Monitoring Particulate Matter Levels and Climate Conditions in a Sheep Yard at the Local Environment of Saudi Arabia

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Abstract: In this study, the concentration, and size distribution of airborne particles in addition to the variation of two climatic parameters (air temperature and relative humidity) were measured and analyzed in a sheep barn in Al-Ahsa of Saudi Arabia. Results shows that the variation of outdoor climatic conditions affects the indoor environment parameters such as temperature and relative humidity and the concentration of the airborne particles. Studying the correlations between air temperature and concentration of particles shows that the production of the majority of particles could be attributed to an increase in air temperature which caused the dryness of the bedding soil helping the aerosolaization of dust. In summer the average TSP, and PM$_{10}$ inside the sheep barn had a significantly greater mean value (2715.1, and 1462.6 µg/m$^3$) than the outside ambient air (1573.4, 1235.7µg/m$^3$) during the experimental period, respectively. While the average PM$_{2.5}$ concentration inside the sheep barn did not significantly differ (138.5 µg/m$^3$) from the outside ambient air (114.2 µg/m$^3$) during the experimental period. In winter the average TSP, and PM$_{10}$ inside the sheep barn had a significantly lower mean value (232.2, and 108.5 µg/m$^3$) than the outside ambient air (371.6 , and 255.1 µg/m$^3$) during the experimental period, respectively. The average PM$_{2.5}$ concentration inside the sheep barn did not significantly differ (15.3 µg/m$^3$) from the outside ambient air (22.1 µg/m$^3$) during the experimental period. In both seasons, the average concentration of TSP, PM$_{10}$ and PM$_{2.5}$ did not exceed the acceptable range of the threshold for indoor air contaminants in livestock barns.

Keywords: Sheep Temperature, Relative humidity, Air quality, Dust, TSP, PM$_{10}$, PM$_{2.5}$
1. Introduction

Animal industry continues to expand rapidly in Saudi Arabia. The industry, however, faces major air quality and environmental challenges. This caused public concern over the welfare of animals used for agricultural production has grown over the past years. Although sheep is considered as a major source of meat in Saudi Arabia, studies focused on sheep and their interactions with environment can be rarely found in literature. Field measurements are limited; there is a need for more complete characterization and accurate quantification of gaseous and PM emissions from different types of animal feed operations (AFOs) such as poultry industry cattle, sheep and camels feedlot.

Atmospheric climatic conditions and pollutants from livestock 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 building contribute to environmental pollution. The developments of intensive system of sheep husbandry inflect considerable stress to sheep by increasing air pollution and unless appropriate remedial practices are adopted, the production may be severely affected (Papanastasiou et al. 2011).

Sheep are known as one of the most heat-resistant species among farmed animals. An inadequate thermal environment induces adverse health effects to animals. It is related to discomfort conditions, affects the animal’s fattening rate and the milk yield and influences the concentrations of air pollutants and particulate matter PM (Seinfeld and Pandis 1998; Seedorf et al. 1998; Teye et al. 2008). Sevi et al. (2001) found that prolonged exposure to maximum air temperatures over 30ºC and to thermal heat index (THI) values over 80 prevent lactating ewes from maintaining their thermal balance. He also found that ventilation plays a main 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. Simonson et al (2002) stated that indoor relative humidity (RH) can 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 in order to describe indoor climate conditions (Papanastasiou et al. 2011).

Air quality relating to livestock buildings has been a major concern for years, particularly with regard to poultry and animal health. Bioaerosols are comprised of airborne bacteria, fungi, viruses and their by-products, endotoxin and mycotoxin (Oppliger et al., 2008).

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 (Phillips et al., 1998). Primary particulates are produced during production cycles in addition to changing in weather. The AFOs industry has also long suspected that air pollutants from
production facilities can impair health and performance. As more stringent air quality standards are developed, there is a critical and urgent need to characterize and control air pollutant emissions. Limited research has characterized air pollutant emissions from production facilities in Saudi Arabia. Data on size distribution of PM emitted are quite limited. Knowing this information and understanding dust effects will lead to obtain the best methods for dust control (Almuhanna et al., 2009).

Airborne dust is one of the primary means by which disease causing organisms are spread. Reductions in airborne dust levels have been associated with even greater reductions in airborne bacteria (Mitchell et al, 2004). This organic dust in livestock buildings is composed both of non-viable particles, generated by such things as faeces, litter, feed, feather formation (which produces a high quantity of allergen dandruff) and of viable particulate matter (also called bioaerosols). Bioaerosols are comprised of airborne bacteria, fungi, viruses and their by-products, endotoxin and mycotoxin (Oppliger et al., 2008).

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, charge) inside livestock buildings vary based on the type of animal, the building, and environmental conditions (Almuhanna, 2007).

Livestock buildings are regarded as a major source of air pollutants (Erisman et al. 2008; Goetz et al. 2008; Lammel et al. 2004; Seedorf 2004; Sidiropoulos and Tsilingiridis 2009). Considerable quantities of particulate matter (PM), ammonia, odors and other toxic substances are released during the farming activities that take place indoors, affecting animal and human health and welfare. Additionally, small amounts of PM could be transported into the building via its ventilation (Papanastasiou et al. 2011).

Suspended PM is considered as 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 (Cambra-López et al. 2010). Moreover, particles that are settled on the floor could be resuspended due to the animal activity. Furthermore, PM concentrations are significantly affected by housing type, animal species, animal characteristics (i.e., age, weight, population), building’s ventilation rate, season and sampling period within a day (Cambra-López et al. 2010; Takai et al. 1998). Particulates are generated by many types of sources, including animal activities, agricultural operations, and by the interaction of gases to produce fine particles. It is important to know the characteristics of these emissions in order 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 strictly 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 (Sevi et al., 2001). Space allocation is known to affect both the performance and welfare of livestock. In addition, stocking density has been shown to affect directly the levels of gaseous pollutants and airborne particles in animal houses. Pollutants can be injurious to the health of both livestock and stockmen and women and affect the general performance of animals (Verstegen et al. 1994). 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, like ammonia, and water vapor in the atmosphere (Papanastasiou et al. 2011).

PM is considered as an important health hazard for animals and workers in livestock operations, either itself or the condensed and nucleated toxic compounds (Bakutis et al. 2004; Razote et al. 2004). 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 of which 50% are being deposited. Lung airways and alveoli retain mostly PM$_{2.5}$ rather than PM$_{10}$ (Valavanidis et al. 2008). In a study, Schimmert et al. (2010) shows that people living within a radius of 2 km from a goat farm (> 400 goats) demonstrate a clinical signs had a significantly higher infection risk (31× higher) than people living in a radius of 5 to 10 km of the farm. Almuhanna et al. (2008) carried out an experiment under controlled laboratory conditions and concluded that spraying with charged water improves the efficiency to remove 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.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Humans</th>
<th>Animals</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhalable (total) dust</td>
<td>2.40$^{[a]}$</td>
<td>3.70</td>
<td>Donham and Cumro (1999a)</td>
</tr>
<tr>
<td>(mg/m$^3$)</td>
<td></td>
<td></td>
<td>Wathes (1994)</td>
</tr>
<tr>
<td>Respirable dust</td>
<td>0.16$^{[a]}$</td>
<td>--</td>
<td>Donham et al. (2002)</td>
</tr>
<tr>
<td>(mg/m$^3$)</td>
<td>0.23</td>
<td>0.23</td>
<td>Donham and Cumro (1999)</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>1.70</td>
<td>Wathes (1994)</td>
</tr>
</tbody>
</table>

$^{[a]}$ Specific threshold concentrations are defined as mixed exposures between NH$_3$ and PM in poultry CAFOs (Donham et al., 2000).
The main goal of this paper is to (a) characterize air contaminants (mainly particulate) in sheep housing, (b) establish the effects of meteorological conditions (i.e., temperature and relative humidity on the characteristics of PM levels as well as to examine the relationships between them.

2. Materials and Methods

Measurements were done for a period of four weeks during month of Jun, 2012 representing summer season and repeated at month of December, 2012 representing winter season. Discrete measurements (three replicates or more) and 24 hour continuous (one minute sampling rate with one hour averaging rate). The measurements were conducted in the sheep unit at the experimental and training station of King Faisal University, Al-Ahsa, Saudi Arabia.

2.1. Sheep Housing Facilities

The sheep barn has an overall width, and length, of 55 m, and 30 m, respectively, and the total surface area of the floor of the barn was 1595 m$^2$, the height of ceiling (37 % of the barn area) was 5 m as shown in figure 1. The naturally ventilated sheep barn was oriented in an east-west axis facing south direction. The side walls were made steel net, and the partial ceiling was made of galvanized sheet metal. The sheep barn were divided to 5 sections (30×11 m) arranged on the east –west axis. Each pen contained one feeder and one drinker and occupied by a total of 25 animals. Sand was used as the bedding material, which was replaced every 6 months.

![Figure 1. Schematic depiction of the sheep barn (plan view, not to scale)](image)

2.2. Measurement of Environmental Parameters

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Meteorological data, including the solar radiation flux incident on a horizontal surface, the air temperature, wind speed and direction, and the relative humidity of the air, were measured by a meteorological station (HOBO U30-NRC Weather Station, Onset Computer, USA). The air temperatures and relative humidity at various locations in the sheep building were measured using a HOBO® U12 Logger with accuracy of ±0.35°C; ambient temperature and relative humidity were recorded for the length of study with time interval for data recording equal to 60 minutes with data acquisition every one minute for integrated measurements.

2.3. Measurement of Airborne Dust Concentration

The following parameters inside and outside the sheep barn were recorded: (1) mass and number concentration of airborne particles, (2) size distribution of airborne particles and (3) concentrations of toxic gases.

A fixed station (Topas, Turnkey Optical Particle Analysis System) monitor designed to continuously record environmental TSP, PM$_{10}$, PM$_{2.5}$ and PM$_{1}$ particles was used to monitor PM concentrations outside the sheep barn. It uses the principle of light scattering of the single particle. The sample air is heated to avoid the relative humidity and can record concentrations up to 6500 μg/m$^3$, with a ±0.1μg/m$^3$ measuring accuracy with a sampling resolution of 1 min, these samples are considered for background concentrations measurements. Samples were collected with an average of one hour readings and sampling height was approximately 2 m above the ground.

Concentrations of TSP, PM$_{10}$, and PM$_{2.5}$ within the sheep barn were recorded every 1 min. Samplers and/or measurement devices were located at or near the center of the building to obtain a representative measurement of the entire house and to avoid overestimating or underestimating the data. An EPAM-5000 real-time sampler (Environmental Devices Corp.) was used for real-time measurement of mass concentration of TSP. The TSP mass concentration was also measured with a gravitational filter sampler (37 mm diameter filter Type AE inside a filter cassette, SKC, Inc.). The PM$_{10}$ and PM$_{2.5}$ mass concentration were measured with an SKC personal environmental monitor (PEM-PM$_{10}$ - PEM-PM$_{2.5}$: SKC, Inc.) at 2 L/min. Filters were conditioned before and after sampling. Furthermore, field blanks for PM were also collected and used to correct the concentrations.

The size distribution and number concentration of airborne particles were monitored using a particle counter (GW3016A, GrayWolf Sensing Solutions). This instrument uses a laser-diode light source and collection optics (particles scatter light from the laser diode) to measure particles with aerodynamic diameters ranging from 0.3 to 10 μm at an air sampling rate of 2.83 L/min (0.1 cfm). Moreover, six channels were used, and a counting efficiency of 100% was employed for particles with diameters >0.45 μm, respectively. The particle counter displayed the particle count and mass
concentration readings in $\mu g/m^3$, and these readings were used for real-time measurements of number and mass concentration of PM$_{10}$ and PM$_{2.5}$.

**Table 2. Variables, instruments used, and manufacturers**

<table>
<thead>
<tr>
<th>Measured Variable</th>
<th>Instrument Used</th>
<th>Detecting Mechanism</th>
<th>Accuracy</th>
<th>Manufacturer</th>
<th>Type of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP, PM$<em>{10}$, and PM$</em>{2.5}$</td>
<td>Topas</td>
<td>Light scattering</td>
<td>$\pm 0.1 \mu g/m^3$</td>
<td>Turnkey Optical Particle Analysis System</td>
<td>Continuous (24 h real-time sampling)</td>
</tr>
<tr>
<td></td>
<td>EPAM-5000</td>
<td>Light scattering photometer (nephelometer)</td>
<td>$\pm 3 \mu g/m^3$</td>
<td>Environmental Devices Corp.</td>
<td>Continuous (24 h real-time sampling)</td>
</tr>
<tr>
<td></td>
<td>Total sampler</td>
<td>37 mm PTFE filter</td>
<td>N/A</td>
<td>SKC, Inc.</td>
<td>Discrete (60 min sampling time)</td>
</tr>
<tr>
<td></td>
<td>Personal environmental monitor for PM$<em>{10}$ and PM$</em>{2.5}$</td>
<td>Single-stage impactor and after-filter</td>
<td>N/A</td>
<td>SKC, Inc.</td>
<td></td>
</tr>
<tr>
<td>Particulate size distribution</td>
<td>GH-3016 particle counter</td>
<td>Light scattering</td>
<td>Efficiency: 50% at 0.3 $\mu$m; 100% for particles &gt;0.45 $\mu$m</td>
<td>GrayWolf Sensing Solutions</td>
<td>Continuous (24 h real-time sampling)</td>
</tr>
<tr>
<td>Meteorological data</td>
<td>HOBO U30-NRC Weather Station</td>
<td>-</td>
<td>-</td>
<td>Onset Computer</td>
<td>Continuous (24 h real-time)</td>
</tr>
<tr>
<td>Temperature ($^\circ C$)</td>
<td>HOBO® U12 Logger</td>
<td>TC type K</td>
<td>$\pm 0.3^\circ C$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH (%)</td>
<td></td>
<td>Capacitive</td>
<td>$\pm 2%$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4. Data Analysis

Particulate mass concentration was also determined by gravimetric method using the following equation:

$$Conc. = \frac{W_f - W_i}{Q*t}$$

where

$Conc.$ = concentration ($\mu g/m^3$)  
$W_i$ = filter initial weight ($\mu g$)  
$W_f$ = filter final weight ($\mu g$)  
$Q$ = sampling system air flow rate ($m^3/min$)  
$t$ = sampling time (min)

Data values were analyzed statistically using PROC GLM in SAS (version 9.1, SAS Institute, Inc., Cary, N.C.). Particulate and gaseous concentration mean comparisons between the two houses were made using Duncan's multiple range test at a significance level of 5%.

3. Results and Discussion

3.1. Climate Conditions of the Sheep Barn
Environmental conditions inside and outside the sheep barn were monitored during the month of June and December, 2012. During summer air temperature inside the sheep house varied between 24.6°C and 45.7°C with an average of 33.1°C (SD = 7.9°C) while the relative humidity ranged from 11.2% to 53.1% with an average of 32.2% (SD = 8.1%).

While during winter air temperature inside the sheep house varied between 8.9°C and 32.1°C with an average of 20.5°C (SD = 6.4°C) while the relative humidity ranged from 29.3% to 95.1% with an average of 62.2% (SD = 16.7%). Fluctuations in the air temperature surrounding animals plays an important role in their growth rate, development, and productivity whereas, RH, are considered as an important factor that affects PM generation (CIGR, 1994).

On the other hand, during summer the outdoor air temperature ranged from 50.2°C to 23.9°C, and the average temperature was 36.7°C (SD = 6.9°C) and the relative humidity of the outdoor air ranged from 46.4% to 4.8%, and the average humidity was 17.9% (SD = 9.5%). While during winter air temperature inside the sheep house varied between 31.8°C and 5.3°C with an average of 18.1°C (SD =5.2°C) while the relative humidity ranged from 22.7% to 98.2% with an average of 64.9% (SD = 20.4%). It is clear that relative humidity levels during winter were higher than summer. In contrast, air temperature were higher levels in summer than winter as shown in Figure 2.

Temperature and relative humidity levels outside (Fig. 3) and inside the sheep building are presented in, while statistics are given in tables 3. The means of outside air temperature and relative humidity did not significantly differ (p > 0.05). During experimental period the indoor and outdoor temperatures were very similar, their difference being ranged between 2.4 °C and 3.6% for winter and summer respectively. No significant differences (P<0.05) were detected between indoor and outdoor relative humidity levels.

Table 3. Means and standard deviations of indoor and outdoor air temperature and relative humidity during the experimental period

<table>
<thead>
<tr>
<th>Season</th>
<th>location</th>
<th>Temp (°C)</th>
<th>RH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean[1]</td>
<td>SD</td>
</tr>
<tr>
<td>Summer</td>
<td>Indoor</td>
<td>33.1a</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>Outdoor</td>
<td>36.7a</td>
<td>6.9</td>
</tr>
<tr>
<td>Winter</td>
<td>Indoor</td>
<td>20.5b</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>Outdoor</td>
<td>18.1b</td>
<td>5.2</td>
</tr>
</tbody>
</table>

[1] Column means followed by the same letter are not significantly different at a 5% level of significance
3.2. Particle Mass Concentration

PM concentration was monitored continuously during the experimental period. The average concentration of TSP inside the sheep barn is summarized in Table 4.

In summer the average TSP inside the sheep barn had a significantly (P<0.05) greater mean value (2715.1 µg/m³) than the outside ambient air (1573.4 µg/m³) during the experimental period. However, the average concentration of TSP did not exceed the acceptable range of the threshold for indoor air contaminants in livestock barns (3400 - 3700 µg/m³) proposed by Wathes et al. (1994) and Donham and Cumro (1999). Furthermore, the average PM₁₀ concentration inside the sheep barn had a significantly (P<0.05) greater mean value (1462.6 µg/m³) than the outside ambient air (1235.7 µg/m³) during the experimental period. In addition to that, the average PM₂.₅ concentration inside the sheep barn did not significantly differ (P<0.05) value (138.5 µg/m³) from the outside ambient air (114.2 µg/m³) during the experimental period. Both PM₁₀ and PM₂.₅ values did not exceed the threshold for indoor air contaminants in livestock barns (230 µg/m³) proposed by Donham and Cumro (1999).
In winter the average TSP inside the sheep barn had a significantly (P<0.05) lower mean value (232.2 µg/m³) than the outside ambient air (371.6 µg/m³) during the experimental period. However, the average concentration of TSP did not exceed the acceptable range of the threshold for indoor air contaminants in livestock barns (3400 - 3700 µg/m³) proposed by Wathes et al. (1994) and Donham and Cumro (1999). Furthermore, the average PM₁₀ concentration inside the sheep barn had a significantly (P<0.05) lower mean value (108.5 µg/m³) than the outside ambient air (255.1 µg/m³) during the experimental period. In addition to that, the average PM₂.₅ concentration inside the sheep barn did not significantly differ (P<0.05) value (15.3 µg/m³) from the outside ambient air (22.1 µg/m³) during the experimental period. Both PM₁₀ and PM₂.₅ values did not exceed the threshold for indoor air contaminants in livestock barns (230 µg/m³) proposed by Donham and Cumro (1999).

Table 4. Mean, standard deviation and range of values (µg/m³) for TSP, PM₁₀, and PM₂.₅ during the experimental period

<table>
<thead>
<tr>
<th>Season</th>
<th>location</th>
<th>TSP</th>
<th>PM₁₀</th>
<th>PM₂.₅</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean[**]</td>
<td>SD</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>Summer</td>
<td>Indoor</td>
<td>2715.1</td>
<td>1370.5</td>
<td>3308.3</td>
</tr>
<tr>
<td></td>
<td>Outdoor</td>
<td>1573.4</td>
<td>1988.1</td>
<td>6527.9*</td>
</tr>
<tr>
<td>Winter</td>
<td>Indoor</td>
<td>232.2</td>
<td>350.8</td>
<td>1959.4</td>
</tr>
<tr>
<td></td>
<td>Outdoor</td>
<td>371.6</td>
<td>911.4</td>
<td>6527.9</td>
</tr>
</tbody>
</table>

[*] Maximum concentrations were observed during incidents of dust storms
[**] Column means followed by the same letter are not significantly different at a 5% level of significance

Figure 4 shows the variation of the daily average value of PM concentration during the monitoring period.
In another experimental study, Papanastasiou et al. (2011) carried out continuous measurements of PM10 concentration at different sheep facilities in Greek using similar instruments as in this study (scatter light photometers). They reported generally higher average TSP, PM$_{10}$, and PM$_{2.5}$ concentrations 110, 777 and 400 μg/m$^3$ respectively. The differences between the mentioned concentrations and the measured concentration may due to the differences in locations and environment putting in mind that Al-Ahsa, Saudi Arabia is surrounded by three deserts with an arid climate conditions.

The difference between PM$_{10}$ and PM$_{2.5}$ includes the coarse fraction of PM$_{10}$, representing the concentration of the coarse particles, while PM$_{2.5}$ and PM$_{1}$ represent the concentration of the fine particles (Papanastasiou et al., 2011).

In order to investigate the impact of the indoor climate conditions on PM levels, the concentrations of the three types of particles were correlated to temperature and relative humidity values observed indoors. The analysis revealed an adequate positive correlation between PM concentration and temperature (Table 5), indicating that the PM concentration increased when the temperature increased this could be resulted by the fact that the production of the secondary fine particles could be attributed to an increase in air temperature which caused the dryness of the bedding soil helping the aerosolaization of dust.

| Table 5. Correlation coefficients between PM concentration and climatic variables observed indoors |
|---------------------------|---------------------------|---------------------------|
|                          | TSP  | PM$_{10}$ | PM$_{2.5}$ |
| Temperature              | 0.471| 0.468     | 0.416      |
| Relative humidity        | -0.493| -0.473    | -0.395     |

Additionally, Table 5 shows that an increase in relative humidity was followed by decrease in the concentration of the particles. These results are similar to what mentioned by Papanastasiou et al. (2011) that the high concentration of coarse particles could be associated to dust re-suspension, which was enhanced by the dry conditions that prevailed in the atmosphere when the levels of relative humidity became low. Furthermore, when the floor is not wet, dust cannot be retained by it and may become airborne due to animal activity. The sand and manure on the floor, also used for bedding, could be considered as a significant factor that determined PM levels, as animal’s movements caused dust re-suspension, contributing to the increase of PM concentration.

Figure 5 reveals that the peak in PM concentrations (specifically in summer) was observed at noon. This increase in PM levels could be attributed to the increase in air temperature + low levels of relative humidity. Furthermore, this phenomenon is not observed in winter due to the same reason (low
temperature + high levels of relative humidity). Another reason for low values of PM concentration during the night time is due to the fact that animals were not active and farming activities were stopped. Therefore, it is important to monitor PM concentration on a 24-h basis in order to identify its daily levels and to take measures at the proper time so as to mitigate the health effects that could be induced to farmers and animals by the increased PM levels (Papanastasiou et al., 2011).

![Figure 5. Average diurnal variation of TSP, PM\textsubscript{10} and PM\textsubscript{2.5} inside the sheep building](image)

### 4. Conclusions

The variation of two climatic parameters (air temperature and relative humidity) and the levels of particulate matter (TSP, PM\textsubscript{10}, and PM\textsubscript{2.5}) were measured and analyzed in a sheep building in Al-Ahsa, Saudi Arabia. From the results of the present study, the following conclusions could be drawn:

- Results show that the variation of outdoor climatic conditions affects the indoor environment 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 to the outdoor climate conditions, as the building was naturally ventilated and uninsulated.
- Studying the correlations between air temperature and concentration of particles, mainly PM\textsubscript{10}, PM\textsubscript{2.5} shows that the production of the majority of the secondary fine particles could be attributed to an increase in air temperature which caused the dryness of the bedding soil helping the aerosolization of dust.
- In summer the average TSP inside the sheep barn had a significantly (P<0.05) greater mean value (2715.1 µg/m\textsuperscript{3}) than the outside ambient air (1573.4 µg/m\textsuperscript{3}) during the experimental period. The average PM\textsubscript{10} concentration inside the sheep barn had a significantly (P<0.05) greater mean value
(1462.6 µg/m³) than the outside ambient air (1235.7 µg/m³) during the experimental period. While the average PM_{2.5} concentration inside the sheep barn did not significantly differ (P<0.05) value (138.5 µg/m³) from the outside ambient air (114.2 µg/m³) during the experimental period.

- In winter the average TSP inside the sheep barn had a significantly (P<0.05) lower mean value (232.2 µg/m³) than the outside ambient air (371.6 µg/m³) during the experimental period. The average PM_{10} concentration inside the sheep barn had a significantly (P<0.05) lower mean value (108.5 µg/m³) than the outside ambient air (255.1 µg/m³) during the experimental period. The average PM_{2.5} concentration inside the sheep barn did not significantly differ (P<0.05) value (15.3 µg/m³) from the outside ambient air (22.1 µg/m³) during the experimental period.

- In both seasons, the average concentration of TSP, PM_{10} and PM_{2.5} did not exceed the acceptable range of the threshold for indoor air contaminants in livestock barns proposed by Wathes et al. (1994) and Donham and Cumro (1999).

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References


