Environmental conditions, potential heat-stress state and their relations in a sheep barn under hot climate

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Abstract: The aim of this study was to examine climate conditions, air quality, potential heat stress and their relations in a sheep barn under Greek hot weather conditions. Hourly averaged values of temperature, relative humidity, wind speed, and coarse and fine airborne Particulate Matter (PM) concentration recorded inside and outside a naturally ventilated sheep barn during July, August and September of 2015 were used. Indoors potential heat-stress levels were assessed by means of the Temperature Humidity Index (THI). Descriptive statistics were presented and relations between the environmental parameters and the THI values were investigated. The results showed that inside the sheep barn, THI was positively correlated ($p < 0.0001$) with wind speed and negatively correlated with relative humidity. Additionally, inside the sheep barn, the concentration of coarse PM was positively and negatively correlated ($p < 0.0001$) with temperature and relative humidity, respectively, whereas the opposite was observed for the concentration of fine PM. Measures that could be applied to alleviate animals' heat-stress were proposed.

Keywords: hot climate; air quality; particulate matter; heat-stress; Temperature Humidity Index; sheep

1. Introduction

The environmental conditions that prevail inside a livestock building induce various physiological and behavioral effects upon animals. Air quality and climate conditions are considered as major factors affecting them. Poor indoor air quality and climate conditions trigger adverse effects to animals related to their welfare, health, growth and production. Thwaites (1985) documented that a combination of high ambient temperature and high relative humidity is detrimental for sheep as it imposes heat-stress. Silanikove (2000) stated that growth, milk production and reproduction of ruminants are impaired by long-term exposure to heat-stress resulting from changes in biological functions. Sevi et al. (2001, 2002) concluded that high temperatures induce adverse effects on the thermal and energy balance, the mineral metabolism, the immune function, the udder health, the milk production and the nutritional properties associated with the fatty acid profile of lactating ewes during summer under the Mediterranean climate. In addition, Finocchiaro et al. (2005) found that milk production yields of Mediterranean dairy sheep are affected by heat-stress conditions, whereas Sevi and Caropresе (2012) clearly demonstrated that exposure of sheep to high ambient temperatures has a detrimental impact on their production performance, including nutritional and technological properties of milk. Aggarwal and Upadhyay (2013) discussed in detail the effects of heat-stress on animal (including sheep) productivity, immunity, and hormonal levels, underlying that under heat-stress, a number of physiological and behavioral responses vary in intensity and duration in relation to the animal genetic make-up and environmental factors. Sitzia et al. (2015) stated that for a continuous (i.e. including summer) milking period in the Mediterranean environment the animal heat-stress risk is maximized and concluded that confined systems may face negative effects due to heat-stress, whereas Todaro et al. (2015) concluded, among others, that although sheep are considered to be among the most heat tolerant species, exposure to high ambient temperatures has a detrimental impact on their production performance, immune function and udder health. Marino et al. (2016) describing the relationships between small ruminant farming and climate change, pointed out that a temperature raise increases the negative effect risks on animal health and Sejian et al. (2017) discussed the impacts of climate change on sheep production, reproduction, immune response, diseases, etc, emphasizing on issues related to heat-stress. Finally, Al-Dawood (2017) presented an in-depth review of issues related to heat stress management of small ruminants.

Poor air quality is a major concern in livestock buildings as it can negatively affect animals' health and welfare. Particulate matter is considered as a major factor that contributes to the degradation of air quality in livestock buildings. An overview of the major problems associated with PM in livestock production systems is provided by Cambra-López et al. (2010), however to our knowledge very limited work has been done on this issue with regards, to sheep production.

Received date: 2018-01-08 **Accepted date:** 2018-03-15
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Papanastasiou et al. (2011) analyzed the size fractionated PM levels and the climate conditions in a sheep and goat building in Greece and examined the relations between them.

The aim of this study was to examine climate conditions, air quality, potential heat stress and their relations in a sheep barn under Greek hot weather conditions. For this purpose, temperature, relative humidity and wind speed values, as well as concentration of coarse and fine PM, recorded indoors and outdoors a naturally ventilated sheep barn were used.

2. Materials and Methods

Information about the livestock building

This study was based on measurements recorded inside and outside a commercial sheep barn located at Almiros area at the east coast of central Greece (39.157 N, 22.765 E) (Figure 1). The length and width of the building were 60 m and 30 m, respectively, while its height at the edges and at the center was 4.4 m and 7.2 m, respectively. The barn had solid floor (rammed soil with straw as bedding material), was not insulated and was naturally ventilated (no ridge opening).

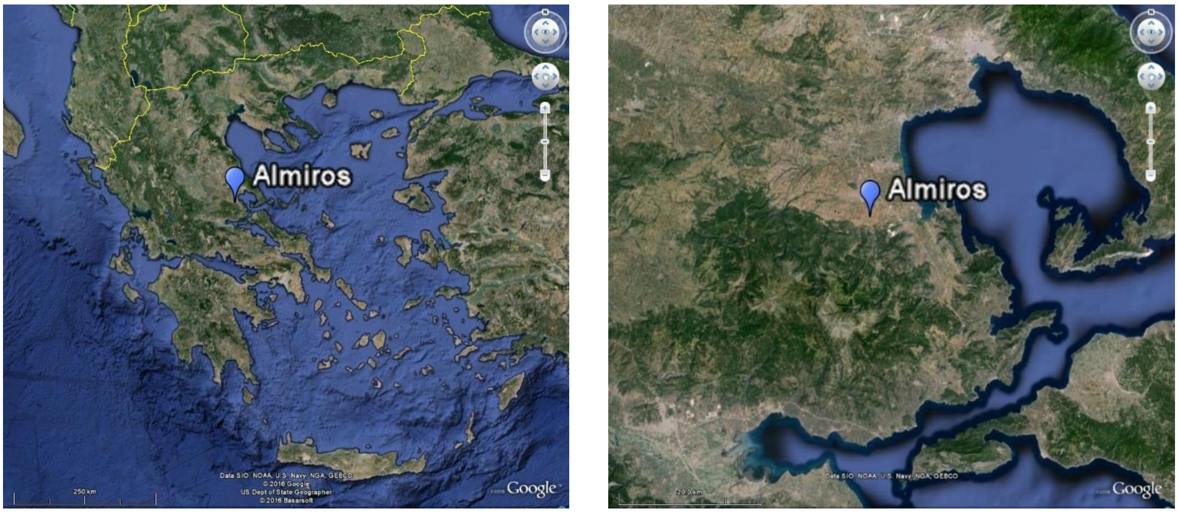

Figure 1: Left: Map of Greece showing the location of the sheep barn; Right: Enlargement of the area where the barn is located

Data used

A miniature device (Hobo Pro v2, Onset, USA) was used to monitor temperature (Tin) and relative humidity (RHin) inside the sheep barn. The device was placed in a white plastic shield for protection and was installed 2 m above the floor so as to be out of animal reach. A 3D anemometer (Gill, UK) was used to monitor wind speed (WSin) components inside the barn. The anemometer was also installed also 2 m above the floor. A portable PM analyzer (Grimm, model 107, Germany) was used to monitor PM concentrations inside the barn. It was placed in a metallic housing (Grimm, model 165, Germany) to be protected against harsh conditions. The analyzer was measuring continuously and simultaneously the concentrations of PM10, PM2.5 and PM1. The sampling height was 3 m above the floor. All the instruments used inside the sheep barn were installed very close to each-other (approximately at the centre). An automated meteorological station (imetos, Pessl, Austria) was used to record temperature (Tout) and relative humidity (RHout) outside the barn. It was installed 2 m above the top of the building. No missing values were detected for the variables monitored inside and outside the sheep barn, while PM missing values were negligible. Data was recorded during the period 23/07/2015 – 05/09/2015 and hourly averaged data were analyzed in this study.

Estimation of sheep's heat-stress

The Temperature Humidity Index (THI) is a very popular heat-stress index. Finocchiaro et al. (2005), Leibovich et al. (2011), Sevi et al. (2001, 2002) and Sevi and Caroprese (2012) used a formula developed by Kelly and Bond (1971) for cattle. In this study the specific definition of THI for sheep (Marai et al., 2007) was applied, as proposed in many heat-stress assessment studies (Panagakis and Chronopoulou, 2010; Papanastasiou et al., 2014; 2015, McManus et al., 2015; Panagakis, 2016; López Armengol et al., 2017). Marai et al. (2007) also defined four heat-stress categories which are presented in Table 1.

$$\mathrm{THI} = \mathrm{Tin} - (0.31 - 0.0031 \cdot \mathrm{RHin}) \cdot (\mathrm{Tin} - 14.4) \qquad (1)$$

Table 1: Definition of heat-stress categories according to THI values

THI class	Heat-stress category
THI < 22.2	absence of heat-stress
22.2 ≤ THI < 23.3	moderate heat-stress
23.3 ≤ THI < 25.6	severe heat-stress
THI ≥ 25.6	extreme severe heat-stress

3. Results and Discussion

Climate conditions indoors and outdoors the sheep barn

Descriptive statistics for Tin, RHin, WSin, Tout and RHout values are presented in Table 2.

Table 2: Descriptive statistics for the meteorological variables observed indoors and outdoors

Value	THI	Tin (°C)	RHin (%)	WSin (m/s)	Tout (°C)	RHout (%)
Maximum	32.3	37.3	86	2.2	37.6	100
90° percentile	29.9	33.4	67	1.0	32.9	68
Average	26.3	28.5	53	0.7	27.1	49

10º percentile	22.7	23.9	38	0.4	21.5	30
Minimum	19.8	20.8	27	0.2	18.4	19

Figure 2 presents the daily maximum, average and minimum Tout values during the study period. The daily maximum hourly Tout value was higher than 30º C and 34º C in 82% and 24% of the days. This fact supports the statement of hot weather. Figure 3 presents the corresponding values of RHout.

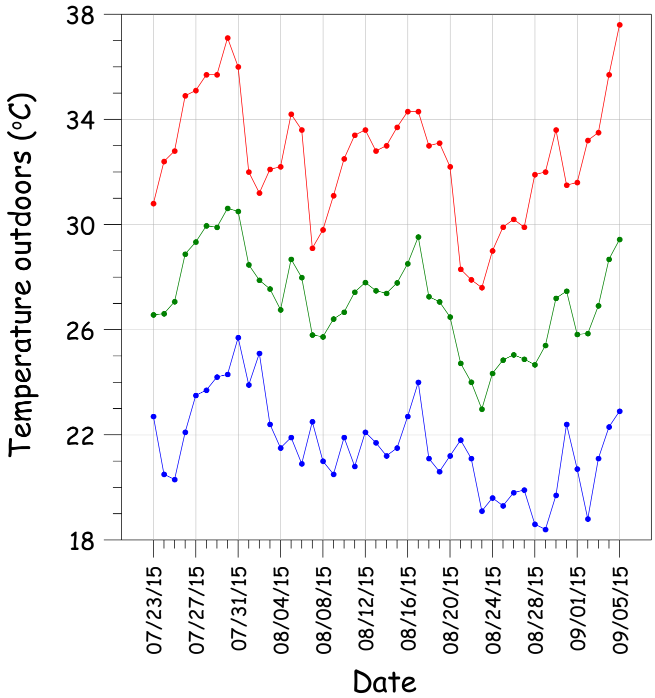

Figure 2: Maximum (red line), average (green line) and minimum (blue line) daily Tout values during the monitoring period

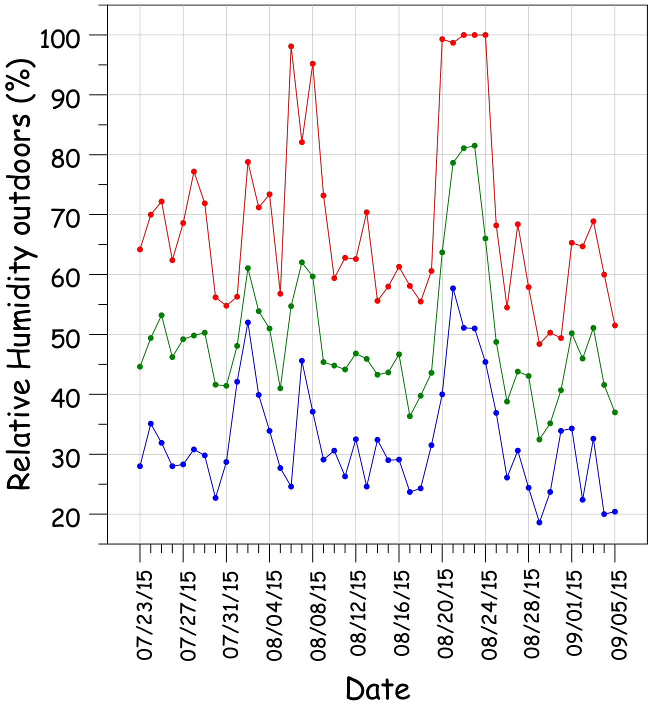

Figure 3: Maximum (red line), average (green line) and minimum (blue line) daily RHout values during the monitoring period

Figure 4 shows the distribution of Tout and Tin values revealing that indoors temperatures were shifted to higher classes. This fact shows that under hot weather conditions natural ventilation alone was not an efficient method to reduce the temperature conditions inside the sheep barn. Outdoors hot air moved indoors by ventilation, thus preventing cooling inside the barn. Therefore, additional protective measures are recommended. Papanastasiou et al. (2014) have proposed active and passive protective measures that could be applied in a sheep barn in order to improve the indoors climate and consequently to improve animals' thermal comfort. Active measures include evaporative cooling using fans and fog, while passive measures include insulating the roof, painting of roof with white reflective paint to reduce the absorption of solar radiation and opening a ridge to enhance natural ventilation due to thermal buoyancy. Additionally, Todaro et al. (2015) proposed that the use of effective nutritional strategies, the provision of shaded areas and adequate housing density could then reduce the heat-stress.

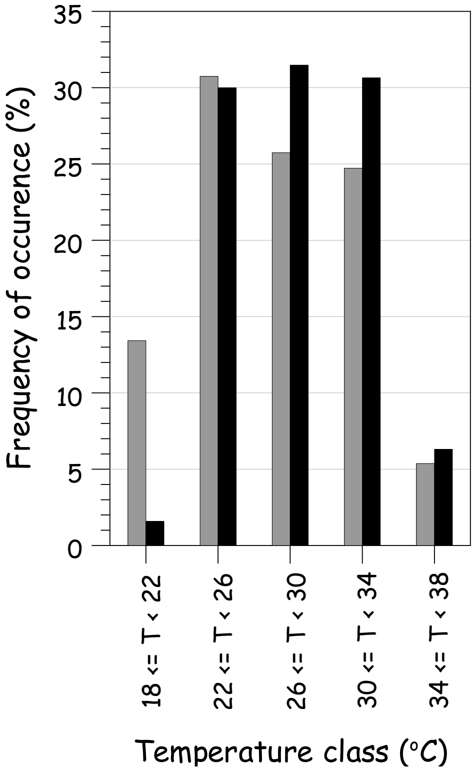

Figure 4: Frequency of occurrence of Tout (gray bars) and Tin (black bars) classes

<u>PM levels inside the sheep barn</u>

Descriptive statistics for the concentration of coarse and fine PM recorded indoors during the studied period are presented in Table 3. Particles with aerodynamic diameters between 2.5 and 10 μm were considered as coarse, while particles with aerodynamic diameters less than 1 μm were considered as fine.

Table 3: Descriptive statistics for the concentration of coarse and fine PM observed inside the sheep barn

Value	Coarse PM ($\mu g/m^3$)	Fine PM ($\mu g/m^3$)
Maximum	2325	40
90° percentile	432	15
Average	207	10
10° percentile	16	6
Minimum	2	2

Figure 5 shows the average diurnal variation of the concentration of the coarse and fine PM inside the sheep barn during the studied period. The concentration peaks were observed around the hours when milking and feeding were starting. Milking was starting at 06:30 and 18:30, while feeding at 07:30 and 19:30 every day. Observed peaks could therefore be attributed to dust re-suspension due to animals' movement and emissions of particles due to feed supplying. As these peaks could be attributed to farming activities that were daily taking place inside the barn, the hours to which they corresponded should be excluded from the analysis studying the relation between THI and PM levels. Consequently, hours 06:00 –

08:00 and 18:00 – 20:00 were excluded from the relation analysis presented later in this paper.

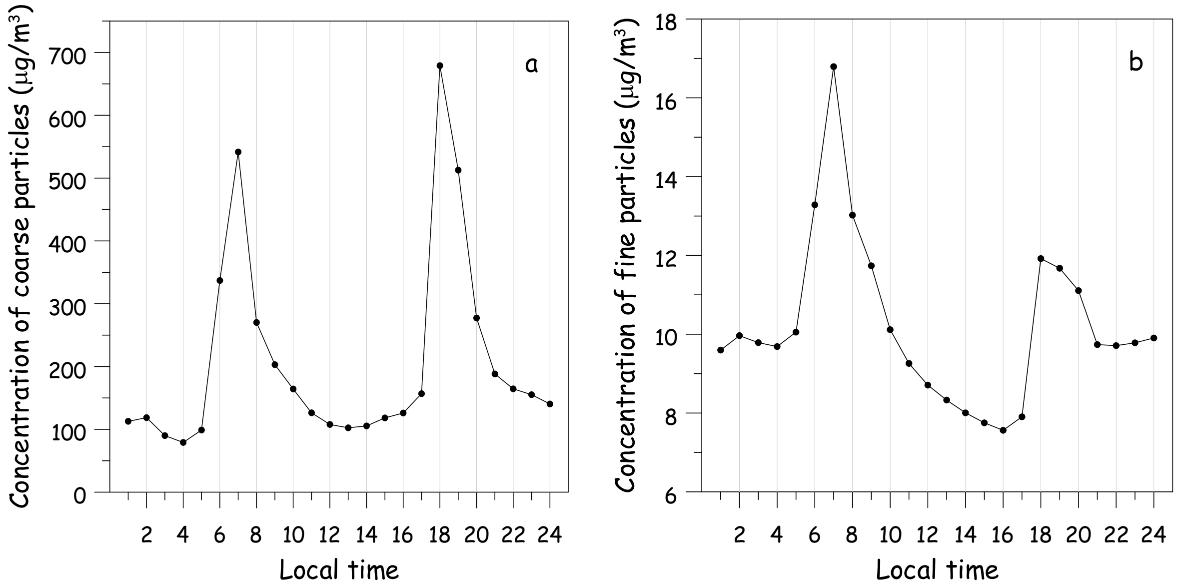

Figure 5: Average diurnal variation of the concentration of coarse (a) and fine (b) PM inside the sheep barn during the studied period

<u>THI levels inside the sheep barn</u>

Figure 6 presents the frequency of occurrence of each heat-stress category according to THI values observed inside the sheep barn. Heat-stress conditions were established in 94% of the days. The maximum, average and minimum THI values were 32.3, 26.3 and 19.8, respectively, while the values that corresponded to 90º and 10º percentiles of THI's distribution were 29.9 and 22.7, respectively.

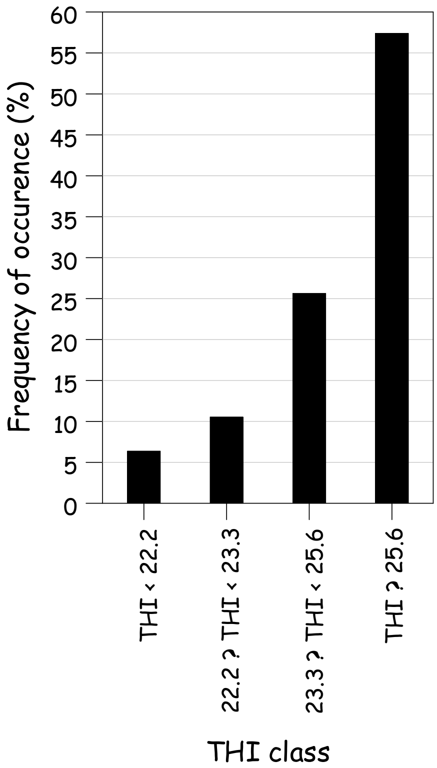

Figure 6: Frequency of occurrence of THI classes (heat stress categories)

The averaged diurnal variation of maximum, average and minimum THI values inside the sheep barn during the studied period is presented in Figure 7. The averaged diurnal variation of maximum THI values shows that THI exceeded the extreme severe heat-stress threshold (THI ≥ 25.6) every day. Based on the averaged diurnal variation of minimum THI values it is concluded that every day sheep were exposed to heat-stress conditions between 09:00 and 24:00 hours, and to extreme severe heat-stress conditions between 12:00 and 18:00 hours. Panagakis and Chronopoulou (2010) reached at the same findings with regards to the part of the day sheep were exposed to heat-stress, namely between 09:00 and 24:00 hours. However, as their study was conducted at the sheep unit of the Agricultural University of Athens (37.58 N, 23.32 E), which is 160 km southern of Almiros, the extreme severe heat-stress conditions lasted more (i.e. between 10:30 and 21:00 hours). It is worth mentioning that afternoon feeding at Almiros sheep barn was provided within the severe heat-stress period (i.e. at 19:30 hours), potentially resulting in lower feed consumption. A constructive management measure could be nocturnal feeding so as to avoid harsh day conditions (Naqvi et al., 2013).

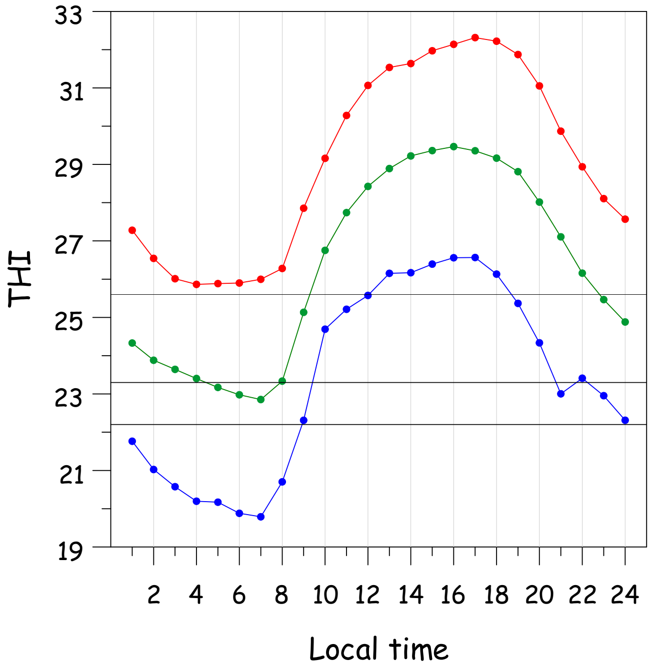

Figure 7: Averaged diurnal variation of maximum (red line), average (green line) and minimum (blue line) THI values inside the sheep barn during the studied period. The horizontal black lines correspond to THI thresholds (i.e. 22.2, 23.3, and 25.6)

Relation of THI with meteorological parameters

Table 4 presents the correlation coefficients between indoors THI and meteorological parameters. Relations of THI with Tin and RHin are obvious because they are included into the equation. It is worth noticing that relative humidity was negatively correlated to THI, a fact that could be mainly attributed to the relation between temperature and humidity. When temperature increases the water vapor capacity of air also increases consequently the relative humidity decreases. This process is assured when moisture content is kept constant. However, further research is needed on the relation between THI and humidity in the sheep barn, as the moisture content doesn't remain constant in the barn, depending on several factors including feeding diet, feed intake, digestibility, ruminal pH, water intake, fecal and urinary characteristics, bedding material and floor type (Panagakis et al. 2004; Ghasemi et al. 2017). WSin was positively correlated to THI, a fact that further supports the negative impact of natural ventilation on indoors temperature levels previously mentioned.

Table 4: Correlation coefficients (R; $p < 0.0001$) between THI and meteorological parameters

RHin	WSin	Tout	RHout
-0.63	0.45	0.95	-0.60

Relation of THI and meteorological parameters observed indoors with PM

The correlation coefficients between THI, Tin, RHin and WSin, and concentration of indoors coarse and fine PM observed during 09:00 to 17:00 and 21:00 to 05:00 are presented in Table 5. The concentration of coarse PM was positively and negatively correlated with Tin and RHin, respectively. When moisture is reduced, air becomes drier, and dust re-suspension is favored. Consequently, the variation of the concentration of the coarse PM could also be attributed to dust re-suspension caused by sheep's activity and by farming activities that were taking place inside the barn. The concentration of fine PM was positively correlated with RHin. For this purpose, the variation of the concentration of the fine PM could be attributed to the production of secondary particles. This process is enhanced when humidity increases.

Table 5: Correlation coefficients (R; $p < 0.0001$) between THI and meteorological parameters, and indoors coarse and fine PM

Parameter	Coarse PM	Fine PM
THI	0.07	-0.06
Tin	0.10	-0.09
RHin	-0.31	0.17
WSin	-0.05	-0.17

The relation of the concentration of coarse and fine PM observed indoors during 09:00 to 17:00 and 21:00 to 05:00 with Tin and RHin was further investigated. Days were divided in two groups, the criterion being the median (i.e. 50^{o} percentile) of the distribution of the daily maximum hourly Tin value. Days when the daily maximum hourly Tin value was lower than the 50^{o} percentile were defined as colder, whereas days when the daily maximum hourly Tin value was higher than the 50^{o} percentile were defined as warmer. The analysis showed that the impact of Tin and RHin on the concentration of coarse PM was more pronounced during the colder days and the impact of Tin and RHin on the concentration of fine PM was more pronounced during the warmer days. During the colder days, the relation of the concentration of coarse PM with Tin and RHin was improved ($p < 0.0001$), becoming 0.14 and -0.39, respectively. During the warmer days, the relation of the concentration of fine PM with Tin and RHin improved ($p < 0.0001$), becoming -0.18 and 0.37, respectively. Finally, the correlation coefficients between RHin and the PM concentration revealed that up to 15% of the variation of the particles could be attributed to changes in relative humidity.

Conclusions

This study examined, in a naturally ventilated sheep barn located at the east coast of central Greece and under hot weather conditions, the levels and relations of climate conditions (temperature, relative humidity and wind speed), air quality (concentration of coarse and fine PM) and potential heat-stress of animals (using THI). Sheep farming is a popular livestock sector in Greece, with great importance for the national economy.

The analysis showed that heat-stress conditions were established in 94% of the days during the monitoring period (23/07/2015 – 05/09/2015). Sheep were daily exposed to heat-stress conditions between 09:00 and 24:00 hours. As afternoon feeding time (i.e. 19:30 hours) coincided with the extreme severe heat-stress period or the severe heat-stress period, feed consumption was potentially lower than required.

Indoor temperature levels were higher than those prevailed outdoors, a fact that shows that under hot weather conditions natural ventilation alone was not an efficient method to reduce the temperature inside the sheep barn. Therefore, additional protective measures, supplementary to natural ventilation, have to be applied in the sheep barn (e.g. integration with a misting system so as not to wet the solid floor) in order to improve the indoors climate and consequently to improve animals' thermal comfort.

The maximum values of the concentration of the coarse and fine PM inside the sheep barn were observed around the hours when milking and feeding were starting. This fact reveals that the observed peaks could be attributed to dust re-suspension due to animals' movement and emissions of particles due to feed supplying. Up to 15% of the variation of the particles could be attributed to changes in relative humidity.

The correlations between indoors temperature, relative humidity and concentration of coarse and fine PM revealed that the variation of the concentration of the coarse and fine PM could be attributed to dust re-suspension and the production of secondary particles, respectively. The impact of indoor temperature and relative humidity on the concentration of coarse and fine PM was more pronounced during the colder and the warmer days, respectively.

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