This can be accomplished by lowering litter pH. Aluminum sulfate $[Al_2(SO_4)_3 \cdot 14H_2O]$, commonly referred to as alum, is an acid that produces 6 moles of H^+ when it dissolves (Moore at al., 1999). The reaction is:

$$Al_2(SO_4)_3 \cdot 14H_2O + 6H_2O \text{ ----------> } 2Al\,(OH)_3 + 6H^+ + 3SO_4^{2-} + 14H_2O$$

The H^+ produced by this reaction will react with ammonia to form ammonium, which can react with sulfate ions if high enough concentrations are reached to form 3 moles of ammonium sulfate (Moore at al., 1999). The reaction is:

$$6NH_3 + 6H^+ \text{ ----------> } 6NH_4^+, \text{ and}$$

$$6NH_4^+ + 3SO_4^{2-} \text{ ----------> } 3(NH_4)_2\,SO_4$$

Ammonium sulfate is a water-soluble fertilizer. The formation of ammonium sulfate as demonstrated in these equations shows that the amount of NH_3 emitted will be lowered. A bonus of alum application is an improvement in the fertilizer value of the litter.

Advantages of Alum

Research shows that for normal poultry production a concentration of 25 ppm of ammonia in the air should not be exceeded (Carlile et al., 1984). Some chemical amendments added to the litter may inhibit ammonia from volatilizing from the litter (Moore et al., 1995).

Chemical amendments usually fall into two categories depending on their mode of lowering ammonia volatilization. These categories are:

- By inhibition of microbial growth, and
- By combination with the released ammonia and neutralizing it.

Some of the chemicals that have been tested include calcium chloride, paraformaldehyde, clinoptilolite, superphosphate, ferrous sulfate, gypsum, magnesium salts, alum and phosphoric acid. Alum and phosphoric acid have been noted to be the best among the other available alternatives to reduce ammonia release.

What makes alum even more promising is that phosphoric acid though effective increases the P solubility in litter by an order of a magnitude. This would greatly increase P runoff problems. Therefore phosphoric acid use should be curtailed in P sensitive watersheds, like the watersheds of Oklahoma and Arkansas.

Moore et al., (1999) compared ammonia levels over a full cycle of year in two broiler farms in northwest Arkansas. Ammonia levels were significantly lower in the alum treated houses than in the controls. Alum was applied after each flock of chickens at a rate of approximately 0.2 lb alum per bird. For a standard 20000-bird poultry house (40 ft x 400 ft) this would be equivalent to approximately 4000 lb alum/flock or 0.248 lb alum/sq.ft /flock. The lower ammonia levels were attributed to lowered pH of the litter. Also worth noting were significant increases in weight gains of the broilers and lowered energy use in winter for the alum treated houses (Moore et al., 1995). Improved broiler performance was due to better environmental conditions owing to lowered ammonia levels.

Moore et al. (1999) showed that alum applications lowered litter pH significantly throughout the grow out, with the greatest effect during the first 3 to 4 weeks of the beginning of each grow out. The pH of the litter increased until the birds were about 4 or 5 weeks old, when the litter pH leveled off at approximately 7.5.

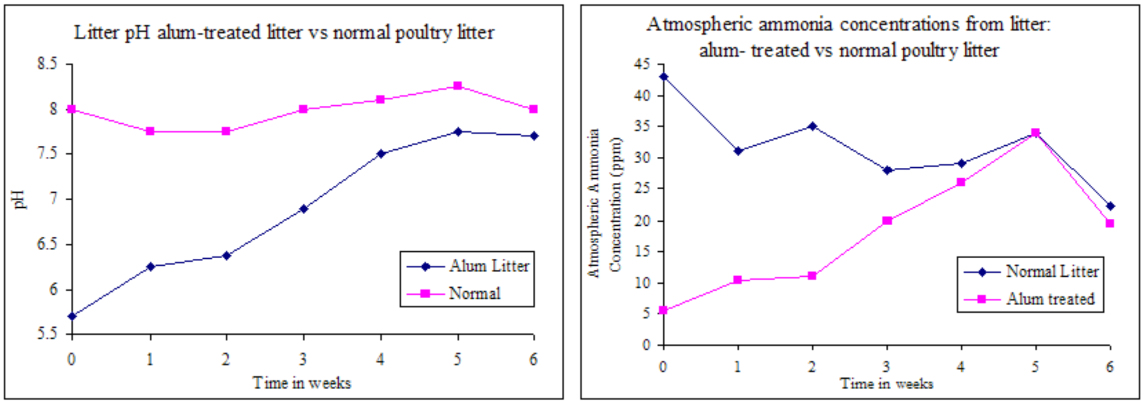


Figure 5. Comparison of alum treated and normal litter for ammonia concentrations and pH.
Source: Adapted from "Reducing phosphorus runoff and improving poultry production with alum", Moore et al., (1999).

Moore et al. (1999) found that the average NH_3 concentration in the control houses was above 25 ppm for the first 5 weeks of the grow out (Figure 5). Decreases in weight gains and poor feed conversion have been demonstrated at this level. Ammonia concentrations in the alum treated houses were very low the first 3 to 4 weeks of the study, which coincided with the stage of growth in birds when they were most sensitive to high ammonia levels. Also it was seen that NH_3 fluxes from the litter were down by 97 percent for the first 4 weeks of the grow out and 75 percent for the full 6 weeks. Brewer et al. (1998) in a similar test found a net ammonia flux of 0 for the first 3 weeks of grow out on alum treated litter.

Another advantage of treating litter with alum is a higher N content due to lower ammonia volatilization and thus higher fertilizer value. Tall fescue yields were found to be higher with alum treated litter application compared to normal or ferrous sulfate treated litter (Shreve et al., 1995). Additionally, these fescue yields had higher N contents.

The offsite damage that P enrichment causes is reduced by alum use. Soluble phosphorus runoff was reported to be 75 percent lower in watersheds fertilized with alum treated litter, compared to normal litter (Moore et al., 1995)

CHAPTER III

CONCEPTUAL FRAMEWORK

A spreadsheet program was developed in Microsoft ®Office Excel 2003 SP-1 and the macros were coded in VBA 6.3 to run the analysis. A macro is usually a short program written to automate several steps. In Excel Macros are written in a programming language called Visual Basic for Applications (VBA).

The basic steps of model developed for this thesis can be summarized as:

- Input data for environmental conditions and bird growth,
- Process information to model bird growth, ventilation, and generation of pollutants like ammonia,
- Simulate different scenarios showing management and compare results for each scenario, and
- Output economic analysis results.

The following schematic figure outlines the flow of control through various stages of the program developed for this thesis.

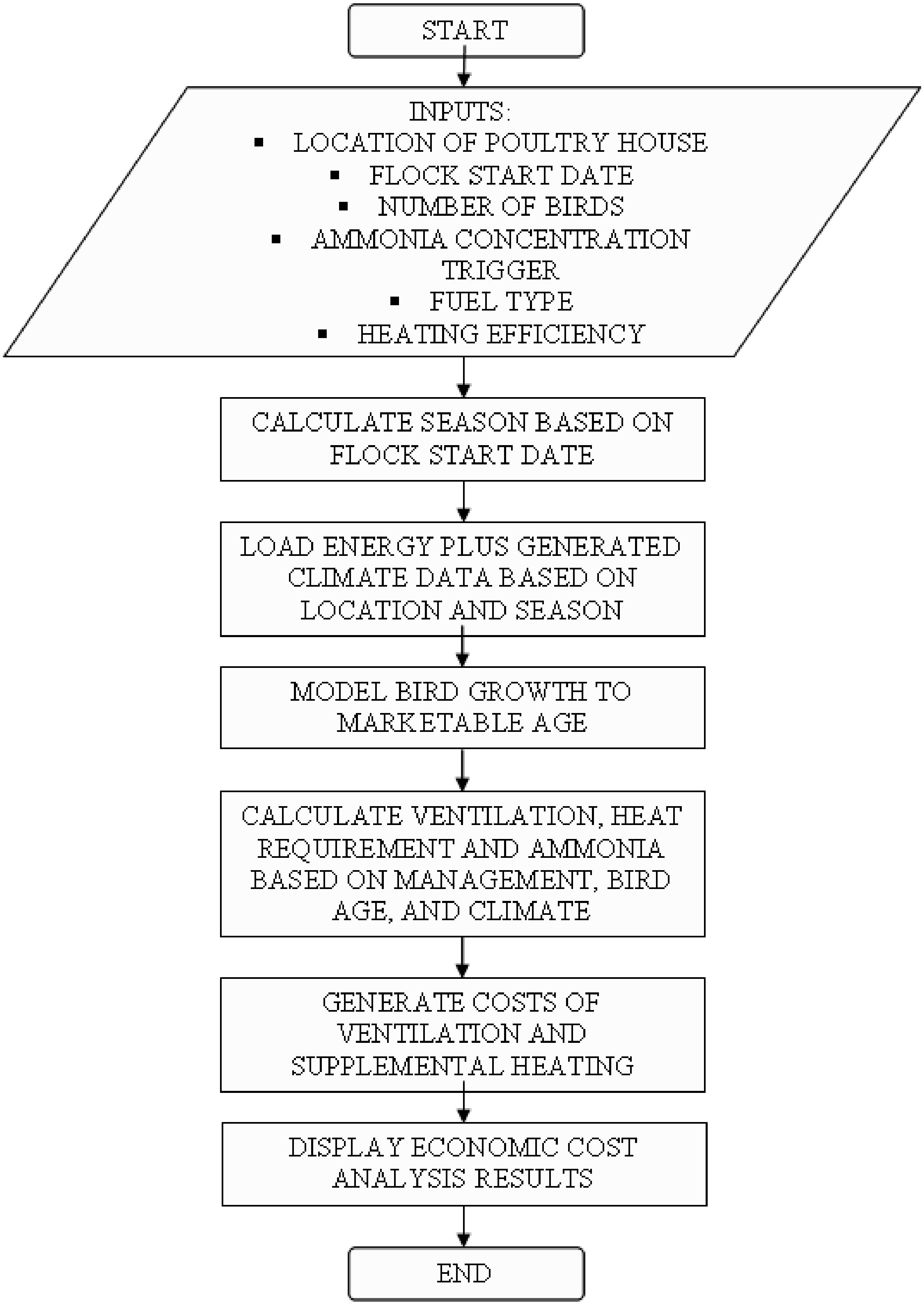


Figure 6. Flowchart showing the logic flow for the spreadsheet program developed to simulate ventilation in a broiler house and analyze economics of ammonia management.

Assumptions For The Program

The assumptions used in this study with respect to geographic location, weather, building characteristics and costs are given below.

- Locations modeled: five stations located in northeastern Oklahoma, northwestern Arkansas and southern Kansas.
- Climate: December through February was assumed to be cold weather (winter), September through November and March through May was assumed as mild weather while June through August was designed with hot weather (summer) ventilation values.
- Building dimensions: 200ft X 40ft X 10ft (average height of the sloping roof).
- Number of birds: 20,000.
- Operating static pressures in inches of water: 1/10" to 1/8" of water.
- Flock growth period: 8 weeks (56 days).
- Target weight at marketable age: 5 lb.
- Ventilation model: steady state.
- Thermal zones in the building: One.
- Temperature variations: averaged daily.
- Thermal Resistance (R) values: R-12 °F hr ft2 / Btu for the ceiling, R-9 °F hr ft2 / Btu for the walls, (Vest et al., 1991).
- Heat stored: walls, ceiling, floor and generated by electrical equipment (not including heaters) is zero.
- Cost of Poultry bedding: $110 (Moore et al., 1999).
- Cost of alum: $200 /ton (Moore et al., 1999).
- Price of Propane: $0.85/ gal (U.S. Dept. of Energy Website).

Calculations

Body Weight

Brooding phase: Weeks 1 through 4: (Reece et al., 1981)

$$W = .04 + 6.91 * 10^{-3} * D + 1.27 * 10^{-4} * D^2 + 2.04 * 10^{-5} * D^3.$$

Grow-out phase: Weeks 5 through 8: (Reece et al., 1981)

$$W = - 0 .71 + .0532 * D,$$

where W is weight in kg and D is chick age in days.

Ventilation Rate

The rate of air changes required was based on the Midwest Plan Service design values as given in Table 3 for the baseline scenario. This guideline gives an estimate of the air volume per unit time required to maintain optimal conditions depending on the weather.

This simulation uses climate data from weather files processed by U.S. Dept. of Energy's Energy Plus to obtain daily average temperatures for each day of the whole year. Based on the flock start date, the program loads the climate data from that period and determines the season. The heating and ventilation loads are determined on the design temperature programmed into the spreadsheet.

Ventilation Rate required for controlling ammonia levels at 25 to 30 ppm is calculated as per Xin et al., (1996):

$$MVR\ am = 134 + 0.2474 * (13 - Age)^3$$

where MVR am is ventilation rate in cuft/min and Age is bird age in days upto 14.

Fan Energy Cost

Fans are selected on the basis of lowest annual cost as described earlier under fan selection criteria. The parameters for the selected fans are shown in Table 4. The variable or fan operating cost is:

$$Cost = \eta * cfm * E\$$$

where η is average efficiency of a fan in cuft/min/watt, cfm is the airflow in cuft/min and E$ is the cost of electricity in $/KWhr.

Table 4. Efficiency and flow for 36 inch diameter fans with the flatest performance curves.

Fan Model	**Airflow** cfm	**Efficiency** cfm/watt	**Airflow Ratio** >= 0.80
ACME BDR36G-A	10330	15.4	0.82
ACME BDR36G-C	11200	17.1	0.82
ACME DDPS36G-C	11860	19.2	0.84
AeroTech AT36CB1ZA	9920	17.3	0.82
AeroTech AT36CB1SCP	9590	15.8	0.81
AeroTech GB36T1P	9120	14.9	0.81
Airstream Cumberland CGSBC36	9380	15.5	0.80
BSM Agri 719 -136741-1	13460	12.0	0.85
Big Dutchman 60-36-5206	15330	15.6	0.83
Big Dutchman 60-36-5206	14460	14.0	0.84
Canarm FG36H	15340	15.6	0.83
Canarm FG36H	14460	14.0	0.84
Prairie Pride	12700	12.0	0.81

Source: Adapted from "Agricultural Ventilation Fans, Performance and Efficiencies" from BESS.

The spreadsheet has the average airflow in cuft/min programmed along with the average efficiency of fans. Based on the cost of a unit of electricity it calculates daily expense in operating fans.

Table 5. Averages of Efficiency and Airflow of the top 5 flat performance curves

Airflow Ratio >= 0.80	**Airflow** cfm	**Efficiency** cfm/watt
0.80	9380	15.5
0.81	10470	14.2
0.82	10483	16.6
0.83	15335	15.6
0.84	13593	15.7
0.85	13460	12.0
0.83	**12120(safe 10000)**	**14.9(safe 12)**

Source: Adapted from "Agricultural Ventilation Fans, Performance and Efficiencies" from BESS,
("Safe" means that conservative estimates for airflow and efficiency have been factored into the calculations)

Optimal Temperatures

For the first week the house should be maintained at 85°F. The following weeks should be progressively cooler with, 80°F for the second, 75°F for the third and 70°F for the fourth week through grow-out (MidWest Plan Service - 34, 1990).

Supplemental Heating

The parameters for the ventilation spreadsheet program were based on information from MidWest Plan Service -32, (1990). Design of environmental control begins with analysis of the heat flows in a system. Heat balance for a livestock house is represented as:

Sensible heat loss by animals
\+
Heat produced by equipment
\+
Supplemental Heat

=

Heat required to evaporate moisture
\+
Heat lost through walls
\+
Heat exchanged through ventilation air
\+
Heat stored by building material

Figure 7. Heat balance in a poultry house
Source: adapted from "Design of ventilation systems for poultry and livestock shelters", (2001), ASAE standards 2002.

$$Qs + Qe + Qsup = Qm + Qb + Qv + Qstored$$

where Qs is sensible heat loss from animals, Qe is heat produced by equipment, Qsup is supplemental heat production, Qm is latent heat loss, Qb is building heatloss, Qv is heat lost in ventilation and Qstored is heat stored by walls, ceiling and the floor. All heat energy computed in this spreadsheet will be in BTU/hr. Qe and Qstored are assumed to be negligible for the scope of this study.

Heat loss through the building is calculated as (MidWest Plan Service - 32, 1990):

$$Qb = A/R * \Delta T$$

where A is total surface are of the house in sqft., R is total resistance of the surface to heat flow and ΔT is difference in temperature between outside and design temperature in °F.

Heat loss through ventilation air is calculated as (MidWest Plan Service - 32, 1990):

$$Qv = 1.1 * cfm * \Delta T$$

where cfm is volume of ventilation air in cuft/min.

Sensible heat production for 1000 broilers in BTU/hr is calculated as: (Reece et al. 1982)

$$Qs = 0.76 * N^3 - 10 * N^2 + 347 * N - 511$$

where N is Age in days.

Latent heat loss is calculated as (Deaton et al., 1969):

$$Qm = W * (11.440 - 2.698 * W + 0.248 * W^2)$$

where W is individual bird weight in lb.

From the above equations Supplemental heating required can be developed. It is calculated as:

$$Qsup = Qb + Qv - Qs.$$

Fuel Cost

Fuel cost depends on the amount and type of fuel required to heat the house to a certain design temperature and the cost of the fuel. It contains a term for the supplemental heat required, the heating value of the fuel, the efficiency of heating, and the current price of fuel. The equation used to calculate the daily fuel cost is:

$$Cost = \eta * F\$ * FC * Qsup$$

where η is efficiency of heating with different methods, and FC is fuel content in Btu and F$ is the cost in $ per unit of fuel.

Table 6. Fuel efficiencies cost and heating values

Fuel	Fuel Content	Cost	Efficiency %
Natural gas	1 therm has 100000 Btu	$ 0.45 / therm	70-90
Propane	1 gal has 93000 Btu	$ 0.85 / gal	70-90
Fuel oil	1 gal has 138000 Btu	$ 1.00 / gal	50-80
Electricity	1 KWhr has 3413 Btu	$ 0.06 / KWhr	100

Ammonia Concentration

Wathes et al. (1997) found ammonia emissions for broilers to be 9 g/hr per 500kg live weight for broilers in winter and summer. This factor was used to calculate the ammonia generated by a single broiler using their daily body weight and multiplied by number of birds to get the total ammonia generated in mg/minute. Using the formula below, ammonia in parts per million was calculated (Adapted from Air Dispersion Modeling Conversions and Formulas):

$$ppm = \frac{(mg/cu.m)*(Temperature)}{12.187 * \text{Molecular Weight of Ammonia}}$$

where ppm is concentration of ammonia in parts per million by volume, mg/cu.m is concentration in milligrams of ammonia per cubic meter of ambient air and temperature is in degrees Kelvin (Celsius + 273.15).

Management Scenarios Analyzed By The Spreadsheet

Based on the choice of normal ventilating rates, higher ventilating rates to control ammonia or lowered ventilation with alum usage, the spreadsheet can model the economic gains. Given below is a description of each scenario

Baseline

The ventilation is designed as per the Midwest plan services guidelines. The rate of air change suggested by these guidelines is not effective for ammonia removal. However due the lower airflow rates, this scheme saves electricity and heating costs. The spreadsheet calculates the costs based on airflow and supplemental heating required without regard to ammonia control.

Ammonia Control

In this case ammonia control is achieved by turning ventilation fans on when the ammonia concentration reaches above 25 ppm. The accumulated ammonia is exhausted along with the ventilation air and the fans switch off. Again ammonia is allowed to accumulate to a concentration of 25 ppm and on exceeding this concentration the ventilation is triggered on.

As research by Xin et al. (1996) shows, the rates of ventilation are much higher in this case and more fuel is required to heat the larger volume of air. The spreadsheet calculates electricity and fuel cost based on higher ventilation rates needed to control ammonia.

Alum Applied

Moore et al. (1999) recommended that alum be applied after each flock of chickens at a rate of approximately 0.2 lb alum per bird. For a standard 20,000-bird poultry house (40 ft x 400 ft) this would be equivalent to approximately 4000 lb alum/flock or 0.248 lb alum/sq.ft /flock. This application rate corresponds to a reduction in ammonia volatilization by 97 percent for the first 4 wk of grow out. The spreadsheet decreases ammonia concentrations by 97 percent and calculates energy costs similar to the ammonia case.

CHAPTER IV

RESULTS

The program was used to run 60 simulations (12 months for 5 stations in Oklahoma, Arkansas and Kansas) with the following variables:

- Birds / flock: 20,000
- Fuel: Propane with a heating value of 93000 BTU priced at $0.85 / gal
- Electricity rate: $0.06 / KWh
- Batch start date: 1st day of every month
- Alum application rate: 3968 lb alum/flock or 0.248 lb alum/sq.ft /flock
- Price of Alum: $200.00 / ton

The results of the simulations are presented and discussed in two parts. The first part deals with simulated heating and the savings alum can generate in fuel usage for heating. The second part shows the simulated ventilation requirements and the savings alum can generate in lowering the required volume of ventilation air. The spreadsheet modeled the three scenarios below.

- Baseline Scenario: Supplemental heating and ventilation requirements were modeled based on industry standard MidWest Plan guidelines where ammonia production at high levels (Wathes, 1997) were not considered.
- Ammonia Scenario: Supplemental heating and ventilation requirements were modeled based on higher volumes of air required to let ammonia concentrations not exceed 25 ppm through ventilation (Xin, 1996 and Wathes, 1997).

- Alum Scenario: Supplemental heating and ventilation requirements were based on an alum application rate of 2 tons per flock bringing about 97 percent reduction in ammonia volatilization.

The results in Figure 8 are representative of a typical winter month for the study areas and shows heat in BTU / hr vs. bird age in days. The figure shows plots of "sensible heat generated" by birds, and the "total heat losses" for the baseline, ammonia and alum scenario. Supplemental heating is required when the total heat loss lines are higher than the sensible heat lines. This means that the heat produced by the birds is lower than what is being lost to the surroundings through ventilation, the walls and the ceiling. If additional heat is not provided, the birds will be exposed to temperatures that are colder than optimum which will lead to lower performance of the broilers. In this graph the total heat loss line for ammonia scenario is higher than the alum scenario for a winter month showing that alum use will save fuel needed for supplemental heating.

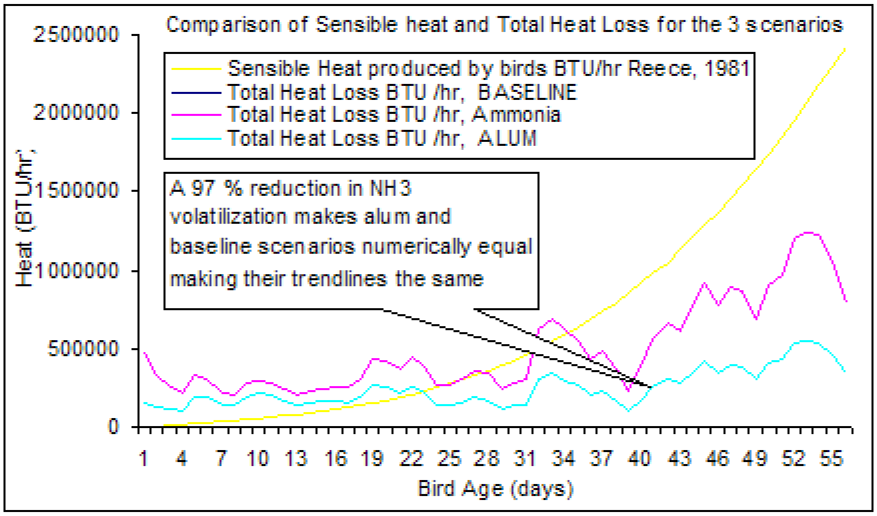
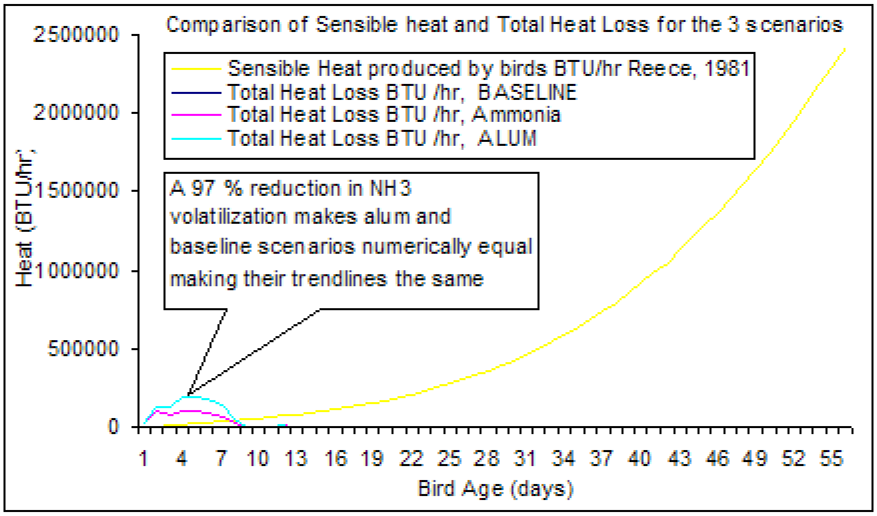


Figure 8. Comparison of Sensible heat generated by broiler and heat lost to the surroundings for baseline, ammonia and alum scenarios for a batch starting on the month of January located in a farm with the climate profile of Oklahoma City.
Source: Model simulation.

Heat balances for a typical summer month have been represented in Figure 9, with flock start date on July 1st, for an area with the climate profile of Oklahoma City, OK. Figure 9 shows that supplemental heating is required only in the first week. In this graph we observe a reverse trend as compared to the winter month chart. Here the baseline is higher than the ammonia scenario line unlike in Figure 8, meaning that higher supplemental heating is needed in the baseline scenario compared to the ammonia scenario. This can be explained because the summer months have high baseline ventilation requirements which are higher than the requirements for ammonia control as seen below in Figure 11.



Comparison of Sensible heat and Total Heat Loss for the 3 scenarios

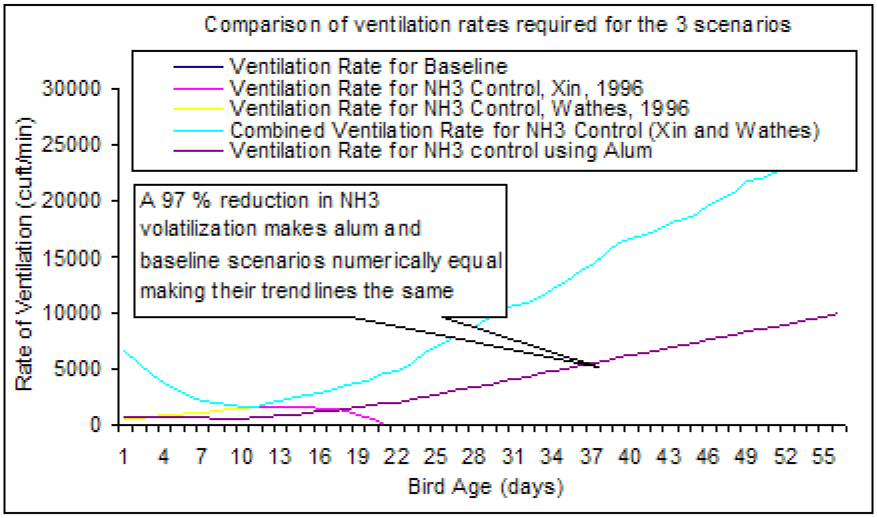
A 97 % reduction in NH3 volatilization makes alum and baseline scenarios numerically equal making their trendlines the same

Figure 9. Comparison of Sensible heat generated by broiler and heat lost to the surroundings for baseline, ammonia and alum scenarios for a batch starting on the month of July located in a farm with the climate profile of Oklahoma City.
Source: Model simulation

Figure 9 shows ventilation rate in cu.ft / minutes vs. bird age in days. The baseline scenario models the ventilation based on Mid West Plan guidelines. The ventilation needed for ammonia control (combined) is based on Xin (1996) and Wathes (1996) models. When we apply alum there is a assumed 97% reduction in ammonia volatilization which brings ammonia levels back to the baseline level. As a result, the alum scenario and baseline scenario are superimposed on each other.

The graph (Figure 8) is for a typical winter month (Oklahoma City, flock starting in January) and shows the combined ammonia trend line being much higher than the alum line proving the benefits of alum in reducing the ventilation rate for winter months.

The summer month graph represented by Figure 11, shows that the baseline requirement for ventilation is much higher than the ammonia scenario. During the summer months while the birds produce sensible heat the building also receives high solar radiation which creates a need for sensible cooling. More rapid air change rates or higher ventilation rates are needed during summer than in winter. The higher ventilation rates remove the ammonia generated. This shows that alum application is not required in summer and would not generate any fuel and electricity savings. This will be proved in the following sections.


Comparison of ventilation rates required for the 3 scenarios

A 97 % reduction in NH3 volatilization makes alum and baseline scenarios numerically equal making their trendlines the same

Figure 10. Comparison of required ventilation rates for baseline, ammonia and alum scenarios for a batch starting on the month of January located in a farm with the climate profile of Oklahoma City.
Source: Model simulation

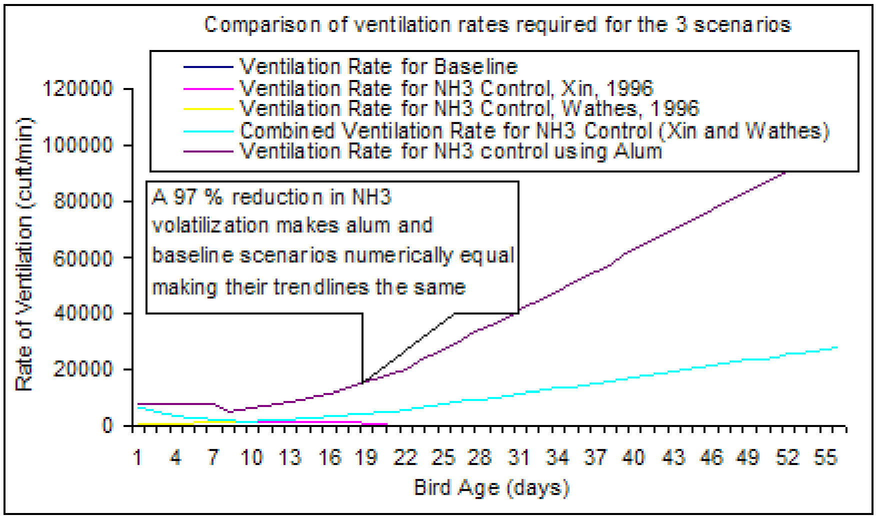


Figure 11. Comparison of required ventilation rates for baseline, ammonia and alum scenarios for a batch starting on the month of July located in a farm with the climate profile of Oklahoma City.
Source: Model simulation

Table 7 summarizes the results of sixty simulations. Each simulation is for a batch of 20,000 broilers raised on used litter, in a house located in one of the five locations from Oklahoma, Arkansas and Kansas. Each batch starts on the 1st day of the indicated month and matures in 56 days. Table 7 shows the fuel and electricity costs of each simulation where "Heat" refers to fuel cost in dollars for supplemental heating, "Fan" refers to cost of electricity in dollars for running ventilation fans and "Total" is the summation of the electricity and fuel costs (E+F) in dollars for each scenario. Gross saving is equal to the difference between the total costs for the ammonia scenario and the alum scenario. The gross savings values show the amount by which fuel and electricity expenses are reduced by using alum because less ventilation is required to remove ammonia. Net savings are calculated by deducting the cost of applying alum from the gross savings. Alum cost is based on $200 per ton of aluminum sulfate with a dosage of 1.8 tons per flock. Negative values have been reported as $0.00 in table 7.

Notice that the cost of fuel required for supplemental heating shows peaks in November and March for the baseline and alum scenarios. This may seem anomalous because March and November are not the coldest months in these regions. The maximum heat energy requirements might be expected around for the months of December and January because the lowest temperatures occur during this time. The fact that the highest total heating cost occurs in November and March is because higher rates of ventilation are required for moisture removal and temperature modification during this "mild weather" period as per Mid West Plan Ventilation Guidelines. These Mid West Plan Guidelines specify rates that are five times higher than the minimum rates required for cold weather ventilation. March and November are months that have low temperatures but are a part of the "mild weather" season. This increased volume of air during a cool climate needs a large amount of heat energy to warm it to the desired level for broiler growth, explaining the "maximum" in fuel costs in March and November months. The first week of broiler growth is crucial because the birds are very young and require a warm climate because they do not produce enough sensible heat to warm their surroundings unlike older birds. The first week usually demands the highest heating requirements. Hence, low temperature occurrences during the batch start day through the end of the first week can greatly impact the total energy cost for that batch.

From the simulation results in Table 7 we find Gross savings ranging from $22 to $1442 per batch of 20,000 birds. Gross savings were found in the months of January, February, November and December for all locations except Kansas (Kansas did not have gross savings for the month of November). Gross savings values are indicative of the reduction in energy costs that can be achieved by reduced ventilation when the litter is treated with alum. The actual saving or the growers' real profit is calculated by deducting the costs involved in applying alum to the litter. Based on a dosage of 1.8 tons of alum per flock a cost of $360 is subtracted from the gross savings. This reduces the gross saving during the four month period starting November through February so that net savings are realized only in December and January for all locations along with February for Little Rock and Oklahoma City. The values of the net savings in all five locations were averaged and found to be $484. This "average net savings" calculated from table 7 gives an estimate of the savings per batch a grower can make by reduced ventilation and alum application during the cold weather. This suggests that a grower can maximize profit by strategically planning his batch start date based on past climate records to make sure 2 batches can fall during this profitable period beginning from the end of November to the beginning of February.

Findings

Based on Table 7 we can summarize our findings as:

- The application rate (of 1800 kg alum/flock which corresponds to 10 percent alum by weight of the litter) simulated minimizes ammonia volatilization by 97 percent making the alum scenario numerically approximately equal to the baseline (no ammonia) scenario.
- Alum application generated savings only in winter months (December, January and February) ranging from a minimum of $19 to a maximum of $1082/month/house.

- Average Net savings for the months of December through February were $484/month/house.
- The average net cost of applying alum for the mild and hot weather months is $355/month/house.
- If alum is applied for flocks growing during the months of December through February the at the end of a year during cleanout after the last flock, alum content of the litter will be 3.2 percent by wet weight (assuming 20 tons litter/flock(wet),5.6 flocks/year, and 1.8 tons alum applied each time for 2 flocks in a year)

Table 7. Cost Comparison of baseline, ammonia and alum scenario simulations

	Batch	BaseLine Scenario Costs			Ammonia Scenario Costs			Alum Scenario Costs			Gross	Alum	Net	Net
Location	Start Month	Heat Hb	Fan Fb	Total, Tb Hb+Fb	Heat Hn	Fan Fn	Total, Tn Hn+Fn	Heat Hl	Fan Fl	Total, Tl Hl+Fl	Saving,Gs Tn - Tl	Cost Ac	Saving Gs - Ac	Cost Ac - Gs
Oklahoma	Jan	599	28	626	1486	73	1559	599	28	626	933	360	573	0
City	Feb	759	120	879	1138	75	1212	759	120	879	379	360	19	0
Oklahoma	Mar	1254	139	1393	677	76	753	1254	139	1393	0	360	0	360
	Apr	664	139	803	562	77	639	664	139	803	0	360	0	360
	May	338	247	585	309	78	387	338	247	585	0	360	0	360
	Jun	406	278	684	200	79	279	406	278	684	0	360	0	360
	Jul	244	278	522	123	79	202	244	278	522	0	360	0	360
	Aug	137	170	307	67	78	145	137	170	307	0	360	0	360
	Sep	84	139	222	81	77	158	84	139	222	0	360	0	360
	Oct	524	139	663	297	75	372	524	139	663	0	360	0	360
	Nov	1128	51	1178	641	74	714	1128	51	1178	23	360	0	337
	Dec	311	28	339	1124	72	1196	311	28	339	857	360	497	0
Tulsa	Jan	566	28	594	1443	73	1517	566	28	594	923	360	563	0
Oklahoma	Feb	1017	120	1136	1039	75	1114	1017	120	1136	22	360	0	338
	Mar	1003	139	1142	611	76	687	1003	139	1142	0	360	0	360
	Apr	501	139	639	450	77	527	501	139	639	0	360	0	360
	May	341	247	588	208	78	286	341	247	588	0	360	0	360
	Jun	400	278	678	242	79	321	400	278	678	0	360	0	360
	Jul	52	278	329	18	79	97	52	278	329	0	360	0	360
	Aug	30	170	200	10	78	88	30	170	200	0	360	0	360
	Sep	140	139	279	86	76	162	140	139	279	0	360	0	360
	Oct	564	139	703	208	75	283	564	139	703	0	360	0	360
	Nov	1373	51	1424	678	73	752	1373	51	1424	23	360	0	337
	Dec	368	28	396	1156	72	1228	368	28	396	832	360	472	0

Table 7. Cost Comparison of baseline, ammonia and alum scenario simulations (Continued)

	Batch	BaseLine Scenario Costs			Ammonia Scenario Costs			Alum Scenario Costs			Gross	Alum	Net	Net
	Start	Heat	Fan	Total, Tb	Heat	Fan	Total, Tn	Heat	Fan	Total, Tl	Savings, Gs	Cost	Savings	Cost
Location	Month	Hb	Fb	Hb+Fb	Hn	Fn	Hn+Fn	Hl	Fl	Hl+Fl	Tn - Tl	Ac	Gs - Ac	Ac - Gs
Fort Smith Arkansas	Jan	439	28	467	1184	74	1258	439	28	467	791	360	431	0
	Feb	812	120	932	912	75	986	812	120	932	99	360	0	261
	Mar	1139	139	1278	713	76	789	1139	139	1278	0	360	0	360
	Apr	432	139	571	382	77	459	432	139	571	0	360	0	360
	May	239	247	486	215	78	294	239	247	486	0	360	0	360
	Jun	256	278	534	123	79	203	256	278	534	0	360	0	360
	Jul	21	278	298	17	79	96	21	278	298	0	360	0	360
	Aug	87	170	257	58	78	136	87	170	257	0	360	0	360
	Sep	74	139	213	55	76	131	74	139	213	0	360	0	360
	Oct	599	139	738	317	75	392	599	139	738	0	360	0	360
	Nov	1294	51	1345	551	73	625	1294	51	1345	23	360	0	337
	Dec	418	28	445	1156	73	1230	418	28	445	785	360	425	0
Little Rock Arkansas	Jan	494	28	522	1159	74	1233	494	28	522	711	360	351	0
	Feb	379	120	499	868	75	943	379	120	499	489	360	129	0
	Mar	977	139	1116	491	76	567	977	139	1116	0	360	0	360
	Apr	358	139	496	257	77	334	358	139	496	0	360	0	360
	May	221	247	468	215	78	293	221	247	468	0	360	0	360
	Jun	190	278	467	110	79	189	190	278	467	0	360	0	360
	Jul	53	278	331	26	79	105	53	278	331	0	360	0	360
	Aug	69	170	239	34	78	112	69	170	239	0	360	0	360
	Sep	60	139	199	59	76	135	60	139	199	0	360	0	360
	Oct	445	139	584	319	75	394	445	139	584	0	360	0	360
	Nov	1146	51	1196	474	74	548	1146	51	1196	23	360	0	337
	Dec	314	28	342	897	73	969	314	28	342	628	360	268	0

Table 7. Cost Comparison of baseline, ammonia and alum scenario simulations (Continued)

	Batch	BaseLine Scenario Costs			Ammonia Scenario Costs			Alum Scenario Costs			Gross	Alum	Net	Net
	Start	Heat	Fan	Total, Tb	Heat	Fan	Total, Tn	Heat	Fan	Total, Tl	Savings, Gs	Cost	Savings	Cost
Location	Month	Hb	Fb	Hb+Fb	Hn	Fn	Hn+Fn	Hl	Fl	Hl+Fl	Tn - Tl	Ac	Gs - Ac	Ac - Gs
Wichita	Jan	592	28	620	1990	72	2063	592	28	620	1442	360	1082	0
Kansas	Feb	1489	120	1608	1371	74	1445	1489	120	1608	0	360	0	360
	Mar	1447	139	1586	783	75	859	1447	139	1586	0	360	0	360
	Apr	686	139	825	425	76	501	686	139	825	0	360	0	360
	May	407	247	654	358	78	436	407	247	654	0	360	0	360
	Jun	237	278	514	136	79	215	237	278	514	0	360	0	360
	Jul	53	278	331	25	79	104	53	278	331	0	360	0	360
	Aug	79	167	246	20	78	97	79	167	246	0	360	0	360
	Sep	96	139	235	94	76	170	96	139	235	0	360	0	360
	Oct	1224	139	1363	391	74	466	1224	139	1363	0	360	0	360
	Nov	1817	51	1867	893	72	966	1817	51	1867	22	360	0	338
	Dec	501	28	529	1814	72	1886	501	28	529	1357	360	997	0

CHAPTER V

SUMMARY AND FUTURE SCOPE

The main focus of this study was the development of a poultry ventilation model and an analysis of the benefits of alum usage by comparing it with ventilation energy costs in the baseline (no ammonia) and ammonia management scenarios. The results show alum use as beneficial only in the winter months (December and January for Tulsa, Fort Smith and Wichita and December through February for OKC and Littlerock), when minimum ventilation requirements are low and ammonia buildup in confined spaces of a poultry house is a problem. For summer, spring and fall weather the ventilation rate for the baseline case is much higher than winter months. This elevated ventilation rate takes care of ammonia volatilization undermining any savings alum would have brought. To optimize the benefits of alum use, flock start dates can be managed so that at least 2 of the 5.6 flocks in a year can overlap with cold weather. This analysis shows alum application for the mild and hot weather months to have a net cost of $355 justifying a restriction of alum use only to the profitable colder months. However, apart from the ventilation savings, researchers have also suggested alum to have additional environmental benefits in reducing Phosphorus runoff. These issues should be addressed in future research which may show additional benefits from alum use.

As a follow-up to this thesis the application of alum should be analyzed by simulating other benefits such as:

- Improved weight gain of birds,
- Improved fertilizer value of the litter,
- Reduction in phosphorus runoff, and
- Reduction in environmental liabilities for the grower (odor reduction, torts etc.).

Additionally, a variant to the current study can be a modification of this program to reflect a trade-off that maximizes grower profit by varying the alum application rate (from a constant 1800 kg alum/flock or 0.1125 kg alum/ft /flock as recommended by Moore et al. (1999) and in this study, to gradually decreasing doses).

Coupled with alum use another promising focus area for future research is the exploration of an optimal temperature for broiler growth by trading off benefits of an ideal temperature with costs in obtaining that temperature. At this time not many empirical or regression models exist that model feed conversion with temperature and exhibit a global maximum that can be used for a tradeoff model. A suggestion is, to use field trials to help us move in the direction of finding a pattern between body weight gain or feed conversion and temperature.

GIS based programming shows promise in customizing the solutions of these studies with a spatial extent and extend them to other regions of the United States and major international hubs of livestock business facing similar issues.

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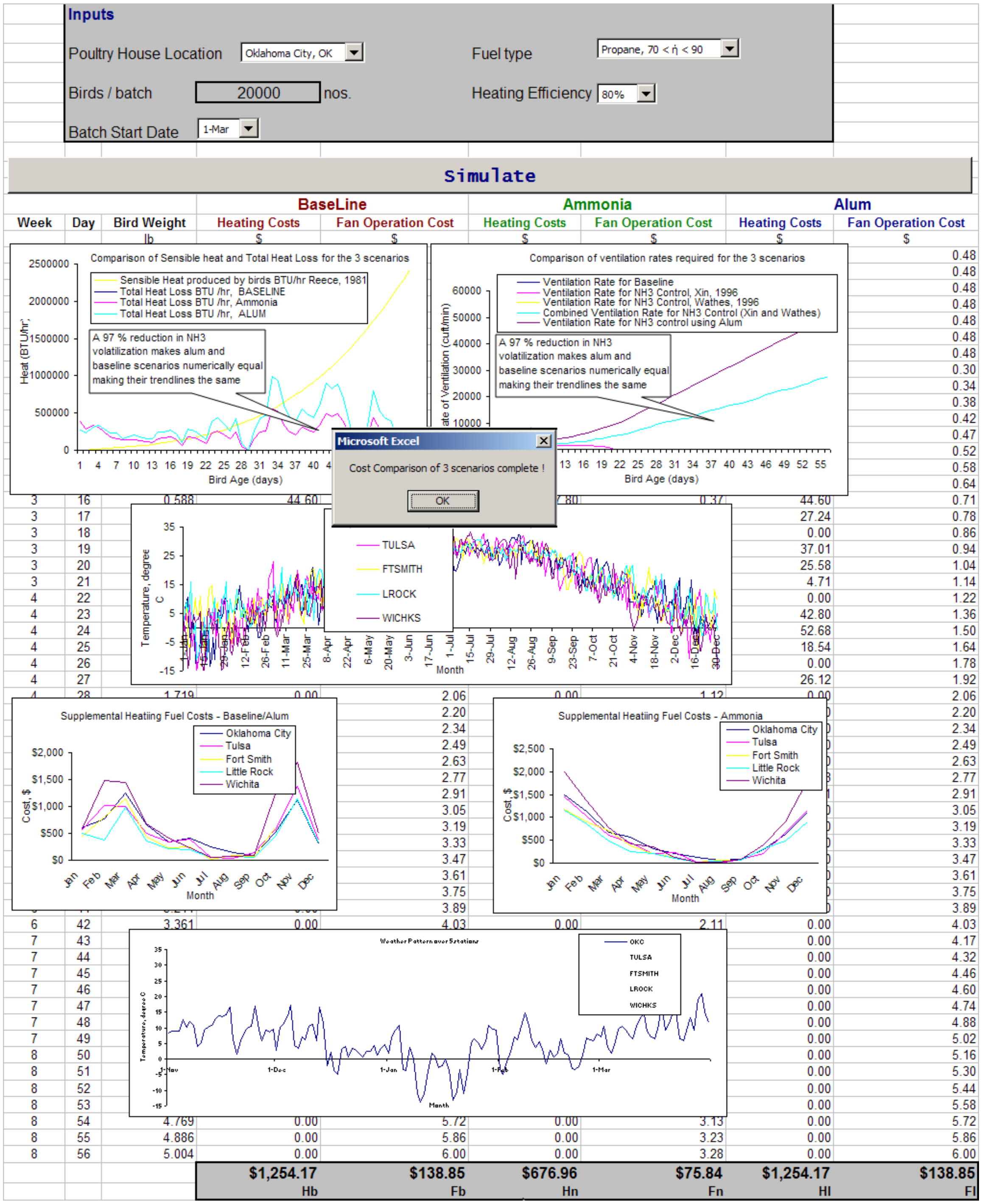
APPENDIX

User Interface of the Simulator



Inputs

Poultry House Location: Oklahoma City, OK

Fuel type: Propane, 70 < ή < 90

Birds / batch: 20000 nos.

Heating Efficiency: 80%

Batch Start Date: 1-Mar

Microsoft Excel

Cost Comparison of 3 scenarios complete !

	BaseLine		Ammonia		Alum	
	Heating Costs	Fan Operation Cost	Heating Costs	Fan Operation Cost	Heating Costs	Fan Operation Cost
	$1,254.17	$138.85	$676.96	$75.84	$1,254.17	$138.85
	Hb	Fb	Hn	Fn	Hl	Fl

VBA Source Code for the program

```
Sub coppas()
'
' coppas Macro
' Macro recorded 2/11/2004 by Agricultural Economics
'
Dim dstr As String, Lx As Integer, Ly As Integer, Sx As String, Sy As String

 Dim x, y  As Integer
x = Range("A5"): Sx = Str(x)
y = Range("B5"): Sy = Str(y)
Ly = Len(Sy): Lx = Len(Sx)
 dstr = "G" + Right(Sx, Lx - 1) + ":G" + Right(Sy, Ly - 1)
 Range(dstr).Select

       Selection.Copy
    Range("j1").Select
    ActiveSheet.Paste
    Application.CutCopyMode = False
    Range("I1").Select

        Application.StatusBar = "done!"
Application.OnTime Now + TimeSerial(0, 0, 5), "ClearStatusBar"
End Sub

Sub ClearStatusBar()
    Application.StatusBar = False
End Sub

Sub DropDown5_Change()
'
' DropDown5_Change Macro
' Macro recorded 7/7/2004 by jsadhu
'location

'    Sheets("clim8").Select

  If Range("N2") = "1" Then

Range("d2:d731").Select
Selection.Copy
Range("K2").Select
    ActiveSheet.Paste
Application.CutCopyMode = False
```

```
ElseIf Range("N2") = "2" Then
Range("e2:e731").Select
Selection.Copy
Range("K2").Select
   ActiveSheet.Paste
Application.CutCopyMode = False

ElseIf Range("N2") = "3" Then

Range("f2:f731").Select
Selection.Copy
Range("K2").Select
   ActiveSheet.Paste
Application.CutCopyMode = False

ElseIf Range("N2") = "4" Then

Range("g2:g731").Select
Selection.Copy
Range("K2").Select
   ActiveSheet.Paste
Application.CutCopyMode = False

ElseIf Range("N2") = "5" Then

Range("h2:h731").Select
Selection.Copy
Range("K2").Select
   ActiveSheet.Paste
Application.CutCopyMode = False


ElseIf Range("N2") = "6" Then

Range("i2:i731").Select
Selection.Copy
Range("K2").Select
   ActiveSheet.Paste
Application.CutCopyMode = False

End If
Range("l2").Select
Sheets("control").Select
Range("b3").Select
```

```
End Sub
Sub DropDown6_Change()
' This macro links combo box date change and takes the 8 week period from the climate
' records from the city data and pastes it to k2 thru twice the whole year

' DropDown6_Change Macro
' Macro recorded 7/7/2004 by jsadhu
'
Dim dstr As String, Lx As Integer, Ly As Integer, Sx As String, Sy As String

 Sheets("clim8").Select

Dim x, y  As Integer
x = Range("N16"): Sx = Str(x)
y = Range("N17"): Sy = Str(y)
Ly = Len(Sy): Lx = Len(Sx)
 dstr = "k" + Right(Sx, Lx - 1) + ":k" + Right(Sy, Ly - 1)
 Range(dstr).Select
  Selection.Copy

   Sheets("calulation").Select
        Range("bb23").Select
    ActiveSheet.Paste

  Sheets("clim8").Select
  dstr = "m" + Right(Sx, Lx - 1) + ":m" + Right(Sy, Ly - 1)
 Range(dstr).Select
  Selection.Copy

  Sheets("calulation").Select
  Range("bq23").Select
  ActiveSheet.Paste

      Application.CutCopyMode = False
    Sheets("control").Select
    Range("d16").Select
'

End Sub

Sub comparecopy()
'
' comparecopy Macro
' Macro recorded 6/23/2004 by jsadhu
'
```

```
'
  If Range("y14") = "5" Then
      Range("X23:X78").Select
    Selection.Copy
  Range("Y23").Select
  Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
     :=False, Transpose:=False
  Application.CutCopyMode = False

  ElseIf Range("y14") = "4" Then Range("v23:v78").Select
    Selection.Copy
  Range("Y23").Select
  Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
     :=False, Transpose:=False
  Application.CutCopyMode = False

  ElseIf Range("y14") = "3" Then Range("R23:R78").Select
    Selection.Copy
  Range("Y23").Select
  Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
     :=False, Transpose:=False
  Application.CutCopyMode = False

  ElseIf Range("y14") = "2" Then Range("P23:P78").Select
    Selection.Copy
  Range("Y23").Select
  Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
     :=False, Transpose:=False
  Application.CutCopyMode = False

  ElseIf Range("y14") = "1" Then Range("N23:N78").Select
    Selection.Copy
  Range("Y23").Select
  Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
     :=False, Transpose:=False
  Application.CutCopyMode = False

     End If
     Range("aj12").Select

End Sub
Sub Calcul8()
'
' Calcul8 Macro
' Macro recorded 7/28/2004 by jsadhu
'
```

```
'
    Sheets("calulation").Select
    Range("I23:I78").Select
        Selection.Copy
    Sheets("control").Select
    Range("d16").Select
        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Application.CutCopyMode = False
    Sheets("calulation").Select
        Range("BV23:BV78").Select
            Selection.Copy
    Sheets("control").Select
    Range("E16").Select
     Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
     Range("E16").Select

    Sheets("calulation").Select
    Range("BZ23:BZ78").Select
    Selection.Copy
    Sheets("control").Select
    Range("F16").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Sheets("calulation").Select
    Range("CF23:CF78").Select
    Application.CutCopyMode = False
    Selection.Copy
    Sheets("control").Select
    Range("H16").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Sheets("calulation").Select
    Range("BW23:BW78").Select
    Application.CutCopyMode = False
    Selection.Copy
    Sheets("control").Select
    Range("G16").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Sheets("calulation").Select
    Range("BX23:BX78").Select
    Application.CutCopyMode = False
    Selection.Copy
```

```
    Sheets("control").Select
    Range("I16").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Range("A1").Select
    MsgBox "Cost Comparison of 3 scenarios complete !"

End Sub

ub Button3_Click()
'
' Button3_Click Macro
' Macro recorded 11/4/2004 by JS
'Dim dstr As String, Lx As Integer, Ly As Integer, Sx As String, Sy As String

   Sheets("calulation").Select
    Range("I23:I78").Select
        Selection.Copy
    Sheets("control").Select
    Range("d16").Select
        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Application.CutCopyMode = False
    Sheets("calulation").Select
        Range("BV23:BV78").Select
            Selection.Copy
    Sheets("control").Select
    Range("E16").Select
     Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

           Sheets("calulation").Select
    Range("BZ23:BZ78").Select
    Selection.Copy
    Sheets("control").Select
    Range("F16").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Sheets("calulation").Select
    Range("CF23:CF78").Select
    Application.CutCopyMode = False
    Selection.Copy
    Sheets("control").Select
    Range("H16").Select
   Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
```

```
Sheets("calulation").Select
Range("BW23:BW78").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("control").Select
Range("G16").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("calulation").Select
Range("BX23:BX78").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("control").Select
Range("I16").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False

  End Sub
```

VITA

Joy Sadhu

Candidate for the Degree of

Masters of Science

Thesis: EVALUATION OF ECONOMIC GAINS TO BROILER PRODUCERS BY MODULATING VENTILATION AND USING ALUM FOR AMMONIA CONTROL

Major Field: Environmental Science

Biographical:

Personal Data: Born in Calcutta, India, On May 02, 1979.

Education: Graduated from Birla High School in Calcutta, India in Jun, 1996; received Bachelors in Environmental Engineering from Kolhapur Institute of Technology's College of Engineering, Shivaji University, Maharashtra, India in July, 2001. Completed the Requirements for the Masters of Science degree with a Major in Environmental Science and a specialization in Environmental Management at Oklahoma State University in May, 2005.

Experience: Raised in India. Employed as a Management Trainee by Bengal Ambuja Housing Development Ltd., Calcutta, India, 2001-2002.Employed as a Research Assistant by the Agricultural Economics Dept. of Oklahoma State University, 2002-to present.

Professional Memberships: Indian Society for Technical Education and World Wildlife Fund.

Name: Joy Sadhu Date of Degree: May, 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EVALUATION OF ECONOMIC GAINS TO BROILER PRODUCERS BY MODULATING VENTILATION AND USING ALUM FOR AMMONIA CONTROL

Pages in Study: 82 Candidate for the Degree of Master of Science

Major Field: Environmental Science

Scope and Method of Study: Livestock is the largest source category of ammonia in the United States. Growing broilers on reused litter exposes birds to high concentrations of ammonia from a very young age. The problem is compounded in winter with growers trying to conserve fuel usage by reducing ventilation rates. Exposure to ammonia above levels of 25 ppm leads to reduced weight gain and feed conversion of broilers. Researchers have claimed that applying alum sulfate reduces ammonia volatilization, improves broiler performance, improves fertilizer value of litter and lowers soluble phosphorus runoff. For this study a ventilation model along with an ammonia generation model was developed. The model considered daily ventilation and heating requirements by age of bird, ammonia level, and by geographic location in Kansas, Arkansas and Oklahoma. The model compared the benefits of increased ventilation against the cost of ventilation and alum use.

Findings and Conclusions: Alum use was found to be beneficial only in winter months with average net savings brought about by reduced electricity and fuel usage to $484.00. Using alum for ammonia control during hot and mild weather is not profitable when compared with climate control costs.

ADVISORS APPROVAL: Dr. Arthur L. Stoecker