American Journal of Experimental Agriculture
4(12): 1877-1897, 2014
ISSN: 2231-0606

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Air Contaminants Emissions at Sheep Feeding Operations as a Part of AFO's Emissions Inventory

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Author's contribution

The study was designed, analyzed and discussed by the author. The author takes full responsibility for the whole study including data collation, manuscript drafting and editing.

Article Information

DOI: 10.9734/AJEA/2014/12119
Editor(s):
(1) Francisco Javier Alarcón López, School of Engineering,Applied Biology Dept, University of Almería, Spain.
(2) Zhen-Yu DU, School of Life Science, East China Normal University, China.
(3) Anonymous Editor.
Reviewers:
(1) Anonymous, Visveshwaraya Technological university, India.
(2) Johnson Grayson Mshana, Dept. of Animal Science and Production, Sokoine Univ. of Agriculture, Tanzania.
Peer review History: http://www.sciencedomain.org/review-history.php?iid=586&id=2&aid=5798

Review Article

Received 18th June 2014
Accepted 7th August 2014
Published 20th August 2014

ABSTRACT

Information about the air pollutants at sheep and goat feeding operations (SFOs) is presented in this review. This survey covers the effects of environmental parameters, including ambient air temperature, relative humidity, gaseous and particulate contaminants on sheep health.
Furthermore, factors affecting air contaminants in sheep buildings, including facility design, manure handling and storage, ventilation, animal activity, type of floor, and stocking density, are discussed. This review found that floor bedding, feces, feed and outdoor dust are the main sources of particulate and gaseous contaminants in sheep husbandry. The majority of the secondary pollutants could be related to an increase in air temperature,

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which caused dryness of the bedding soil and helped with the aerosolization of dust. Shielding the wind side of the building will possibly help toreduce the effect of ambient dust and control the indoor dust concentration. The ranges of literature values for total suspended particles (TSP), particulate matter with a diameter less than or equal to 10 µm (PM_{10}) and particulate matter with a diameter less than or equal to 2.5 µm ($PM_{2.5}$) were0.75-3.6, 0.03-2.0 and 0.04-0.05mg/m^3, respectively.

Keywords: Sheep; particulate contaminants; gaseous contaminants; air quality; dust; TSP; PM_{10}; and $PM_{2.5}$.

1. INTRODUCTION

Animal Feeding Operations (AFOs) are agricultural operations where animals are kept and raised in confined situations. AFOs congregate animals, feed, manure and urine, dead animals, and production operations on a small land area. Feed is brought to the animals rather than the animals grazing or otherwise seeking feed in pastures, fields, or on rangeland [1]. The importance of clean and healthy indoor air for a prosperous and healthy society has been revealed in many scientific investigations, which have shown that both the indoor climate and the indoor air quality (IAQ) can influence comfort, health, and productivity [2]. Furthermore, there is a need for a more complete characterization and accurate quantification of the gaseous and particulate matter (PM) emissions from different types of AFOs and other operations such as poultry, cattle, sheep and camel feedlots. Additionally, limited information is available on the physical and biological characteristics of these emissions. Understanding the nature of air contaminants will lead to obtain the best control methods [3] so AFOs can provide clean and healthy indoor air.

Livestock operations produce a variety of particulates and gases that influence ambient air quality. Measurements of emissions from livestock operationsare necessary for determining the contributions to air pollution by these facilities and for determining the efficacy of pollution mitigation techniques. It is important to characterize these emissions to analyze the impact of livestock operations on human and animal health and quality of life. Essential characteristics include the rate of emission, the emission constituents, and the spatial distribution of the emissions. Air quality relating to livestock buildings has been a major concern for years, particularly with regard to animal health [4]. The importance of clean, temperate and healthy indoor air for a prosperous and healthy society has been revealed in many scientific investigations, which have shown that both the indoor climate and the indoor air quality can influence comfort, health, and productivity [5-8,2].

The animal industry continues to expand rapidly in Saudi Arabia, and sheep and goats are a major source of meat. However, the industry is facing major air quality and environmental challenges leading to public concern regarding the welfare of animals used for production.

1.1 Air Pollution in Sheep Feeding Operations

An intensive system of sheep husbandry inflects considerable stress on sheep by increasing air pollution and, unless appropriate remedial practices are adopted, production may be severely affected. Moreover, research on the impacts of various important factors on air quality is vital for helping animal producers and environmental researchers to understand the parameters that influence livestock air quality so that they can make wise decisions regarding the selection and implementation of gas/odor mitigation techniques. So far, few researchers have evaluated the possible effects of different animal management practices and geographic area factors on long-term source air quality because it is a complex and difficult task in the field [9]. Pickrell et al. [10] found that animal buildings contain more ammonia, hydrogen sulfide, carbon dioxide, respirable dust particles, and endotoxins than buildings occupied by humans. Livestock buildings, in general, are regarded as a major source of air pollutants [11-14]. Considerable quantities of PM, ammonia, odors and other toxic substances are released during the farming activities that take place indoors, which affect animal and human health and welfare. Additionally, small amounts of PM could be transported into the building via its ventilation system [15]. Airborne gaseous and particulate pollutants from livestock, feed and manure also influence air quality in and around livestock buildings. Air quality inside the building affects human and animal health and welfare, while emissions from the buildings can lead to local and even global environment pollution [16,17].

As more stringent air quality standards are developed, there is a critical and urgent need to characterize and control air pollutant emissions. Little research has been conducted to characterize air pollutant emissions from production facilities in Saudi Arabia. Moreover, data on the size distribution of PM emitted are quite limited. This information will increase our understanding on the effects of dust and will lead to the development of the best methods for dust control [3]. The suggested threshold values for indoor air contaminants in livestock housing are provided in Table 1.

Table 1. Suggested threshold values for indoor air contaminants in livestock buildings

Contaminant	Humans	Animals	Reference
Inhalable dust	2.40[a]	3.70	[18]
(comparable to TSP) (mg/m^3)	--	3.40	[19]
Respirable dust *(comparable to PM_4)*	0.16[a]	--	[20]
(mg/m^3)	0.23	0.23	[21]
	--	1.70	[19]
Carbon dioxide (CO_2) (ppm)	1540	1540	[22-24]
Ammonia	7	11	
(NH_3) (ppm)	12[a]	--	
Hydrogen sulfide (H_2S) (ppm)	5	--	

[a]Specific threshold concentrations are defined as mixed exposures between NH_3 and PM in poultry CAFOs [24]

Sources of airborne pollutants within and from livestock production facilities are affected by barn characteristics, outdoor weather conditions, indoor climate, diurnal and seasonal effects, animal growth cycles, in-house storage levels, and barn management. Research on the impacts of these factors on air quality is very important in helping environmental researchers and animal producers understand the parameters influencing livestock air quality so that they can make wise decisions regarding the selection and implementation of odor and gas mitigation techniques [9].

1.2 Effects Environmental Parameters on Sheep

Atmospheric climatic conditions and pollutants from sheep operations influence air quality inside sheep buildings. The climate that prevails inside the barns affects human and animal health and welfare as well as productivity, while emissions from the buildings contribute to environmental pollution. An intensive system of sheep husbandry inflects considerable stress on sheep by increasing air pollution and, unless appropriate remedial practices are adopted, production may be severely affected.

Environmental factors (ambient temperature, relative humidity, solar radiation and wind speed), animal factors (breed, coat color, stage of lactation and health status), and thermoregulatory mechanisms (circulatory adjustments, sweating and panting) have significant impacts on the energy exchange between the animal and the environment [25]. Abbouda et al. [26] studied the variation of two climatic parameters (air temperature and relative humidity) and the levels of particulate matter (TSP, PM_{10}, and $PM_{2.5}$) in a sheep building in Al-Ahsa, Saudi Arabia. From their study, the variation in outdoor climatic conditions affected the indoor environmental parameters, such as temperature and relative humidity, and the concentration of the airborne particles inside the sheep barn. Furthermore, indoor temperature and relative humidity levels were strongly dependent on the outdoor climate conditions because the building was naturally ventilated and not insulated.

Christianson [27] found that the drop in livestock productivity because of less than optimal environmental conditions accounted for an estimated 20% reduction in gross agriculture output. Moreover, the climate that prevails inside the barns affects human and animal health and welfare as well as productivity, while emissions from the buildings contribute to environmental pollution. An intensive system of sheep husbandry inflects considerable stress on sheep by increasing air pollution and, unless appropriate remedial practices are adopted, production may be severely affected [28].

Sheep are one of the most heat-resistant species among farmed animals. An inadequate thermal environment causes adverse health effects in animals and is related to discomfort conditions, which affects the animal's fattening rate and the milk yield. An inadequate thermal environment also influences the concentrations of air pollutants and PM [29]. Sevi et al. [30] found that prolonged exposure to maximum air temperatures greater than 30ºC and to thermal heat index (THI) values greater than 80 prevented lactating ewes from maintaining their thermal balance. They also found that ventilation plays a major role in sustaining the welfare and performance of farmed livestock through affecting thermal exchanges between the animal's body surface and the environment and by removing aerial pollutants, which originate from animals and their excreta. Simonson et al. [2] stated that indoor relative humidity (RH) could significantly affect thermal comfort, occupant health, the durability of building materials, material emissions, and energy consumption. Air temperature and relative humidity are those parameters that are widely used to describe indoor climate conditions [28]. Environmental factors also play an important role. Part of the PM is composed of secondary particles that are formed by a gas to particle conversion process, a process that increases the air's relative humidity [31,12].

1.2.1 Air temperature

Sheep are one of the most heat-resistant species among farmed animals. Additionally, because of reproductive seasonality, sheep are generally in the later stages of lactation during the warmest period of the year. Such peculiarities may contribute to minimize the impact of high summer temperatures on sheep welfare and milk yield.

Increased respiration rate is the first reaction of animals exposed to air temperatures exceeding their thermal neutral zone [32]. If this and the other physiological mechanisms fail to balance the excessive heat load, the body temperature rises and the animal enters the acute phase of heat stress [33]. Sevi et al. [30] found that prolonged exposure to maximum air temperatures over 30ºC and to THI values over 80 prevented lactating ewes from maintaining their thermal balance. Simonson et al. [2] stated that indoor RH can significantly affect thermal comfort, the perception of IAQ, occupant health, the durability of building materials, material emissions, and energy consumption. Ambient temperature and relative humidity were unaffected by the stocking density of the ewes. Stocking density is a critical factor when housing lactating ewes, and it has been suggested that a space allocation of <2m^2 per animal may have an adverse effect on their health and performance. Hence, if lactating ewes cannot be allocated adequate room, it will be necessary to control the other factors that influence ambient levels of microorganisms. The greatest benefits may be obtained by adjusting their microenvironment, especially ventilation rate and the thermal and hygrometric conditions, by improving the hygiene of the bedding, and by using products that reduce enzyme and microbial activity [34].

1.2.2 Relative humidity

Dust predominates at low moisture content and odor at high moisture content, so minimizing both dust and odor by moisture management alone is impossible. However, Sweeten et al. [35] and other researchers found that when the moisture content of the open lot surface is between 25% and 40%, both dust and odor potential are at manageable levels. Indoor RH can significantly affect the thermal comfort [36-40], the perception of IAQ [41,42], occupant health [43-47], the durability of building materials [48,49], material emissions [50] and energy consumption [51,52].

1.3 Air Pollutants in Sheep Buildings and Their Effect on Sheep Health

Animals and/or their wastes in livestock buildings generate different forms of air pollution, including ammonia, carbon dioxide, methane and nitrous oxide gases, as well as dusts and microorganisms [53]. Table 2 represent an estimation of air pollutant emissions in sheep feeding operations as mentioned on different literatures.

Table 2. Estimation of air pollutant emissions in sheep feeding operations

Air pollutant	Estimation		Author	Remarks
Ammonia	0.7%	US production	[54]	
	440	mg NH_3 / Nm^2.h	[55]	outdoor concrete yards
	7.43	Lb / head .yr	[56]	-
Methane	6.5	Tg / yr	[57]	-
	0.12	mg CH_4 / m^2.h	[55]	outdoor concrete yards
NO_2	17.17	µg N_2O / Nm^2.h	[55]	outdoor concrete yards
Microorganisms	Markedly lower than other animal		[58,59,60]	-

Research findings by Donham and [22,23] suggested an exposure limit for swine confinement workers: 2.4 mg/m^3 total dust, 0.23mg/m^3 respirable dust and 7ppm ammonia (NH_3) as shown in Table 3. Note that these limits are considerably lower than the threshold limit values (TLVs) specified by the American Conference of Governmental Industrial Hygienists [61] for industrial occupational settings, largely because of the high biological activity of the dust and the additive or synergistic reactions of the combined mixture of dust and gases [62] in livestock buildings. Clearly, air quality in livestock confinement facilities should be improved to prevent occupational health problems.

1.3.1 Gaseous contamination

Global population increases, coupled with intensive animal and livestock production practices, have resulted in the generation, accumulation, and disposal of large amounts of wastes around the world. Aerosolization of microbial pathogens, endotoxins, odors and dust particles is an inevitable consequence of the generation and handling of waste material [63]. Bio aerosols can be a source of microbial pathogens, endotoxins and other allergens. Given the close proximity of population centers to concentrated animal-rearing operations and municipal treatment facilities in many parts of the world, there is concern regarding the occupational and public health impacts associated with the exposure to bio aerosols from municipal and animal wastes. Major advances have been made in our understanding of bioaerosol characteristics, in identifying the hazards, and in identifying possible human and animal health links with aerosolized pathogens and allergens [63].

Table 3. Threshold limit values for gaseous (ppm) and particulate contamination (mg/m^3)[1]

Contaminant	TLV-TWA[2]	TLV-STEL[3]	Max-Human[4]
CO_2	5,000	30,000	1,500
NH_3	25	35	7
H_2S	10	15	5
CO	25	-	50
Nuisance/airborne dust	1 0	-	2.4
Respirable dust	-	-	0.23
Endo toxin	-	-	800 IU/ m^3

[1]Source: values in columns 2 and 3 = 1993-1994 Threshold limit values for Chemical substances and Physical Agents and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists, Cincinnati, OH. [2]TLV-TWA-Threshold limit value for time weighted average exposure concentration for a normal 8 to 10 hr workday. [3]TLV-STEL-Short term exposure limit: 15 min time-weighted average exposure limit for any time during a workday even if the 8-hr threshold limit value is the TLV-TWA [4]Recommended maximum levels of human health (winter) [22]

1.3.1.1 Ammonia (NH_3)

Ammonia (NH_3) losses from livestock wastes have been recognized since the early 19th century. Approximately 1900 direct and indirect measurements have proven that storage and handling of livestock wastes and the application of these wastes to land were all associated with NH_3 losses. Ammonia is produced as a by-product of the microbial decomposition of organic nitrogen compounds in manure. Nitrogen occurs as unabsorbed nutrients in animal feces and as urea in urine (mammals) or uric acid (poultry) [64]. Concern about the effects of gaseous ammonia on the growth cycle of broilers has been focused primarily on the concentration of ammonia inside broiler housing units because high ammonia concentrations affect bird performance. In addition to pulmonary disease, exposure to ammonia leads to eye, sinus, and skin irritation. Similar to the effects observed in humans, ammonia causes the following conditions in poultry: reduced body weight at ammonia concentrations of 25ppm, respiratory irritation, predisposition to infectious disease, and cornea/conjunctiva inflammation (keratoconjunctivitis) at ammonia concentrations of 50ppm. On a global scale, animal farming systems emit approximately 20Tg N per year as NH_3 [65] to the atmosphere, which comprises 50% of the total NH_3 emissions from terrestrial systems [66]. In sheep pens, the ammonia level was found to be highly significant ($P<0.01$) and positively correlated with dust, total bacterial count, coliform count and relative humidity, whereas a highly significant ($P<0.01$) negative correlation was observed between NH_3 and air temperature and air velocity [67].

1.3.1.2 Hydrogen sulfide (H_2S)

Hydrogen sulfide is a colorless gas but has a pungent odor characteristic of rotten eggs. It is heavier than air and thus tends to stay near the floor in non-ventilated, quiescent rooms. Hydrogen sulfide is water-soluble, can be produced from the putrefaction of organic wastes, and is a very toxic gas, even at low concentrations. It has caused numerous deaths in humans and livestock when acute levels were generated under cretin conditions [68]. It may also cause adverse health effects (irritation, headache, dizziness) even at concentrations as low as 10ppm [69]. Because of its toxic properties and its significant contribution to odor, emissions of hydrogen sulfide from known sources (i.e., manure pits, storage tanks) are closely monitored to prevent accumulation to fatal levels and to evaluate its impact on the environment.

1.3.1.3 Methane (CH_4)

Methane, a colorless gas, is also produced from the anaerobic decomposition of manure. Methane is a greenhouse gas and it is estimated to contribute approximately 18% to the total global warming potential [70]. In livestock systems, ruminant digestive activity, manure decomposition and silage fermentation are the main sources of methane, accounting for 29% of total annual methane emission in the United States [71]. An inventory of methane production and an accurate assessment of contributions of all sources and sinks is essential to the development and implementation of strategies to reduce methane emissions [70]. In ruminant animals, $CH_4$is generated as a by-product of the microbial breakdown of carbohydrates, principally cellulose, to produce volatile fatty acids that are metabolized. In the animal, 90% of the $CH_4$is generated in the rumen and is released via the mouth and nostrils by eructation, and the remaining 10% is generated in the large intestine. The vast majority of the CH_4 in the large intestine is absorbed into the blood stream and is released via the lungs in the animal's breath [72].

Emissions of CH_4 from the animal are linked to food intake and have been shown to rise sharply immediately after ingestion [73,70]. Penning et al. [74], who studied sheep behavior, found that 72% of sheep grazing occurred in daylight and especially during a 4h period immediately prior to sunset. Judd et al. [75] found that during the daytime a concentrated period of grazing occurred for 3 h after sunrise and 3 h before sunset and that in the middle of the day the sheep were relatively inactive and ruminating. This period corresponded with the highest periods of CH_4 emissions, while at night CH_4 emission rates were reduced with declining grazing activity. On clover swards, a different pattern of emission was seen where approximately 48% of the CH_4 was produced in the period from midnight to noon, whereas the sheep on grass swards produce approximately 41% of the total in the same period. Parsons et al. [76] and Murray et al. [77] found a strong diurnal pattern of preference for clover rather than grass in the mornings. It appears that sward composition can influence the diurnal pattern of CH_4 production.

1.3.1.4 Carbon dioxide (CO_2)

The concentration of carbon dioxide (CO_2) in the Earth's atmosphere is approximately 390 ppm (parts per million) by volume as of 2010 [78]. In animal housing units, additional carbon dioxide is released from the biological decomposition of manure and the respiration of animals. Carbon dioxide constitutes more than 40% of the air bubbles rising from liquid manures stored under slotted floors, in lagoons, or in oxidation ditches. At higher concentrations, CO_2 can asphyxiate humans and animals by reducing the amount of oxygen in the local environment [79]. Carbon dioxide emitted to the atmosphere is the most abundant contributor to global warming, accounting for approximately 60% of the greenhouse effect [70]. Increased concentrations of CO_2 may also come from poor ventilation and improperly vented fuel-burning heaters, which may also give rise to carbon monoxide CO, another potentially hazardous gas [80].

1.3.1.5 Volatile organic compounds and odorous gases

Volatile organic compounds (VOCs) and odorous gases are generated by the biological decomposition of livestock manure. Each of these various compounds, 168 of which were listed by Mackie et al. [81], may occur only in trace amounts and generally are not found at levels considered hazardous to human and animal health. However, their combined effect is responsible for unpleasant odors associated with animal facilities [82]. The emission and transport of these compounds over extended distances during favorable atmospheric conditions have caused serious conflicts between animal farmers and concerned citizens, initiating concerted efforts to quantify and control odors from animal production facilities.

1.3.1.6 Odor emissions

Odor complaints have increased dramatically with the increased number of confined animal feeding operations (CAFO’s). Development of appropriate systems to control the odor emanating from these facilities requires knowledge of the compounds that make up the odor as well as their relative concentrations. Previous studies focused mainly on characterizing the odor coming from the manure as well as the air in and around these facilities [83]. O’Neill and Phillips [81] listed more than 160 compounds associated with the odor in livestock operations. Odorous compounds adsorbed on airborne dust can be transported over long distances where they can be perceived as a nuisance. Thus, there is a need to characterize the odorous compounds adsorbed on the airborne dust.

Most agree on what is the source of odor; however, little agreement or understanding exists as to what constitutes an odor from AFOs. Many point to gaseous emissions as the main source of odor [84,85], but the correlation of odor with VOCs is often weak [86,87]. Others speculate compounds absorbed to particulates are the main cause of odor [88,89]. Yet still others believe there is an additive or synergistic effect between gaseous and PM emissions that is responsible for odor [90-92]. The presence of odors in rural landscapes has been shown to affect the quality of life surrounding these facilities [93, 94]. In fact, Schiffman and Williams [92] have speculated that odors may not only be a nuisance but also have potential environmental and health effects associated with them. Currently, little data exists linking odors in rural landscapes to any type of respiratory impairment [90] and most health-related effects associated with agricultural odors are based on self-reporting of symptoms (i.e., headaches, runny nose, etc.) in both laboratory [92] and rural community surveys [93,94].

1.3.2 Particulate contamination

1.3.2.1 Particulate matter (PM)

Airborne particulates include both solid and liquid particles. Viable particles are living microorganisms or any solid or liquid particles that have microorganisms associated with them [95]. Airborne dust is one of the primary means to spread disease-causing organisms. Reductions in airborne dust levels have been associated with even greater reductions in airborne bacteria [96]. The organic dust in livestock buildings is composed both of non-viable particles, generated by such things as feces, litter, feed, feather formation (which produces a high quantity of allergen dandruff), and of viable particulate matter (also called bio aerosols). Bio aerosols are comprised of airborne bacteria, fungi, viruses and their by-products, endotoxins and mycotoxins [4].

Dust is an environmental stressor and can become extensive in confined animal feeding operations especially during dry environmental conditions. Dust events are very common in agricultural production systems. Dust characteristics (concentration, number and mass) inside livestock housing vary based on the type of animal, building and environmental conditions [97,3]. Suspended PM is considered to be a major factor that contributes to the degradation of air quality in livestock buildings. Sources of primary particles are feed, bedding material, the animals themselves and their feces [98]. Moreover, particles that have settled on the floor can be re-suspended because of animal activity; Table 4 shows the potential of some factors that influence particulate concentrations in animal housing. Furthermore, PM concentrations are significantly affected by housing type, animal species, animal characteristics (i.e., age, weight, population), the building's ventilation rate, season, and sampling period within a day [98,99]. Particulates are generated from many types of sources, including animal activities, agricultural operations and through the interaction with gases to produce fine particles. It is important to know the characteristics of these emissions to analyze the impact of agricultural operations on the environment and on human health and quality of life. Essential characteristics include the rate of emission, the emission constituents, and the spatial distribution of the emissions. Stocking density, airspace, group size, feeding system, and litter management also play a role in modifying the amount of particulates suspended in the air. All these factors were kept similar in all the experimental rooms. PM is considered to be an important health hazard for animals and workers in livestock operations, either itself or the condensed and nucleated toxic compounds [100,101]. The size of the particles and their surface area determine the potential to elicit inflammatory injury, oxidative damage, and other biological effects. These effects are stronger for fine and ultra-fine particles because they can penetrate deeper into the airways of the respiratory tract and can reach the alveoli where 50% are deposited. Lung airways and alveoli retain mostly $PM_{2.5}$rather than PM_{10} [102]. In his study, Schimmert et al. [103] found that people living within a radius of 2 km from a goat farm (>400 goats) had clinical signs and a significantly higher risk of infection (31× higher) than people living in a radius of 5 to 10 km of the farm. Almuhanna et al. [97] carried out an experiment under controlled laboratory conditions and concluded that spraying with charged water improves the efficiency of removing PM. They also found that the removal efficiency is significantly greater during longer charged water spray durations (4 and 6 min) than during shorter duration (2 min), while the spraying method and the charge polarity did not significantly influence particle removal efficiency.

Donham [104] stated that dust is a hazard in four basic ways in livestock buildings: (1 worker health, (2 animal health, (3 deterioration of equipment and facilities, and (4 neighbor health).

Table 4. Potential of some factors to influence particulate concentrations in animal housing

Factors (if present or increased)	Particulate concentration*
Feeding-dry	+
Feeding-liquid	-
Activity of animals	+
Bedding	+
Stocking density	+
Air temperature	+
Relative humidity	-
Ventilation rate	-
Airspace per animal	-

** + increased - decreased [59]*

1.3.2.2 Bioaerosols

Bioaerosolare defined as a collection of aerosolized biological particles [105]. Bioaerosols vary greatly in size, ranging from 0.02 to 100 m in diameter [106]. The composition, size, and concentration of the microbial populations comprising the bioaerosol vary with the source, dispersal mechanisms in the air, and, more importantly, the environmental conditions prevailing at a particular site [107]. Bioaerosols are comprised of airborne bacteria, fungi, viruses and their by-products, endotoxins and mycotoxins [4]. Major advances have been made in our understanding of bioaerosol characteristics, in identifying the hazards, and in identifying possible human and animal health links with aerosolized pathogens and allergens [107]. The microorganisms present in the air of animal houses originate mainly from the bedding and the animals themselves, with their concentration depending on various factors such as temperature, humidity, ventilation, and the volume and surface area allotted to each animal [108]. There are allergic agents, infectious microorganisms, enzymes, and toxic gases, and, for most of these compounds, it is not clear what are their impacts; combined effects of several compounds are usually suggested as likely problems [108]. Major advances have been made in our understanding of bioaerosol characteristics, in identifying the hazards, and in identifying possible human and animal health links with aerosolized pathogens and allergens [63].

1.3.3 Microbial contamination

The concentration of microorganisms in the air was markedly lower in sheep houses compared with the values previously reported for cattle, pig or poultry [59], possibly because of differences between species [60]. Dairy goats were indicated as the primary source of a zoonosis, caused by *Coxiellaburnetii*, and exposure to humans appeared to be facilitated by the recent developments in dairy goat production with an increasing number of farms with open naturally ventilated buildings. The small distance between farms with aborting dairy goats and dairy sheep and a large number of people living in the vicinity, appeared to have been the main causes of the large Q-fever outbreak in the Netherlands [109]. Schimmert et al. [103] found that people living within a radius of 2 km from a goat farm (>400 goats) had clinical signs and a significantly higher risk of infection (31x higher) than people living in a radius of 5 to 10km from the farm.

1.4 Factors Affecting air Contamination in Sheep Houses

Airborne gaseous and particulate pollutants from livestock, feed and manure influence air quality in and around livestock buildings. Air quality inside the building affects human and animal health and welfare, while emissions from the buildings can led to local, meso-scale and even global environmental pollution [16]. Most recent studies have investigated the effects of several parameters, such as sampling sites, time of day, season, ambient air temperature, building ventilation rate, flooring systems, and pen hygiene, on the odor and gas concentrations and emissions (OGCERs) for various animal facilities [110-116]. However, few have explored how animal management practices (e.g., the thermal insulation characteristic of an animal building, barn set point temperature scheme, and animal production schedule) and geographic factors impact long-term source air quality. It is reasonable to hypothesize that enforcing different animal management policies may be a simple, inexpensive, and effective abatement strategy to reduce airborne pollution, although no evidence to support or refute this hypothesis was found in the literature [117].

1.4.1 Facility design

Building design often has an effect on animal health and performance. Ventilation, animal isolation, ease of cleaning, access to feed and water, and susceptibility to injury are some areas that are impacted by design. Ability to move animals easily is another. Once construction is completed, changes are either expensive or impossible to make; therefore, it is important for the original design to be correct. Animal production of any type introduces manure into the environment. High animal concentrations produce large volumes of manure. Ventilation plays a major role in sustaining the welfare and performance of farmed livestock by affecting thermal exchanges between the animal's body surface and the environment and by removing aerial pollutants, which originate from animals and their excreta [59]. Poor ventilation can lead to increased airborne particulate and gaseous pollutant concentrations, which can present a significant burden to the respiratory tracts of humans and livestock.

1.4.2 Manure handling and storage

Animal production of any type introduces manure into the environment. High animal concentrations produce large volumes of manure. Animals and/or their wastes in livestock buildings generate different forms of air pollution, including ammonia, carbon dioxide, methane and nitrous oxide gases as well as dust and microorganisms (Phillips et al. [22]). Primary particulates are produced during production cycles, in addition to changes in the weather. The AFOs industry has also long suspected that air pollutants from production facilities can impair health and performance.

1.4.3 Ventilation

The gradual increase in intensive housing for sheep, as a consequence of the increased size of specialized dairy flocks, and the fact that this species is mainly raised in warm climates, requires more specifications for ventilation rates and regimens in sheep houses [29]. Aerial concentrations of dust and microorganisms were not significantly affected by ventilation regimen. This is not surprising, because aerial dust, which is also the main carrier of microorganisms, has a very complex behavior [118]. Indeed, small particles may remain in the air for a long time, with elimination only achieved by sedimentation, and then return to the air relatively quickly by dispersion [58]. Additionally, evidence suggests that ventilation systems are more significant, but not the only factor that influences the concentration of airborne particulates in animal houses. Stocking density, airspace, group size, feeding system, and litter management also play a role in modifying the amount of particulates suspended in the air [107].

1.4.4 Animal activity

Reduction in active behaviors may help animals to reduce their heat production under high air temperatures. Indeed, decreased levels of activity have been found to have a definite thermoregulatory purpose in sheep [29]. Animals in a building affect the airflow around them, and airflow and animal activity are both important factors influencing the spatial and temporal variations in dust concentration.

1.4.5 Type of floor

Yasotha et al. [119] found that sheep reared on salted floors had significantly ($P<0.01$) higher body weight and gain when compared with sheep reared on a mud floor. This study also showed that type of floor plays a major role in air pollution levels in sheep pens. They determined the mean levels of air pollution and climatic variables in sheep pens with different flooring patterns. Total dust concentration, ammonia level, total bacterial count and mold count were significantly ($P<0.01$) higher in mud floors than in slatted floors, whereas the type of floor had no effect on coliform count or climatic variables. Sheep prefer to lie down on straw compared with wooden slats. However, sheep will also lie down on wooden slats. Misselbrook et al. [54] measured the emissions from outdoor concrete yards used by sheep (Table 5).

Table 5. Mean emission rates for outdoor concrete yards used by sheep [54]

Gaseous pollutant	Concentration	Measured units
Ammonia NH_3	440	mg NH_3-$Nm^{-2}h^{-1}$
N_2O	17.17	µg N_2O-$Nm^{-2}h^{-1}$
Methane CH_4	0.12	mg CH_4 $m^{-2}h^{-1}$

1.4.7 Stocking density

Stocking density, airspace, group size, feeding system, and litter management also play a role in modifying the amount of particulates suspended in the air. All these factors were kept similar in all the experimental rooms. Reduction in active behaviors may help animals to reduce their heat production under high air temperatures. Indeed, decreased levels of activity have been found to have a definite thermoregulatory purpose in sheep [29]. Space allocation is also known to affect both the performance and welfare of livestock. Additionally, stocking density has been shown to directly affect the levels of gaseous pollutants and airborne particles in animal houses (Curtis, 1983). Pollutants can be injurious to the health of both livestock and stockmen and women (Owen, 1994) and affect the general performance of animals [120]. Gas to particle conversion can be accomplished by condensation, which adds mass onto pre-existing aerosols, or by direct nucleation from gaseous precursors forming an aerosol. This process strongly depends on the concentration of precursor gases, such as ammonia, and water vapor in the atmosphere [14]. Ambient temperature and relative humidity were unaffected by the stocking density of the ewes. Stocking density is a critical factor when housing lactating ewes and a space allocation of <2 m^2 per animal may have an adverse effect on their health and performance. Hence, if lactating ewes cannot be allocated adequate room, it will be necessary to control the other factors that influence ambient levels of microorganisms. The greatest benefits may be obtained by adjusting their microenvironment, especially the ventilation rate and the thermal and hygrometric conditions, by improving the hygiene of the bedding and by using products that reduce enzyme and microbial activity [33].

2. CONCLUSIONS

Information about air pollutants from and within sheep feeding operations (SFOs) is quite limited. A literature review covering information about the air pollutants at sheep and goat housing facilities is presented in this review. This survey covers: 1) the effects of environmental parameters on sheep, including ambient air temperature and relative humidity; 2) air pollutants in sheep buildings and their effects on sheep health, including gaseous contaminants such as ammonia, hydrogen sulfide, methane, carbon dioxide, volatile organic compounds and odorous gases, and particulate contaminants, including dust and bio aerosols. Furthermore, factors affecting air contaminants in sheep houses need to be identified, including facility design, manure handling and storage, ventilation, animal activity, type of floor, and stocking density. This review found that floor bedding, feces, feed and outdoor dust are the main sources of particulate and gaseous contaminants in sheep houses. The majority of the secondary pollutants could be related to an increase in air temperature, which caused dryness of the bedding soil and helped to aerosolize the dust. Shielding the wind source side of the building could help in controlling indoor dust concentration. PM concentration exhibited three peaks during the day that coincided with milking, feeding, and cleaning hours. The ranges of literature values for TSP, PM_{10} and $PM_{2.5}$ concentrations were 0.75 - 3.6, 0.03 - 2.0 and 0.04 - 0.05 mg/m^3, respectively.

ACKNOWLEDGMENT

Author would like to thank either publishers, owners and authors of the articles used in this review, without their efforts this review cannot be done.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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