Combustion gases

$$C_{pCG} = C_{pa} + \frac{f}{1+f}\theta_{CG}$$

where

$$\theta_{CG} = CG_0 + CG_1 T + CG_2 T^2 + CG_3 T^3 + \ldots$$

where

Symbol	Temperature range 800–2200 K (J/kg)
CG_0	+1.0887572 E+03
CG_1	−1.4158834 E−01
CG_2	−1.9160159 E−03
CG_3	−1.2400934 E−06
CG_4	+3.0669459 E−10
CG_5	−2.6117109 E−14

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ANALYSIS OF THERMAL COMFORT CONDITIONS IN ATHENS, GREECE

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Abstract—Two models, the Eggenberger–Polya and the William's logarithmic series have been used to predict the probability of occurrence of varying length mild and hot spells, respectively, for the summer period using a 13-yr hourly database from Athens, Greece. The proposed models provide the necessary information to energy analysts and climatologists contributing towards a more precise analysis of the summer comfort conditions.

Cooling power index Thermal comfort Athens Greece

INTRODUCTION

Achievement of thermal comfort inside buildings is of primary concern in hot climates. Energy consumption due to the use of conventional air-conditioners has a very serious impact on the peak electricity load. It has been reported that 38% of the non-coincident peak demand in the United States is induced by air-conditioners [1].

Unpleasant climatic conditions have a direct impact on energy consumption of buildings for air-conditioning purposes. Due to the serious heat waves observed in Greece during the period of 1987–1989, there was an increase of about 800% in annual purchases of air-conditioning units [2]. It should be pointed out that a relative increase of sales of air-conditioning units by approx. 300% has also been reported for the period 1976–1985 [3].

Exact knowledge of the climatic data that influences thermal comfort in the interior of a building is necessary for energy calculations. Analysis of the fundamental climatic parameters like temperature, humidity, or wind speed can indpendently provide useful information. However, these data do not permit a global evaluation of comfort conditions at a given place. For this purpose, various bioclimatic indices have been proposed. These indices are based on the combination of various parameters like dry bulb temperature, humidity, wind velocity, clothing, or metabolic rate. A synoptic presentation of several such biometeorological indices is given in Ref. [4].

The cooling power index proposed by Vinje [5] has gained an increasing acceptance for representing summer comfort conditions in a very simple way. An analysis of the cooling power index for Athens, Greece using a 13-yr hourly database has been attempted in Ref. [6]. It was then concluded that there is a persistence of occurrences for both the hot and mild conditions, with consecutive periods often exceeding 24 h at a time. Taking into account the importance of such an effect, further analysis of this phenomenon has been attempted and is presented in this paper. Using statistical techniques, models predicting the corresponding persistence of an occurrence for hot and mild conditions are proposed. These models provide the necessary information to energy analysts and climatologists contributing towards a more precise analysis of the summer comfort conditions.

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Table 1. Number of spells (S) and total number of hot and mild hours (N)

	Hot			Mild		
Month	S	N	Frequency	S	N	Frequency
May	460	750	0.08	1189	3785	0.39
June	609	2215	0.24	1177	4660	0.50
July	735	3624	0.37	1129	4349	0.45
August	763	3313	0.34	1216	4690	0.49
September	674	2159	0.23	1155	4438	0.47

MODEL DEVELOPMENT

The dry cooling power (H) has been calculated for Athens, Greece [6] using a correlation suggested by Vinje [5], expressed as a linear function of the body and the air temperature difference, and a power of the wind speed and is given by:

$$H = 20.52 V^{0.42} (36.5 - T) \tag{1}$$

where

H = cooling power (kcal/m^2 h)
V = wind speed (m/s)
T = dry bulb air temperature (°C).

The calculated cooling power values can be related to the corresponding sensations experienced by humans in accordance with a properly devised scale (Hot for $H < 5$, Mild for $5 < H < 10$). The calculations were based on meteorological data from the National Observatory of Athens for a period of 13 yr (1977–1989) and for the months of May–September.

Table 1 summarizes the total number of hours for every month for each of the hot and mild conditions. Based on a previous study [6], the hot conditions occur primarily during the mid-day hours. Consequently, they represent a smaller percentage of the corresponding mild conditions for all the 5 months. Together, the hot and mild conditions constitute 70–83% of the total conditions during the time period of June–September. During May, the prevailing mild weather conditions result in acceptable levels of thermal comfort which reduce the corresponding occurrences of the hot and mild conditions to less than 47% of the total hours during this month.

In addition, it was observed that there is a persistence of occurrences for both the hot and mild conditions, with consecutive periods often exceeding 24 h at a time. These type of spells have a very important impact on energy consumption. For that reason, it was decided to analyze this persistence statistically. The objective was to develop an algorithm which could be used to calculate the probability of occurrence of varying length spells.

Among the known models for defining the persistence of an occurrence, the model of Eggenberger–Polya and the William's logarithmic series can be used to accurately predict the probability of occurrence of varying length spells.

According to the Eggenberger–Polya model [7], the persistence can be taken into account by modification of the Poisson distribution. The theoretical probability of a spell of length x (in hours) is given by:

$$f_1 = 1/(1+d)^{m/d}$$
$$f_k = f_{k-1}[(m + (k-1)d)/k(1+d)] \tag{2}$$

Table 2. Results for the χ^2-test and the degree of freedom (d.f.) for the theoretical and observed values

	Hot		Mild	
	$\Sigma\chi^2$	d.f.	$\Sigma\chi^2$	d.f.
May	6.804	4	21.843	13
June	14.621	13	22.512	17
July	16.431	18	14.357	16
August	8.798	16	17.020	12
September	17.492	12	18.171	15

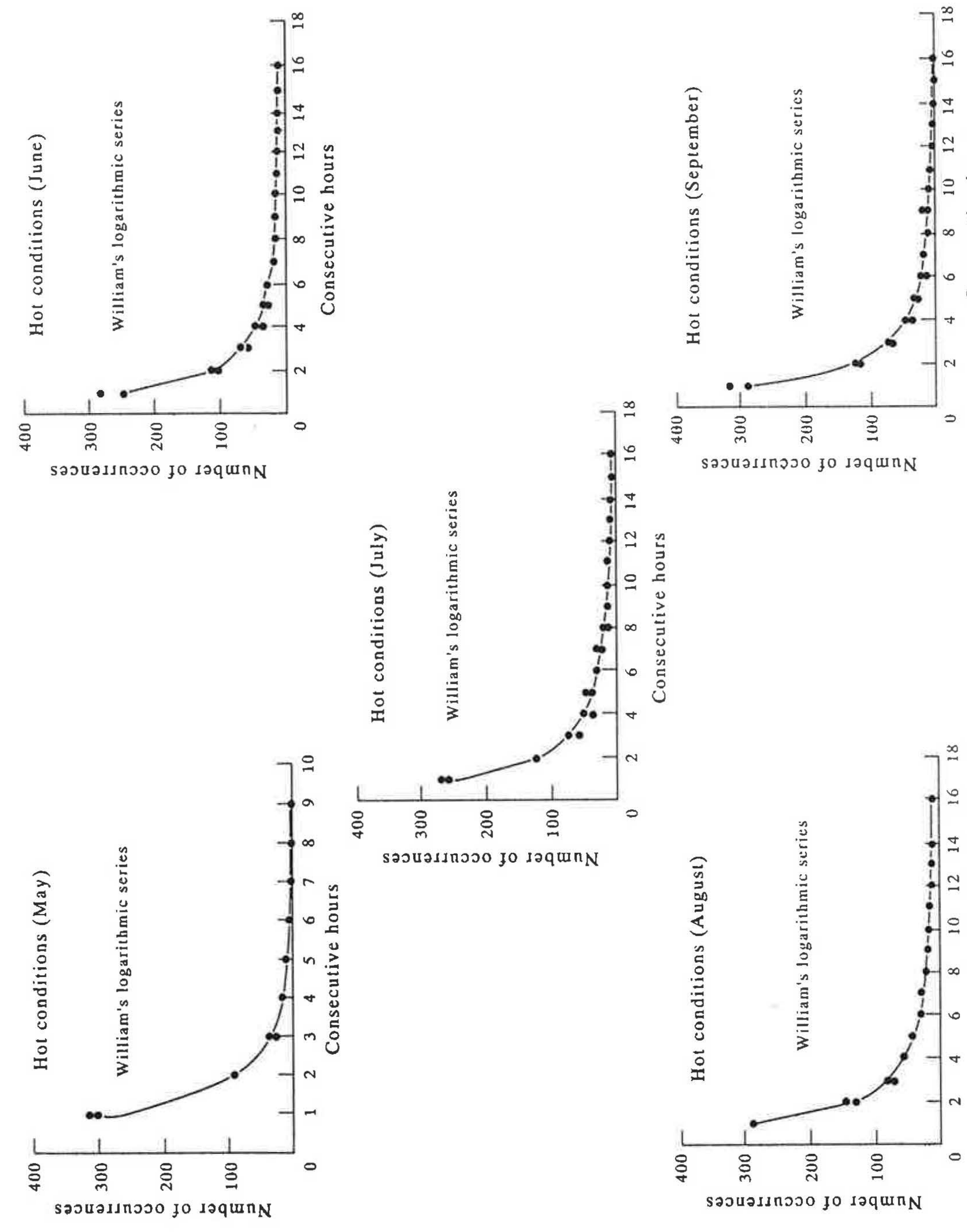

Fig. 1. The correlation of the number of consecutive hours for hot conditions during the summer months. The curve represents the predicted values by the Williams logarithmic model and the data points represent the original data.

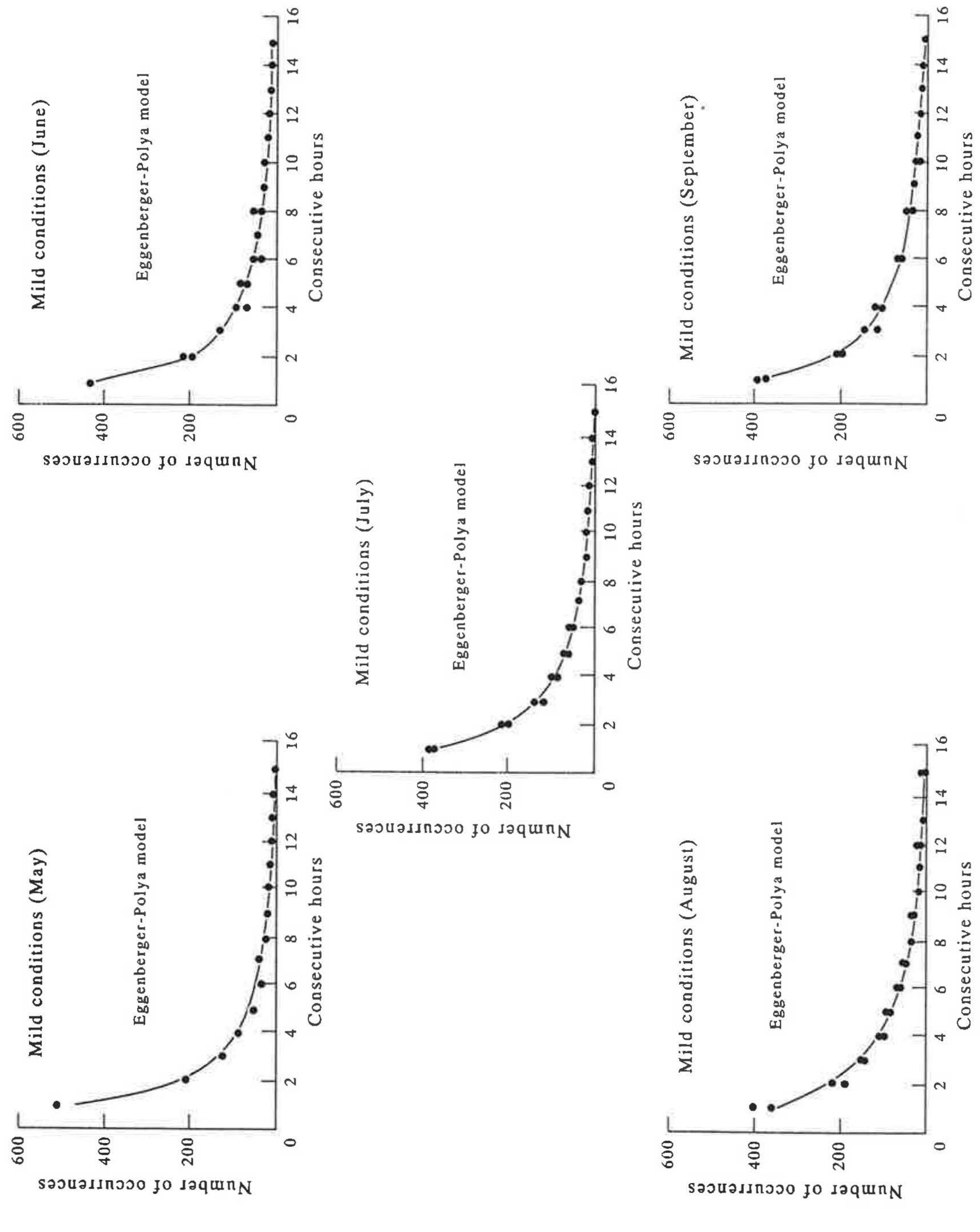

Fig. 2. The correlation of the number of occurrences with the number of consecutive hours for mild conditions during the summer months. The curve represents the predicted values by the Eggenberger-Polya model and the data points represent the original data.

where

N/S = mean length of a spell
$m = N/S - 1$
N = total number of hot (mild) conditions
S = sum of spells x_i (hot or mild)
$d = (s^2/m) - 1$ is the persistence factor
$k = 2, 3, \ldots$.

The Eggenberger–Polya distribution is, in fact, a negative binomial distribution [8]. The analysis of our data has shown that all the series of consecutive hours with mild conditions are well adapted to the Eggenberger–Polya distribution. As shown in Table 2, the values of the χ^2-test are, for all cases, smaller than the critical values which correspond to a significance level of 0.05.

The Williams logarithmic series [9] is mathematically expressed by the equation:

$$f_i = ax_i/i \quad i = 1, 2, \ldots, n. \tag{3}$$

The constants a and x $(0 < x < 1)$ can be calculated from the following system of two simultaneous equations,

$$S = aln(1 + N/a)$$

$$N = ax/1 - x \tag{4}$$

where

S = total number of spells (hot or mild)
N = total number of hot or mild hours.

The results from the χ^2-test (Table 2) indicate that the logarithmic series fits satisfactorily the distribution of the continuous hot hour series at the 0.05 significance level. Therefore, the Eggenberger–Polya and the Williams logarithmic models can be used to predict accurately the probability of occurrence of varying length spells for the mild and hot conditions, respectively.

CONCLUSIONS

The present work completes the analysis of the summer discomfort conditions given in Ref. [6] by comparing several models for defining the persistence of an occurrence for hot and mild conditions in Athens, Greece. The Eggenberger–Polya model was found to represent the variations of the series of consecutive hours with mild conditions, while the Williams logarithmic model was found to represent the conditions for the hot hour series.

Comparison of the predicted with the real data has shown that there is very good agreement between the two sets of data (hot and mild) for all five summer months (May–September). This work provides very useful information to energy analysts contributing towards a more accurate analysis of the summer comfort conditions.

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