Global NEST Journal, Vol 14, No 4, pp 532-539, 2012

THERMAL COMFORT ESTIMATION IN RELATION TO DIFFERENT ORIENTATION IN MOUNTAINOUS REGIONS IN GREECE BY USING ARTIFICIAL NEURAL NETWORKS

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Received: 05/07/10
Accepted: 17/02/12

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ABSTRACT
This study focuses on the estimation of thermal comfort conditions in a high alt. site (1455 m) in Apodotia (MA), Greece, by using the *MLP* neural network model. This estimation is based on the air temperature (t) and relative humidity (f) data of the middle (1078-1163 m) and of the low altitude levels (816-862 m) in relation to different orientations in MA. Also, the *MLP* model was applied on the top of the Mt. Koromilies (alt. 1350 m) for the estimation of thermal comfort conditions based on the t and f of a site (alt. 797 m) on the northern slope of Mt. Parnassos. In both MA and Parnassos regions the "Cold" and "Comfortable" classes of thermal comfort prevailed. The *MLP* model provided more satisfactory estimations of the THI values from the t and f of the middle alt. level compared to the respective estimations from the low alt. level. The model provides less accurate estimations of the THI values at 1455 m alt., in the case of sites located near watery surfaces in MA. The application of the *MLP* model in the case of the Mt. Koromilies, in Parnassos indicated more accurate estimations of the THI values compared to the respective estimations in Apodotia.

KEYWORDS: multilayer perceptron model, air temperature, relative humidity, thermohygrometric index, Apodotia, Parnassos.

INTRODUCTION
Mountainous regions are remote from major centers of human activity (Barry, 2001) and they are often considered as marginal from an economical point of view (Price, 1995). However, in recent years these regions have become attractive destinations of large numbers of people for their recreation and tourism (Beniston, 2003).

The aforementioned regions are characterized by distinct relief elements such as summits, slopes and valleys (Barry, 2001). The amounts of radiation ending on inclined ground surface depends on the solar declination (time of year), the solar altitude (time of day), the cloudiness, as well as on the direction, the angle and the azimuth of the slope (Geiger *et al*., 2003). The differences in the total monthly solar radiation for the various slopes with different orientations affect air temperature of the layers near the ground surface. It has been reported that the eastern slopes are cooler than the western ones (Seemann, 1979).

Thermal comfort may be expressed by a large number of biometeorological indices and it is used to quantify the integral effects of the heat exchange between the human body and the thermal environment (Nastos and Matzarakis, 2006; Jendritzky and de Dear, 2009). The thermal comfort conditions can be evaluated by using a widely and easily used biometeorological index, the thermohygrometric index which requires only temperature and humidity data (Toy *et al*., 2007). The aforementioned conditions are strongly affected by the physical environment. This environment, characterized by different topography, vegetation, fauna and relief, in combination with human thermal comfort, influences tourist decision-making regarding the destination selection (Lin and Matzarakis, 2006) during vacation periods. Also, thermal comfort plays an important role on the development of health tourism (Didaskalou and Nastos, 2003; Didaskalou *et al.*, 2007; Matzarakis and Karagülle, 2007).

The meteorological stations network is sparse especially at mid- and high elevation sites of mountainous regions because there are difficulties in installing and maintaining its instruments (Barry, 2001; Friedland *et al.*, 2003; Tang and Fang, 2006). Recently, many studies have been developed for the estimation of meteorological variables in the mountainous regions based on geostatistical approaches and statistical analysis techniques (Benavides *et al.*, 2007; Guler *et al.*, 2007; Pape *et al.*, 2009; Guan *et al.*, 2009). A robust computational technique, the artificial neural network (ANN) approach, has been applied in many cases due to the advantages of iteration and learning ability, compared to simple regression techniques (Shank *et al.*, 2008). It has been reported that the application of ANN models resulted in satisfactory estimations of air temperature in comparison with multiple linear regression approaches (Chronopoulos *et al.*, 2008; Ustaoglou *et al.*, 2008). Also, these models have been applied successfully to estimate the thermal comfort conditions in mountainous forested areas (Kamoutsis *et al.*, 2010).

The main purpose of this study is the estimation of the human thermal comfort conditions, by applying ANN models, in high altitude sites in the mountainous region of the municipality of Apodotia. This estimation is based on the air temperature and humidity conditions of low altitude sites which are located on slopes of different orientations in the particular region. Furthermore, the aforementioned models were applied in the case of Parnassos mountain, municipality of Parnassos.

METHODOLOGY

Study Area and Instrumentation

This research was carried out in the mountainous region of Apodotia (Municipality of Apodotia, Prefecture of Aitoloakarnania, west continental Greece), as well as in a part of the mountain Parnassos (max. alt. 2459 m), Municipality of Parnassos, Prefecture of Phocis, Central Greece (Figure 1a). The study region of Apodotia (Figure 1b) is located northwest of mountain (Mt.) Vardousia and lies in the Mt. Sarantena (max. alt. 1865 m) and the study region of Parnassos (Figure 1c) is located north-northeast of Amfissa city, the capital of the Prefecture of Phocis.

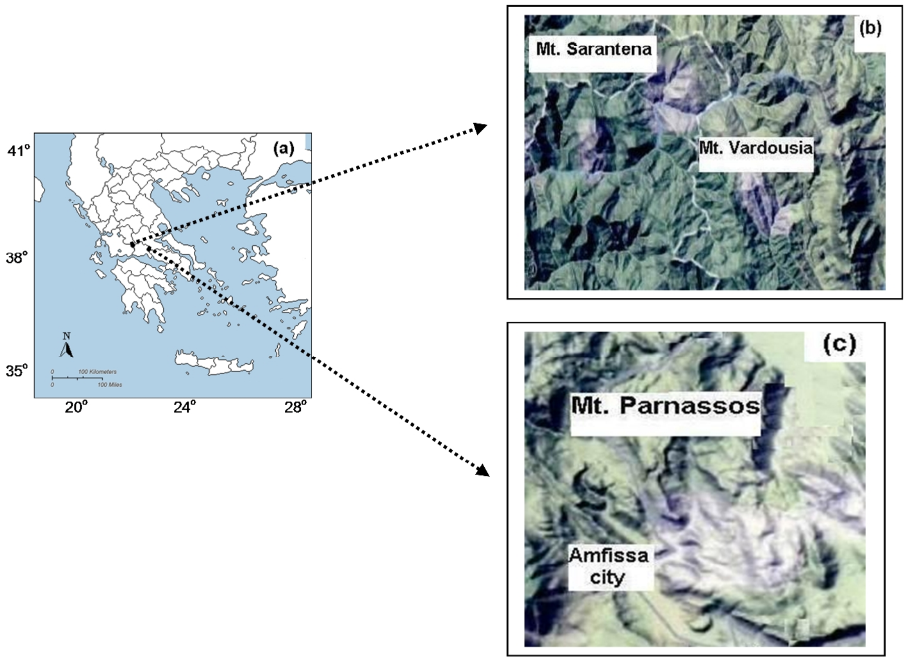

Figure 1. Locations (a) and terrain maps of the study mountainous regions of municipalities of Apodotia (b) and Parnassos (c), Greece, (Mt.: mountain)

Evergreen dense fir (*Abies cephalonica* L.) forests dominate in the zone of conifers, at high altitudes, while various evergreen broadleaved plant species exist in abundance at lower altitudes in the mountainous Apodotia (MA). It is noted that this region is known for its beautiful beech forest (*Fagus silvatica* L.), the southernmost beech forest in Europe. The natural beauty of mountainous Apodotia, due to the various vegetation types as well as the diverse relief and the presence of many brooks which flow into the Evinos River, indicate a region of rich ecological value and great development potential for ecotourism and recreational activities. This region is almost unexploited region with unimportant commercial, industrial or other human activities, due to its abandonment by most inhabitants that emigrated to foreign countries or to the great urban areas of Greece. The mountainous region of Parnassos is characterized by dense fir (*Abies cephalonica* L.) forests, plenty of springs and natural beauty. This region is a popular tourist destination, particularly in the winter period due to the operation of a famous ski resort.

One site on the top of Mt. Sarantena, four sites on the eastern and western slopes of this mountain and four sites on the northern and southern sides of the bank of Evinos River, were selected in MA. The main criterion for the selection of each slope and side orientation was the altitude. Thus, in each orientation there were two altitude levels (Table 1), one comprised of the low examined altitudes (from 816 to 862 m) and the other of the middle examined altitudes (from 1078 m to 1163 m). In the case of Parnassos, one study site (K_T) was on the top of Mt. Koromilies and the other (N_E) in the northern slope of the Mt. Parnassos in the area of Eptalofos. The orientation, the altitude, the latitude and the longitude of each site were evaluated using a mobile Global Positioning System (Garmin eTrex Vista) and cross-checked against 1:50000 topographic maps.

Table 1. Study sites on the top, the eastern and western slopes of Mountain (Mt.) Sarantena and on the northern and southern side of the Evinos River bank in the mountainous region of Apodotia (a) and on the top of Mt. Koromilies as well as on the Northern slope of Mt. Parnassos in the mountainous region of Parnassos (b), Greece

	Site	Altitude (m)	Latitude		Longitude	
		APODOTIA (a)				
Mt. Sarantena						
Top	S_T	1455	38°44´30.9´´	N	21°58´45.4´´	E
Slope Orientation						
Eastern	E1	1143	38°44´04.6´´	N	22°00´24.4´´	E
	E2	824	38°43´19.2´´	N	22°01´02.5´´	E
Western	W1	1078	38°43´58.8´´	N	21°57´59.9´´	E
	W2	835	38°44´02.3´´	N	21°57´34.5´´	E
Evinos River bank side Orientation						
Northern	N1	1082	38°42´14.2´´	N	21°57´50.4´´	E
	N2	862	38°42´40.9´´	N	21°57´50.1´´	E
Southern	S1	1163	38°43´26.6´´	N	21°58´09.2´´	E
	S2	816	38°43´10.0´´	N	21°57´39.8´´	E
		PARNASSOS (b)				
Top of Mt. Koromilies	K_T	1350	38°34´41.8´´	N	22°28´51.2´´	E
Northern slope of Mt. Parnassos	N_E	797	38°35´52.9´´	N	22°29´33.8´´	E

In each study site in Apodotia, air temperature and relative humidity data were recorded simultaneously every 15 minutes by sensors with dataloggers (Hobo type Pro, H08-032-08, accuracy ±0.2 °C at 25 °C and ±3% RH over 0 °C to 50 °C), from September 1, 2005 to August 31, 2007. Similarly, the data of the aforementioned parameters were recorded at the sites K_T and N_E in Parnassos from April 1, 2009 to March 31, 2010. Before the installation of the measuring instruments, they were calibrated in the laboratory against reference sensors, and tested for a period of five days. In addition, every six months, the instruments were tested in situ against the reference sensors. The initial and the intermediate tests revealed no drift errors for any of the sensors and so, their stability was confirmed during the examined period. The data loggers were enclosed in appropriate shelters screened from rainfall and direct solar radiation and placed under selected evergreen trees 1.5 m above the ground surface. The form of the shelters allowed acceptable air ventilation.

Data analysis and Artificial Neural Network (ANN) model description

The recorded air temperature and relative humidity data were used for the calculation of the thermohygrometric index (Toy *et al.,* 2007) according to the following equation:

$$\text{THI } (^{o}\text{C}) = t-[(0.55-0.0055f)(t-14.5)] \quad (1)$$

where THI=thermohygrometric index, t=air temperature (^{o}C) and f=relative humidity (%). The selection of the previous index was based on its suitability to provide a detailed approach of biometeorological conditions in mountainous areas (Kamoutsis *et al.,* 2007). The THI values were used for the evaluation of the classes of human thermal comfort (Toy *et al.,* 2007). Also, the relative frequencies of THI classes were calculated for the whole examined period.

A most commonly used artificial neural network model, the multilayer perceptron (*MLP*) was used for the THI values estimation at the top of Mt. Sarantena (S_T) based on the t and f data of the low (N2, S2, W2 and E2 sites) and middle (N1, S1, W1 and E1 sites) alt. levels taking into account the measurement time. Recent studies showed that *MLP* models can be effectively used to evaluate microclimatic conditions in remote mountainous canyons (Chronopoulos *et al.,* 2008; 2010).

The output of the MLP model with one hidden layer is given by the following general equation:

$$f(x) = \phi^{s}\left(\sum_{i=1}^{I} w_{is}\phi^{i}\left(\sum_{e=1}^{n} w_{ei}x_{e} + w_{0}\right) + w_{s}\right) \quad (2)$$

where I is the number of hidden nodes, *n* is the number of input variables, w_{ei} and w_{is} are the weights of the input-to-hidden and hidden-to-output layer, w_0 and w_s are the corresponding thresholds (bias), ϕ^{i} and ϕ^{s} are the units' activation functions (Rumelhart *et al.*, 1986a). The neural network structure was 2-9-1 (input-hidden-output nodes).

For *MLP* training, first the backpropagation (Rumelhart *et al*., 1986b; Fahlman, 1988; Fausett, 1994) and then the conjugate gradient descent algorithms (Fletcher and Powell, 1963; Fletcher and Reeves, 1964) were used in two phases. The activation function for the hidden units as well as the output unit was the logistic sigmoid function $\phi(x) = \left(1 + e^{-x}\right)^{-1}$. A trial-and-error approach was also applied to select the best network architecture. One hidden layer with various numbers of nodes formed each network. The training set consisted of ½ of the data, the selection set of ¼ of the data and the test set of the remaining ¼ of the data was randomly assigned.

In our study, the inputs were the measurement time, the t and the f of the sites of the middle (N1, S1, W1 and E1 sites) and of the low (N2, S2, W2 and E2 sites) alt. levels while the output was the THI values of the S_T site on the top of the Mt. Sarantena in Apodotia. Similarly, in the case of Parnassos, the inputs were the measurement time, the t and the f of the site of the low alt. (N_E) in Eptalofos and the output was the THI values at the top (K_T) of Mt. Koromilies. All results were considered significant at $p < 0.05$.

RESULTS AND DISCUSSION

The analysis of the relative frequencies of each thermal comfort class indicated that the "Cold" and "Comfortable" classes prevailed, in terms of total percentages for all the classes, at all studied sites in both Apodotia and Parnassos regions, for the whole examined period. Specifically, at the S_T site, the 54.0% and the 24.9% of the THI values were classified as "Cold" and "Comfortable", respectively. Similar percentages were observed for the aforementioned classes at the K_T site. Noticeable percentages, namely 49.7% (in average) and 45.9% in Apodotia and Parnassos, respectively, belonged to the "Cold" class at the low alt. levels (816 to 862 m in Apodotia and 797 m in Parnassos). The 49.4% (in average) of the THI values at the middle alt. level of Apodotia was classified as "Cold". Also, the 22.9% (in average) and the 29.6% of these values were classified as "Comfortable" at the low alt. levels in Apodotia and Parnassos, respectively, and at the middle alt. level in Apodotia, the 20.2% (in average) of the THI values belonged to the “Comfortable” class.

The results of the development and application of the *MLP* method at the examined sites of Apodotia are presented in Figures 2 and 3.

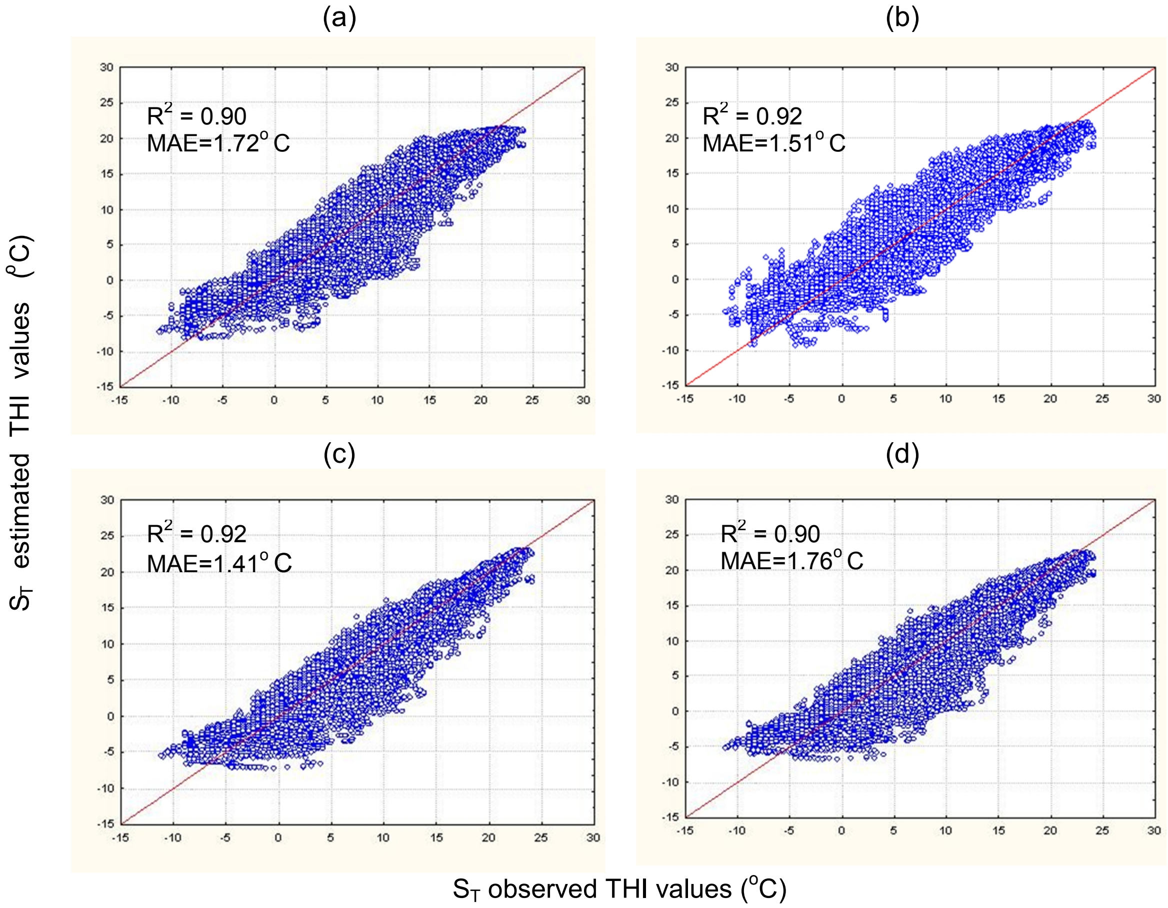

Figure 2. Scatter plots of observed vs. estimated THI values on the top (site S_T) of Mt. Sarantena. The estimations were based on temperature and relative humidity data of the northern (a) and the southern (b) sides of the Evinos River bank and, of the western (c) and eastern (d) slopes of the aforementioned Mt., at the middle alt. level (1078 to 1163 m) in Apodotia, Greece. THI: Thermohygrometric index, Mt.: mountain, alt.: altitude, R^2=Coefficient of determination, MAE=Mean absolute error, $p < 0.05$

THI values estimations for the S_T site were both similar (Figure 2a, b, c, d) and very satisfactory according to the high values of the determination coefficients (R^2 = 0.90 to 0.92) in all cases. However, the Mean Absolute Error (MAE) was lower in the cases of Figure 2c and 2b compared to the other examined cases (Figure 2a and 2d). Thus, the model provided better estimations of the THI values using the t and the f, primarily from the western slope of Mt. Sarantena (Figure 2c) and secondarily from the southern side of the Evinos River bank (Figure 2b).

The values of R^2 and MAE were lower and higher, respectively (Figure 3), in the case of the estimation of THI values on the top of Mt. Sarantena using the t and f at the low alt. level (816 to 862 m) compared to the respective estimation from the middle alt. level (Figure 2) in Apodotia. Among the various cases of Figure 3 (a, b, c and d), the R^2 and the MAE took the highest and the lowest values, in the case of Figure 3a, and Figure 3b, respectively. Therefore, the model provided better estimations of the THI values using the t and the f, primarily of the northern side of Evinos River bank (Figure 3a) and secondarily of the western (Figure 3c) and eastern slopes of Mt. Sarantena (Figure 3d).

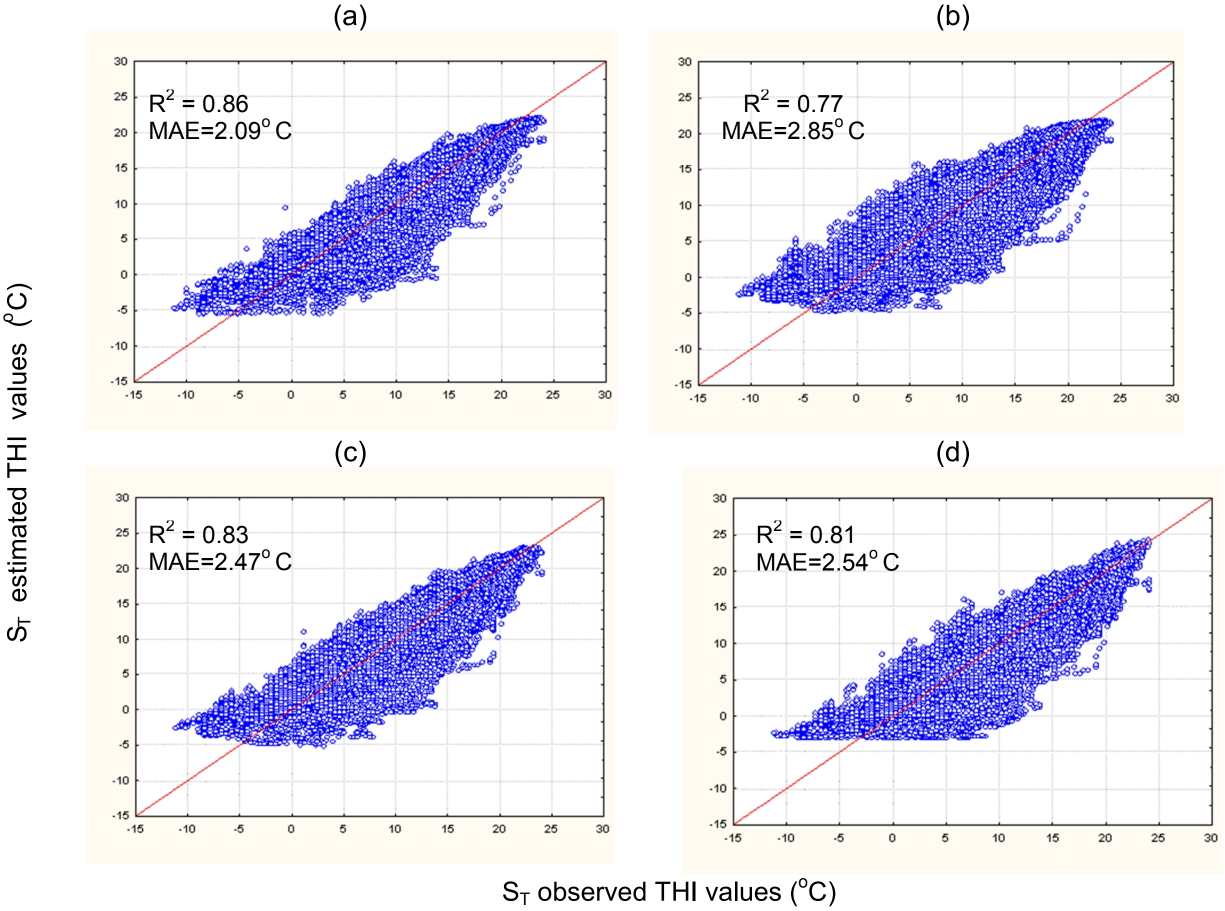

Figure 3. Scatter plots of observed vs. estimated THI values at the top (site S_T) of the Mt. Sarantena. The estimations were based on temperature and relative humidity data of the northern (a) and the southern (b) sides of the Evinos River bank and, of the western (c) and eastern (d) slopes of the aforementioned Mt., at the low alt. level (816 to 862 m) in Apodotia, Greece. THI: Thermohygrometric index, Mt.: mountain, alt.: altitude, R^2=Coefficient of determination, MAE=Mean absolute error, $p < 0.05$

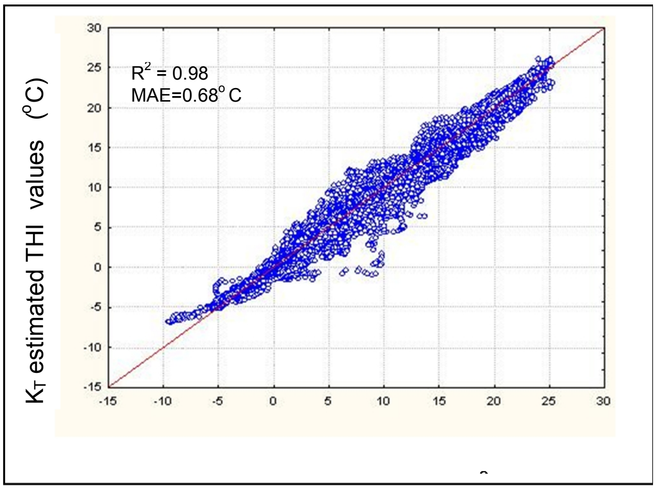

Figure 4. Scatter plots of observed vs. estimated (THI) values at the top (K_T) of Mt. Koromilies based on the temperature and relative humidity data of the site at the low alt. level (797 m), in Parnassos, Greece. THI: Thermohygrometric index, Mt.: mountain, alt.: altitude, R^2=Coefficient of determination, MAE=Mean absolute error, $p < 0.05$

It is interesting to note the presence of watery surfaces near the examined sites of the low alt. level, in contrast to the examined sites of the middle alt. level. From the comparison of Figures 2 and 3,

with regard to R^2 and MAE, it seems that the model provides less accurate estimations of the THI values at the top of Mt. Sarantena in the case of sites located near the watery surfaces.
The application of the *MLP* model in the Mt. Koromilies, Parnassos indicated more accurate estimations (Figure 4) of the THI values at the K_T site (alt. 1350 m) compared to the respective estimations in Apodotia (Figure 2 and 3) due to the higher value of R^2 (0.98) and the lower value of MAE (0.68). The S_E site, near the Eptalofos community, is characterized by the absence of watery surfaces.

CONCLUSIONS

The results of this study suggest that *MLP* artificial neural network models could be used efficiently for the estimation of the thermal comfort conditions as expressed by the thermogygrometric index (THI) values in the high altitude sites (1455 m) of the mountain Sarantena in Apodotia, Greece, by using air temperature and relative humidity data of middle (1078-1163 m) and low altitude levels (816-862 m) in relation to different orientations (Northern, Southern, Eastern, Western). The *MLP* model provided better estimations of the THI values, primarily from the western slope of Mt. Sarantena and secondarily from the southern side of Evinos River bank in the middle alt. level. Also, this model provided better estimations of the THI values, primarily from the northern side of Evinos River bank and secondarily from the western and eastern slopes of Mt. Sarantena. The *MLP* model provided more satisfactory estimations of the THI values from the middle alt. level compared to the respective estimations from the low alt. level. The model provides less accurate estimations of the THI values at the top of Mt. Sarantena, in the case of sites located near watery surfaces. The application of the *MLP* model in the case of Mt. Koromilies (alt. 1350 m), in Parnassos indicated more accurate estimations of the THI values compared to the respective estimations in Apodotia.

ACKNOWLEDGEMENT

This research was partially funded by the European Social Fund & National Resources – Operational Programme for Education and Initial Vocational Training (EPEAEK II), "Environment-Pythagoras II-Funding of Research Groups in Agricultural University of Athens".

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