International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July

Ref: C0628

Relation between potential sheep heat-stress and meteorological conditions

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Abstract

It is well known that heat-stress affects the body growth, the biological functions and the productive and reproductive characteristics of sheep. Heat-stress levels are significantly determined by the prevailing meteorological conditions. The aim of this paper is to investigate qualitatively and quantitatively the impact of some meteorological parameters (i.e. incoming solar radiation, wind speed, wind direction, rainfall) on sheep's thermal comfort conditions during summer. Data recorded during the summers of the period 2007 – 2012 by an automated meteorological station that operates in a rural area near the east coast of central Greece is analyzed. Potential sheep's heat-stress is assessed using the Temperature Humidity Index (THI). Daytime (08:00 – 20:00 local time) and night time (21:00 – 07:00 local time) hours were examined separately. During daytime sheep were exposed to potential heat-stress (THI ≥ 22.2) in 84% of the hours. In more than half of the hours (53%), THI exceeded the extreme severe heat-stress threshold (i.e. 25.6). During night time sheep were exposed to potential heat-stress in 32% of the hours. The hourly mean of THI values remained higher than the extreme severe heat-stress threshold approximately during the hours 11:00 – 20:00 (local time). As expected, solar radiation is related to adverse heat-stress conditions. Even low irradiance values were associated with high hourly THI values. 80% of the hourly THI values exceeded the severe heat-stress threshold (i.e. 23.3) when the irradiance was over 421 $W \cdot m^{-2}$, while when irradiance was over 841 $W \cdot m^{-2}$ the corresponding value was 94%. Wind speed was related to unfavorable thermal comfort conditions both during daytime and night time hours. This fact could be mainly attributed to mesoscale circulations that develop in the greater area. Additionally, THI levels were much lower during rainy days than during non rainy days both during daytime and night time hours.

Keywords: sheep, heat-stress, temperature humidity index, meteorological conditions

1 Introduction

One of the major factors that affect animal health and welfare is climate conditions, as unfavourable conditions can trigger heat-stress to ruminants. Heat-stress affects crucially the body growth, the biological functions and the productive and reproductive characteristics of sheep, therefore, it is considered as a serious threat to their short- or long-term thermal welfare. Silanikove (2000) stated that in the long-term growth, milk production and reproduction of ruminants are impaired under heat-stress due to changes in biological functions. Sevi et al., 2001) stated that high temperatures induce adverse effects on the thermal and energy balance, the mineral metabolism, the immune function, the udder health, and the milk production of lactating ewes during summer under the Mediterranean climate. Also, Sevi et al. (2002) reported that high temperatures may induce a worsening of nutritional properties associated with the fatty acid profile of ewe milk. Finocchiaro et al. (2005) found that milk production yields of Mediterranean dairy sheep are affected by heat- stress. Panagakis and Chronopoulou (2010) found that under abnormally hot summer conditions, dairy ewes had respiration rates above normal altering their shade seeking behavior. Sevi and Caroprese (2012) stated that a reduction of thermal stress in dairy sheep results in cumulative beneficial effects such as lengthening of lactation, maintenance of good processing features of milk and a reduction in veterinary costs.

The influence of meteorological factors on animals' heat-stress has been studied by many authors. A widely accepted method to study animals' heat stress is the application of the THI, which is estimated by exploiting temperature and relative humidity values (Marai et al., 2007). It is well documented that a combination of high ambient temperatures and high relative humidity is unsuitable for sheep (Thwaites, 1985). A poor thermal environment can affect the incidence and severity of certain endemic diseases, as well as the animals' thermal comfort, growth rate and milk yield (Papanastasiou et al., 2013; Seedorf et al., 1998). Some authors have also incorporated measurements of solar radiation and wind speed to assess heat-stress conditions (Eigenberg et al., 2005; Mader et al., 2006).

The economic importance of the sheep sector must be pointed out (Theocharopoulos et al., 2007). Sheep farming is the largest livestock sector in Greece, accounting for 30% of the total value of livestock output. Sheep milk and meat are among the major agricultural commodities with a share of ~9% of the total value of agricultural production. Greece is among the main producers of sheep milk and meat in EU as 670 Ktonnes of sheep milk and 80 Ktonnes of sheep meat are produced annually, accounting for the 10% of total EU production.

The aim of this study is to assess sheep's thermal comfort conditions during summer and to investigate qualitatively and quantitatively the impact of some meteorological parameters (i.e. incoming solar radiation, wind speed, wind direction, rainfall) on them.

2 Materials and methods

2.1 Data

Hourly averaged values of temperature, relative humidity, incoming solar radiation, wind speed, wind direction and rainfall observed during the summers of the period 2007 – 2012 were exploited in this study. Data was recorded by an automated meteorological station that operates in Velestino, a rural area near the east coast of central Greece (figure 1), by the Laboratory of Agricultural Engineering and Environment, Institute for Research and Technology of Thessaly, Centre for Research and Technology Hellas.

2.2 Estimation of sheep's potential heat-stress

Marai et al. (2007) suggested that an appropriate climatic index to estimate the severity of sheep heat-stress is the THI given in equation 1, where T is the dry-bulb temperature (°C) and RH is the relative humidity (%). The same authors defined four heat-stress categories which are presented in Table 1. The hourly averaged values of temperature and relative humidity were exploited to calculate the hourly values of THI that were analyzed in this study.

$$THI = T - (0.31 - 0.0031 \cdot RH) \cdot (T - 14.4) \quad (1)$$

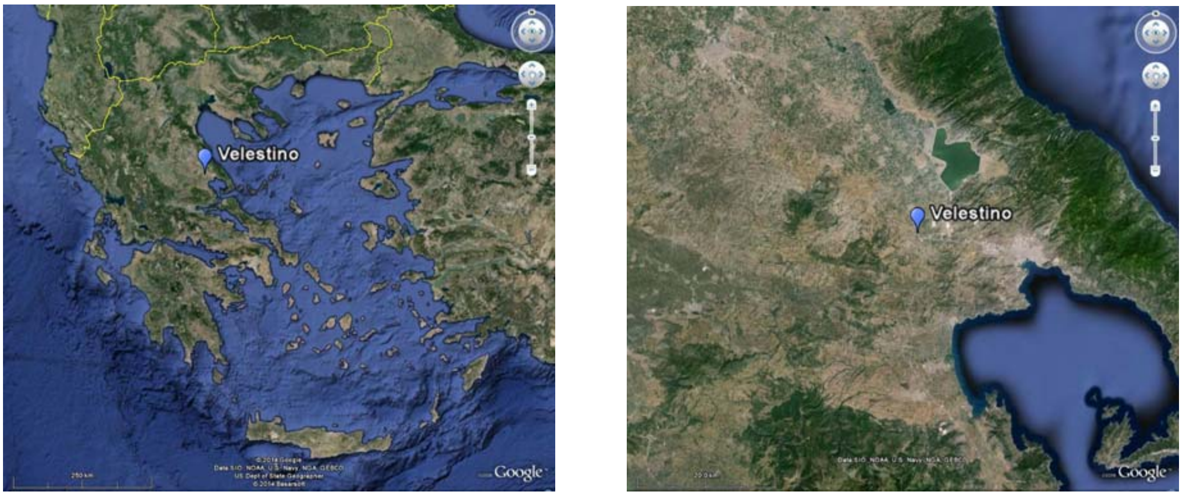


Figure 1: Location, where measurements were recorded (Velestino, 22º 45´ E, 39º 24´ N). Left map: map of Greece; right map: focused on the greater Velestino area.

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

Daytime (08:00 – 20:00 local time) and night time (21:00 – 07:00 local time) hours were examined separately in this study.

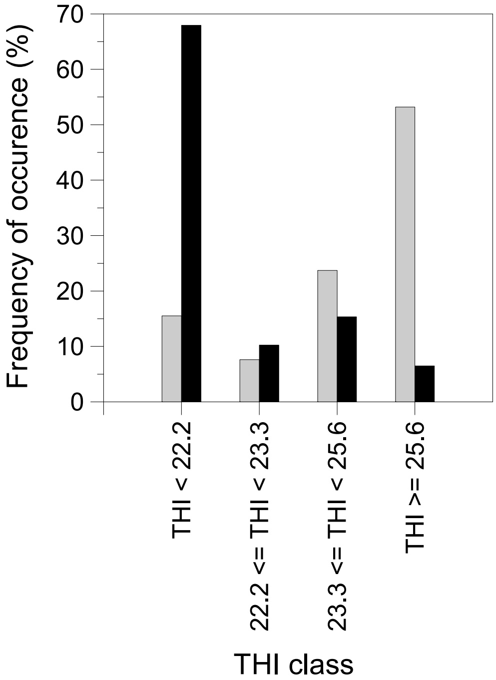


Figure 2: Frequency of occurrence (%) of THI classes during daytime (gray bars) and night time (black bars).

The distribution of the hourly THI values during daytime and night time is presented in figure 2. Figure 2 shows that during daytime sheep were exposed to potential heat-stress

(THI ≥ 22.2) in 84% of the hours. In more than half of the hours (53%), THI exceeded the extreme severe heat-stress threshold (i.e. 25.6). During night time sheep were exposed to potential heat-stress in 32% of the hours. Figure 3 shows that sheep were exposed to potential extreme severe heat-stress approximately during the hours 11:00 – 20:00 (local time). On the contrary, the hourly average of THI values remained lower than the heat-stress threshold (i.e. 22.2) approximately during the hours 23:00 – 09:00. This fact shows that the nocturnal exceddances of the heat-stress threshold identified in figure 2 were spread all night long, being not often observed during specific hours.

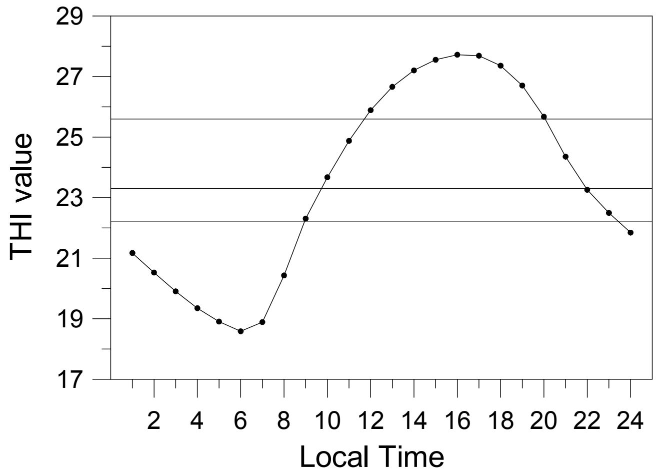


Figure 3: Average diurnal variation of THI values. The horizontal lines correspond to THI thresholds (i.e. 22.2, 23.3 and 25.6)

Table 2: Frequency of occurrence (%) of THI classes per solar radiation classes

THI class	Incoming solar radiation class (W·m^{-2})				
	0 - 210	211 - 420	421 - 630	631 - 840	841 - 1050
THI < 22.2	40	24	11	4	1
22.2 <= THI < 23.3	8	12	9	5	5
23.3 <= THI < 25.6	21	24	31	22	21
THI >= 25.6	31	40	49	69	73

Table 2 verifies that sheep's heat-stress levels were strongly determined by the incoming solar radiation. Even when irradiance was extremely low (i.e. 0 – 210 W·m^{-2}), 60% and 31% of the hourly THI values were higher than the heat-stress threshold and the extreme severe heat-stress threshold, respectively. These percentage increased as irradiance increased, reaching 99% and 73%, respectively, when irradiance was very high (i.e. 841 – 1050 W·m^{-2}).

Figure 4 shows the distribution of the hourly THI values during daytime and night time in relation to the prevailing wind speed. This figure shows that all wind speed classes could be associated with unfavourable THI classes both during daytime and night time hours. However, this relation was more pronounced during daytime. This fact shows that wind speed was not a factor that strongly affected heat-stress levels. However, this conclusion should be treated with caution and should be examined jointly with the variation of the wind direction. Figure 5 shows the prevailing wind directions per wind speed class during daytime. Figure 5a shows that when wind speed was very low (i.e. 0 – 2.1 m·s^{-1}) the wind blew from north directions. When wind speed increased (figures 5b and 5c), the wind also blew from southeast directions (i.e. 2.1 – 6.3 m·s^{-1}) and from west directions (i.e. 4.2 – 6.3 m·s^{-1}), while when speed was very high (i.e. 6.3 – 8.3 m·s^{-1}) (figure 5d) wind blew mainly from west directions. Taking into account the topography of the greater area (figure 1, right map), the following conclusions could be drawn:

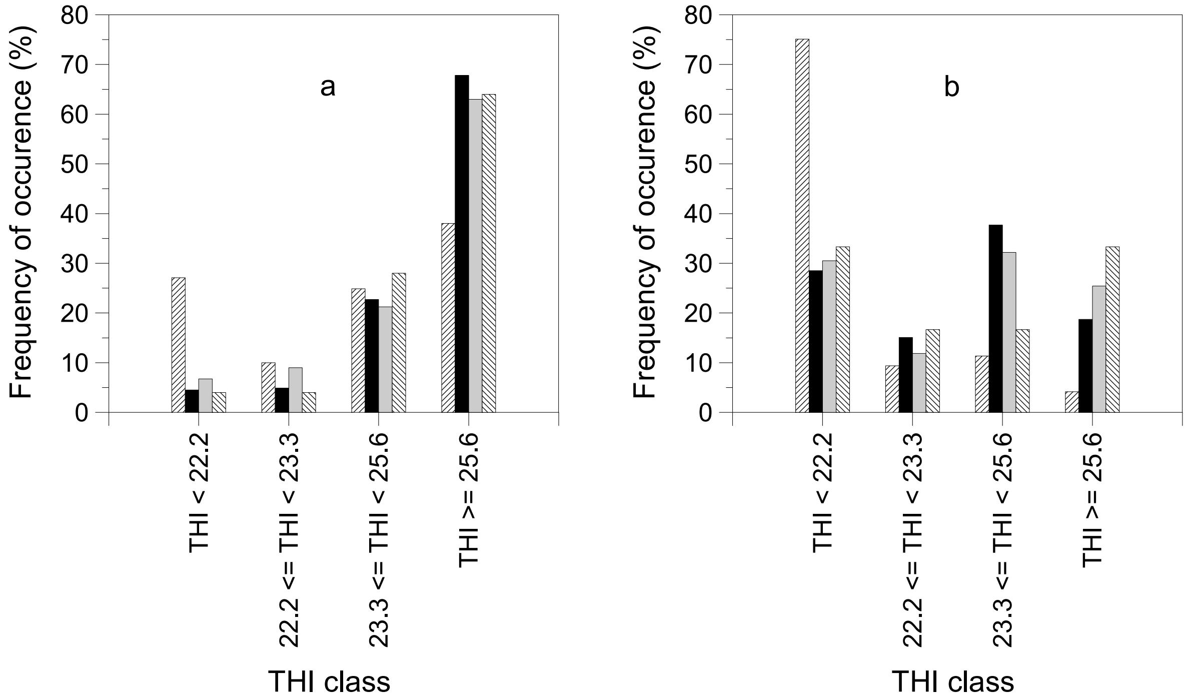
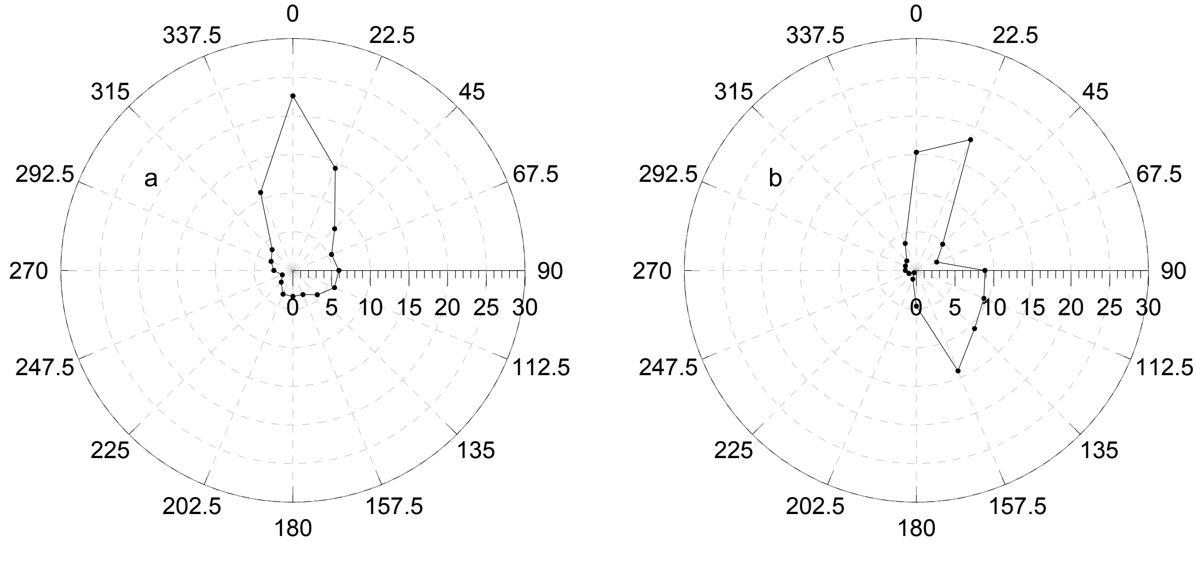


Figure 4: Frequency of occurrence (%) of THI classes per WS classes during daytime (a) and night time (b). Forward slashed bars: $0 < WS \leq 2.1\ m \cdot s^{-1}$; black bars: $2.1\ m \cdot s^{-1} < WS \leq 4.2\ m \cdot s^{-1}$; gray bars: $4.2\ m \cdot s^{-1} < WS \leq 6.3\ m \cdot s^{-1}$; backward slashed bars: $6.3\ m \cdot s^{-1} < WS \leq 8.4\ m \cdot s^{-1}$.

a. North directions could be associated to the transport of relatively cold air masses from the neighbouring mountains to the study area. Consequently, when wind speed was very low, non heat-stress conditions prevailed in the 27% of the examined hours (figure 4a).

b. Southeast directions could be associated to the sea breeze circulation that develops frequently in the area in the summer (Papanastasiou & Melas, 2009). When sea breeze develops, cool sea air is advected over the land, triggering a reduction in temperature and an increase in relative humidity. The temperature reduction triggers a decrease in apparent temperature, while the increase in relative humidity triggers an increase in apparent temperature. The fact that heat-stress conditions deteriorated when wind speed also blew from southeast directions (figure 4a) shows that the effect of relative humidity on THI was more pronounced than the effect of temperature. A similar conclusion has been drawn by Papanastasiou et al. (2010) when studying human comfort levels in the area.

c. West directions could be associated with the advection of warm air from the Thessaly plain, where noon temperatures remain at high levels during summer. This fact could explain the deterioration of heat-stress conditions when wind speed was very high (figure 4a).



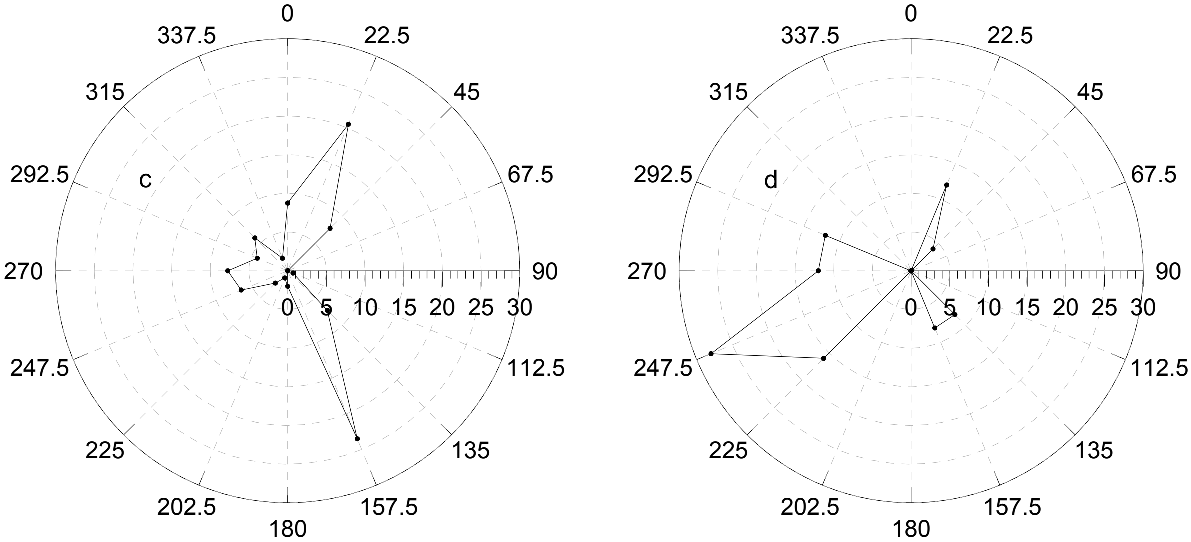


Figure 5: Frequency of occurrence (radius axis, %) of wind direction (angle axis, °) during daytime. a: 0 < WS ≤ 2.1 m·s^{-1}; b: 2.1 m·s^{-1} < WS ≤ 4.2 m·s^{-1}; c: 4.2 m·s^{-1} < WS ≤ 6.3 m·s^{-1}; d: 6.3 m·s^{-1} < WS ≤ 8.4 m·s^{-1}.

Table 3: Frequency of occurrence (%) of THI classes during rainy and non rainy days, during daytime and night time

THI class	Daytime		Night time	
	Rainy days	Non rainy days	Rainy days	Non rainy days
THI < 22.2	65	15	88	68
22.2 <= THI < 23.3	6	7	7	10
23.3 <= THI < 25.6	23	24	4	15
THI >= 25.6	6	54	1	7

Table 3 reveals that heat-stress conditions were worse during non rainy days than during rainy days, both during daytime and night time hours. During daytime and during non rainy days, the hourly THI value surpassed the severe and the extreme severe heat-stress threshold in 78% and 54% of the hours, respectively. The corresponding percentages for rainy days were 29% and 6%, respectively. During the daytime hours of the rainy days, cloudiness is increased, causing a reduction in the amount of solar radiation that reaches the ground. As it is above mentioned, the incoming solar radiation affected decisively the heat-stress levels. Therefore, THI levels were diminished.

4 Conclusions

This paper studied the impact of incoming solar radiation, wind speed, wind direction and rainfall on sheep's thermal comfort conditions that prevail during summer in a rural area near the east coast of central Greece. Sheep's potential heat-stress was assessed by means of THI. Daytime and night time hours were examined separately.

The analysis showed that sheep were exposed to potential moderate, severe and extreme severe heat-stress in 8%, 24% and 53% of the daytime hours, while heat-stress was absent in 15% of the daytime hours. The corresponding percentages for the night time hours were 10%, 15%, 7% and 68%, respectively. Sheep were usually exposed to potential extreme severe heat-stress during the vast majority of daytime hours (approximately during the hours 11:00 – 20:00, local time), while they usually were not exposed to heat-stress during the night time hours.

The analysis revealed that the major meteorological factor that affects THI levels was the incoming solar radiation, followed by the wind direction. Even low irradiance values were related to unfavorable heat-stress conditions. Additionally, low irradiance values were associated with increased cloudiness, a fact that contributed to the reduction of the hourly THI values during rainy days. Wind direction affected THI levels as either warm air masses or cold air masses rich in moisture could be advected to the study area. It was also found that the effect of relative humidity on THI was more pronounced than the effect of temperature, when cold air rich in moisture was advected to the area. The analysis showed that wind speed did not have a significant impact on THI levels

5 Acknowledgement

This work was supported by the Joint Call of ERANET ICT-Agri C-2 projects "Smart Integrated Livestock Farming: integrating user-centric & ICT-based decision support platforms – SILF"

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