Climatic-related Evaluations of the Summer Peak-Hours' Electric Load in Israel

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ABSTRACT

The interrelationship between the summer peak electric load in Israel and pertinent meteorological parameters, including the commonly used outdoor biometeorological comfort index, is evaluated conceptually and statistically. Linear regression that was established between the peak electric load and these parameters indicated high correlation for the comfort index. Estimation of climatic change impact on the summer peak electric load indicated (i) mild effects as a result of changes in land use, and (ii) noticeable long-term changes due to potential climatic change associated with doubling of the atmospheric CO_2.

1. Introduction

Diurnal electric-load features of utilities (especially during the peak hours) are important in operational management considerations, as well as for planning long-term electric-energy capacity. During the work week in the summer, the load has a typical diurnal cycle that is modified mostly by the use of air conditioning. During the summer midday hours, electric energy for air conditioning may reach 20% of the total load in some geographical locations (Le Comte and Warren 1981). Weather conditions that affect considerably the thermal balance in buildings, therefore, may result in noticeable changes in the peak electric load. Various studies have attempted to correlate weather parameters and the electric load during the summer (Thompson 1976; Campo and Ruiz 1987). Apparently, however, no attempt has been made to examine the interrelationship between the summer daytime electric load used for air conditioning during peak hours and (i) the outdoor biometeorological comfort feeling of humans, (ii) land-use changes, and (iii) potential climatic changes. In this note, we provide preliminary evaluation of these interrelationships for Israel. Most of the summer air-conditioning energy in Israel is consumed in the coastal area, where the relevant weather conditions are nearly uniform in the south–north direction. These characteristics enable examination of (i)–(iii) while using a simplified methodology.

We first provide conceptual evaluations that suggest analogies between weather impact on thermal storage in buildings and human biometeorological comfort feelings (section 2). We then describe the interrelationship between the summer peak load and meteorological conditions in Israel (section 3). In addition, we estimate the impacts of land-use change and potential climatic change from doubling atmospheric CO_2 ($2 \times CO_2$) on the summer peak electric load.

2. Conceptual evaluations

a. Meteorological effects on thermal balance in buildings

The summer peak electric load in Israel usually occurs between 1200 and 1400 local standard time (LST).

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Conceptually, it is suggested that in a first approximation the electric energy E needed for air conditioning is given by the relation (ASHRAE 1991)

$$E = E(T, T_d, R_s, U), \tag{1}$$

where T and T_d are the shelter dry and dewpoint temperatures, respectively, R_s is the global solar irradiance at the horizontal surface, and U is the surface wind speed.

The thermal balance of buildings is affected by two primary factors: (i) the solar irradiance that is absorbed in building envelopes or transmitted through windows to the building interior, and (ii) the outdoor air temperature that affects thermal conduction through windows and walls, as well as heat exchange by ventilation or air leakages through windows and doors. Air conditioning results in water vapor condensation where the related latent heat energy is dependent on specific humidity q of the air or equivalently on T_d [$T_d = T_d(T, T_w)$, where T_w is the wet-bulb temperature]. On clear days during the summer in Israel, the interdaily variation of the accumulated global solar irradiance is relatively small (Stanhill 1966). Also, usually the amount of the early afternoon cloudiness is negligible (occasional significant cloudiness in these hours is associated with relatively low T values). Therefore, in a first approximation, summer interdaily variations in E are practically unaffected by R_s. Increase in wind speed affects the thermal balance of buildings in opposing ways: (i) increase of atmospheric heat exchange with the building envelopes, which typically reduces the need for air conditioning, and (ii) increase of indoor–outdoor exchange of heat and moisture through leakages, which typically enhances the need for air conditioning. In the summer afternoons the interdaily variability of the wind speed is small in the coastal area of Israel (Skibin and Hod 1979). Therefore, only mild dependence of E on the wind speed can be assumed as a first approximation. In conclusion, an alternative to relation (1) is given by

$$E = E(T, T_w, U). \tag{2}$$

b. *Outdoor biometeorological comfort index*

Common practical biometeorological indices C, which are used for implying the outdoor comfort feeling, are expressed through the relation (Givoni 1974)

$$C = C(T, T_w, U). \tag{3}$$

For moderate wind speeds, the dependence of C on U is low. Considering the identical independent variables in relations (2) and (3) and the similarity of their physical effect in both cases, the following relation is suggested:

$$E = E(C). \tag{4}$$

Alternatively, relation (4) can be suggested based on the following considerations. Assume a building in which the air-conditioning cooling system is off; however, its natural or mechanical ventilation is maintained. The indoor comfort feeling is then related to the outdoor comfort biometeorological index C. When the air conditioning is on, the indoor environment is forced to that of a standard optimum comfort-index value C_0. Therefore, $E = E(C - C_0)$, or, equivalently, $E = E(C)$.

In section 3a, the accuracy of relation (4) is examined statistically and is compared with additional relations expressing dependence of E on relevant meteorological parameters.

3. Quantitative evaluations

a. *Electric load and meteorological parameters*

We selected the summer peak-hours' electric-load pattern in Israel during two summers, 1987 and 1988. The summer comprises June, July, and August; nonwork days (Friday, Saturday, and holidays) were excluded. The load increased from an average of 2739 MW in 1987 to 2950 MW in 1988, attributed in part to socioeconomic effects. The coastal area of Israel, where most of the summer electric consumption for air conditioning originates, has a relatively straight

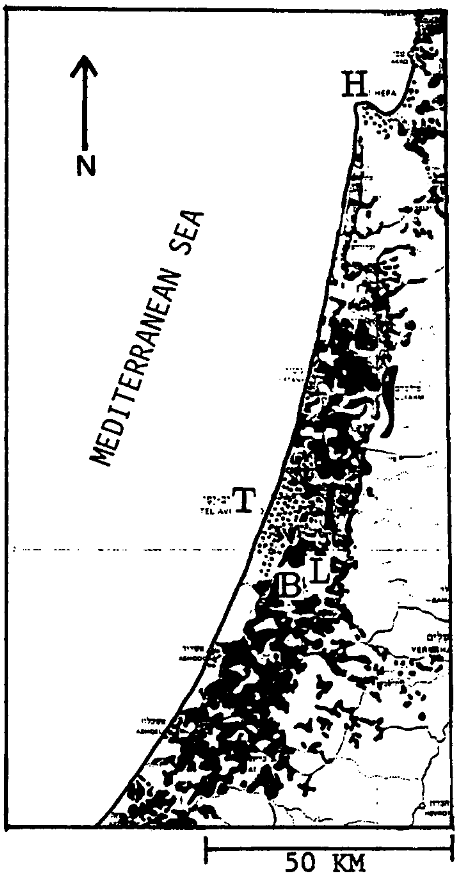

FIG. 1. Map illustration of the coastal area of Israel. Irrigated areas are darkened; major urban areas in the coastal area are dotted. T—Tel Aviv, H—Haifa, B—Bet Dagan, and L—Lod.

shoreline (Fig. 1) and uniform terrain. In this area during the summer, the 1400 LST shelter temperature typically ranges between 28° and 32°C (The Survey of Israel 1985), where correspondingly $T_w \approx 20°$–25°C. Higher shelter temperatures are usually due to warm, dry offshore flows in the beginning of the summer, or are caused by an intense upper-air subsidence following an onset of a ridge over the area. The latter situation is usually accompanied by an increase in the lower-atmosphere moisture due to a reduction in the mixing-layer depth. On the other hand, occasional synoptic perturbations that are associated with deepening of the summer surface-pressure trough prevailing in the eastern Mediterranean (most significantly when accompanied by an upper cold-air trough) result in decreased temperature and increased morning convective cloudiness.

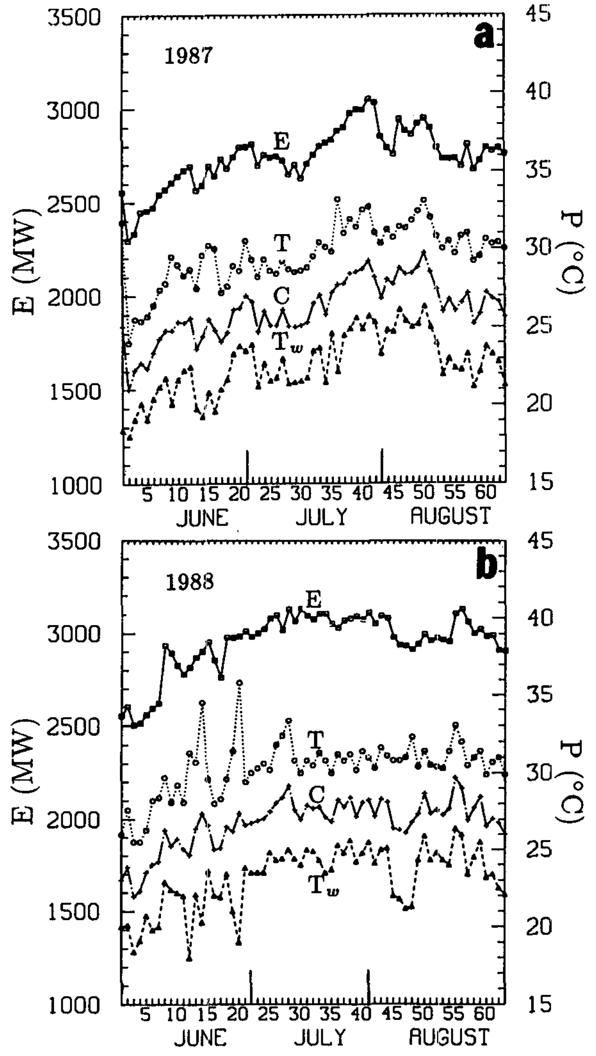

FIG. 2. The 1400 LST workday values of meteorological parameters p (as observed in Bet-Dagan), which are relevant to the electric-load level, and the corresponding 1200–1400 LST-averaged summer electric load in Israel, E (MW). Lengthened tick marks indicate beginning of a month: (a) summer 1987; (b) summer 1988.

Figure 2 presents the mean electric load E during 1200–1400 LST in the summers of 1987 and 1988 versus the 1400 LST values of T, T_w, and $C = 0.5(T + T_w)$ at Bet Dagan [B, approximately 7 km onshore; the summer weather conditions in this station are representative for large portions of the populated area in Israel, (e.g., Mandel 1991)]. The adopted expression for C (suggested by Sohar et al. 1963) provides the biometeorological heat-load index that is commonly used in Israel. As seen in Fig. 2, the load increases with T and T_w. Exceptions, however, are days with increased T and reduced T_w (i.e., warm and dry days). The electric load is affected in such days by contrasted meteorological forcings, and it is established in an intermediate level as implied by C (e.g., day 20 in June 1988). Finally, the average values of T and T_w in 1988 (30.3° and 23.1°C, respectively) were somewhat higher than the 1987 values (29.6° and 22.6°C, respectively). Thus, the higher average load in 1988 should be attributed in part to the difference in the climatological conditions in both summers.

Linear regressions between E and various meteorological predictors (based on Bet Dagan observations) are given in Table 1. Due to the electric-load growth trend (associated with economic growth and an increase in air-conditioning use), the linear regressions were computed separately for the two years.

Table 1 indicates relatively high correlations between all the weather predictors and the electric load. Considering regressions only with 1400 LST predictors [Eqs. (1)–(7)], the lowest correlations were computed for T^{14}. Somewhat higher correlations were computed for T_w^{14} and for EN^{14} [$\mathrm{EN} = \mathrm{Lq} + C_pT$ is the specific enthalpy per unit air mass, where L is the latent heat of evaporation (in this study at $T = 30°\mathrm{C}$)], and C_p is the air specific heat at constant pressure. Multiple linear regressions including T^{14} and T_w^{14} [Eq. (3)], as well as T^{14} and the specific humidity q^{14} [Eq. (5)], improved the correlations appreciably. The highest correlations were computed for Eq. (4) with C^{14} as predictor, and Eq. (7) with C^{14} and U^{14} as predictors, which supports the conceptual evaluations presented in section 2. Comparing regression equations (4) and (7), it is evident that the wind speed has insignificant effect on the summer load prediction.

The two regressions only with the 0800 LST predictors [Eqs. (8) and (9)] showed high correlation coefficients, implying mostly a high intercorrelation between these predictors values at 0800 LST and their corresponding values at 1400 LST. If these high correlations are proven to be consistent for a larger set of years, these regressions should be very supportive in daily peak-load management considerations.

Regressions with a mix of 0800 LST predictors and C^{14} [Eqs. (10) and (11)] provided some improvement in the load estimations. In both regressions, the 0800 LST predictors account for the weather conditions affecting buildings' thermal storage in the early period of the day.

TABLE 1. Linear regression equations of the summer peak-hours' electric load in Israel, E (MW), based on various meteorological predictors (the superscripts indicate the local time) and the corresponding correlation coefficients r (Note: all are significant at the 95% level), the absolute mean error AME, and the relative absolute mean error RAME.

Predictor	Regression equation	r	AME (MW)	RAME (%)
(1) T^{14}	(87) $E = 68.61T^{14} + 704.8$	.847	81.6	2.18
	(88) $E = 64.44T^{14} + 994.6$	.731	110.4	2.95
(2) T_w^{14}	(87) $E = 68.16T_w^{14} + 1200.4$	.884	71.1	2.10
	(88) $E = 65.20T_w^{14} + 1442.1$	.807	95.5	2.43
(3) (T^{14}, T_w^{14})	(87) $E = 43.94T_w^{14} + 35.59T^{14} + 692.2$	.934	54.1	1.55
	(88) $E = 49.39T_w^{14} + 42.62T^{14} + 514.4$	.918	63.2	1.81
(4) C^{14}	(87) $E = 79.76C^{14} + 656.4$	.934	54.4	1.54
	(88) $E = 92.43C^{14} + 478.7$	.920	63.6	1.83
(5) (T^{14}, q^{14})	(87) $E = 52.13T^{14} + 24.48q^{14} + 846.5$	.895	67.2	1.83
	(88) $E = 56.12T^{14} + 33.06q^{14} + 749.3$	.913	64.8	1.86
(6) (EN^{14})	(87) $E = 0.019\mathrm{EN}^{14} - 3639.6$	.881	72.6	2.11
	(88) $E = 0.018\mathrm{EN}^{14} - 3184.5$	.804	96.7	2.45
(7) (C^{14}, U^{14})	(87) $E = 81.27C^{14} - 5.09U^{14} + 655.0$	.935	42.0	1.53
	(88) $E = 92.71C^{14} + 7.73U^{14} + 402.6$	.922	51.9	1.76
(8) (T^8, T_w^8)	(87) $E = 9.94T^8 + 63.81T_w^8 + 1089.9$	.883	56.4	2.06
	(88) $E = 64.26T^8 + 37.48T_w^8 + 405.7$	.954	38.9	1.32
(9) (C^8)	(87) $E = 76.67C^8 + 910.5$	.867	59.2	2.16
	(88) $E = 97.61C^8 + 567.6$	.946	42.2	1.43
(10) (C^{14}, T^8)	(87) $E = 78.33C^{14} + 1.85T^8 + 646.0$	.933	42.2	1.54
	(88) $E = 63.10C^{14} + 35.66T^8 + 311.4$	.934	46.9	1.59
(11) (C^{14}, C^8)	(87) $E = 75.12C^{14} + 5.26C^8 + 652.4$	.933	42.3	1.54
	(88) $E = 33.42C^{14} + 66.21C^8 + 440.6$	.954	38.6	1.31

To obtain additional insight into the regression representation, the absolute mean error (AME) of the regression,

$$\mathrm{AME} = \frac{\sum_{i=1}^{N} |E_i - \hat{E}_i|}{N}, \tag{5}$$

and the relative absolute mean error (RAME),

$$\mathrm{RAME} = \frac{\mathrm{AME}}{\bar{E}}, \tag{6}$$

were computed, where N is the number of days in each summer, E_i is the peak-hours' electric load in day i, $\hat{E}_i$ is the estimated peak-hours' electric load in day i, $\bar{E}$ is the summer average electric load.

For the regressions presented, the AME reaches values as low as 40 MW. The RAME values are as low as 1.4%. The AME and RAME improved somewhat when a mix of 1400 and 0800 LST predictors was considered, as compared with regressions consisting only of 1400 LST predictors. For the regression given by Eq. (5), where the two predictors (T^{14} and q^{14}) are not intercorrelated, the difference in RAME between the years 1987 and 1988 is negligible, suggesting further analysis with these two parameters.

Finally, when a single predictor regression is considered, we define the elasticity EL of the electric load E as

$$\mathrm{EL} = \frac{1}{\bar{E}} \frac{dE}{dp}, \tag{7}$$

where p is one of the parameters T, T_w, or C. Elasticity EL provides the changes in the normalized electric load due to change in p.

Using the high-accuracy regression, Eq. (4) yields EL = 2.9% in 1987 and 3.1% in 1988 (i.e., for 1° increase in, C the corresponding increase in E was 2.9% in 1987 and 3.1% in 1988). These results indicate increased usage of air conditioning in 1988 compared with 1987, in response to socioeconomic influences.

b. *Land-use change*

Modification of land use in the coastal plain of Israel in the last century has included the following patterns: (i) increases in the vegetated area, mostly until 1970; and (ii) urbanization, which has been prominent during the last four decades (The Survey of Israel 1985). During summer daytime, the coastal plain of Israel is typically under the influence of marine flow (composed of northwesterly synoptic flow and sea breeze). Permanent capping upper-layer inversions with typical bases in the range of 400–1000 m (Dayan et al. 1988) cause accumulations of moisture within the mixing layer (see illustration in Fig. 3). The daytime processes governing the moisture and temperature variations within the atmospheric boundary layer (ABL) and near the surface consist of (i) onshore advection of marine moisture and temperature, and (ii) the supply of latent and sensible surface heat fluxes into the ABL as determined by the land-use properties. (See Mahrt 1976; Steyn 1990; and Segal et al. 1992a.)

During summers a century ago, the coastal area consisted mostly of dry land (limited areas were covered by swamps, orchards, and transpiring native

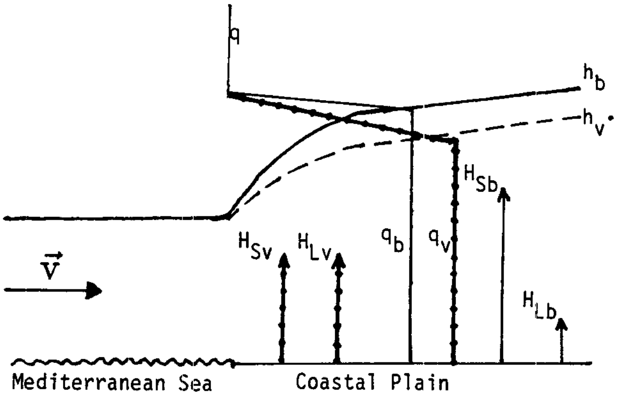

FIG. 3. West–east vertical cross section schematic illustration of characteristics that are relevant for land use and meteorological evaluation of summer electric load in the coastal plain of Israel. The subscripts *b* and *v* indicate bare ground and vegetated ground, respectively. The relative magnitudes of the sensible and latent heat flux (H_S and H_L) are illustrated by arrows. Illustrated also in variation of the ABL depth *h*, the vertical profile of the specific humidity *q*, and the prevailed wind **v**.

grass). Therefore, in a first approximation, it is assumed that urbanization has not led to substantial changes in surface thermal fluxes. Cultivation of the rural region resulted in an increase in the lower atmosphere moisture of the region and possibly a decrease in temperature. Indication of a decreased trend in the shelter temperature was reported by Alpert and Mandel (1986). Further quantification of such trends is provided in Fig. 4. The site of Lod ($L \sim 15$ km onshore) indicates an increase in the 1400 LST air specific humidity of approximately 3 g kg^{-1} during the years 1953–89, which is associated with an undefined temperature trend. Trends of increase in specific humidity and mild reduction in the shelter temperature were computed in several rural sites in the coastal plain (not shown). On the other hand, in a site at the shoreline of Tel Aviv (T), which is unlikely to be affected during the daytime by advection from the irrigated areas, trends toward some decrease in air moisture and undetermined trend in air temperature are observed. Increase in moisture in the inner coastal plain is attributed conceptually to two factors: (i) reductions in onshore ABL depth *h* as a result of decreases in the Bowen ratio, which consequently lead to the reduction of the vertical dilution of the marine moisture that is advected onshore, and (ii) intensification of the evapotranspiration source as a result of increased cultivated areas [similar patterns are reported by Segal et al. (1989) for the South Platte River basin in Colorado]. Figure 3 provides schematic illustration for the impact of the aforementioned processes.

Two extreme scenarios were adopted while using a scaling approach in evaluating the impact of land-use change on electric load. The first scenario assumes that all populated areas of the coastal plain were affected by the maximum changes of temperature ΔT and humidity Δq indicated for Lod and other onshore rural locations during 1953–89. The second scenario considers the fact that major urban areas are located within narrow strips along the Mediterranean shore (indicated by dots in Fig. 1). Therefore, we adopted in this scenario, following the METROMEX results (Changnon 1981), a mild, early afternoon urban-heat-island temperature increase. In urban areas, typically the daytime specific humidity reduces. In order, however, to provide an extreme scenario from the electric-load demand point of view, we assumed that such reductions in specific humidity are offset by a contribution of moisture from the vegetated coastal area. Evaluation of ΔE for various ranges of ΔT and Δq in the two adopted scenarios were carried out using regression equation (5) in Table 1.

Adopting the first scenario (see a_1, a_2, and a_3 in Table 2) for the extreme situation of changes in *q* and *T*, a_3: $\Delta q = 3$ g kg^{-1} (as indicated in Fig. 4) and $\Delta T = -0.5$°C, we find only a mild potential increase in the peak-hours' load of 47 MW (1.72% of the average peak load) for the summer of 1987 and 71 MW (2.41%

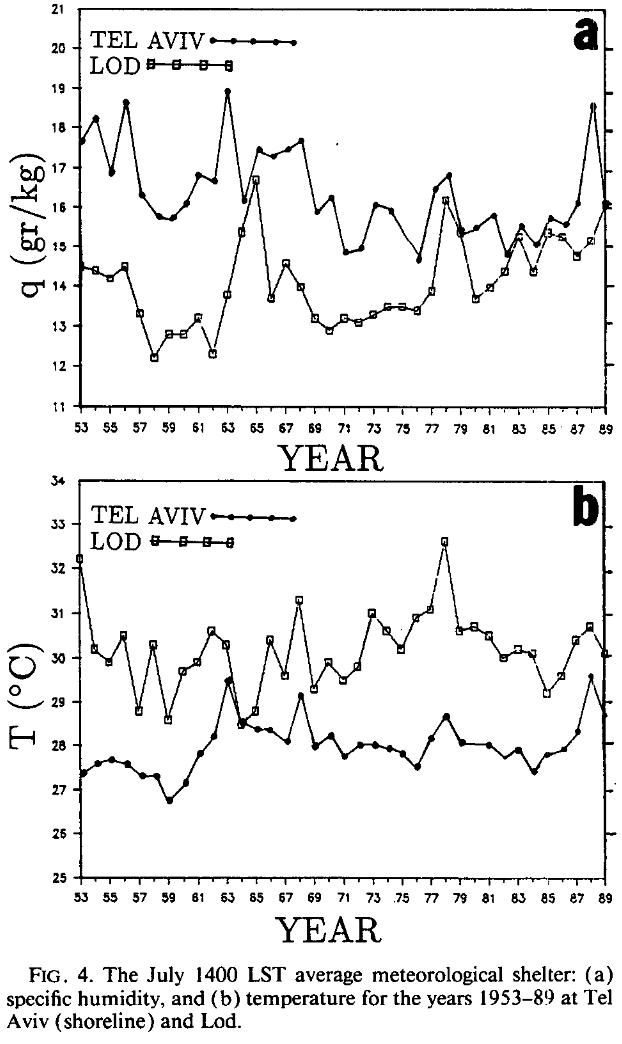

FIG. 4. The July 1400 LST average meteorological shelter: (a) specific humidity, and (b) temperature for the years 1953–89 at Tel Aviv (shoreline) and Lod.

of the peak load) for 1988 as a result of the change in land use. For smaller Δq (a_1 and a_2), the change in ΔE becomes negligible. Further expansion of urbanization in cultivated areas, or reduction of the irrigated regions (due to water shortages) as is the current trend, would reduce the aforementioned increase in moisture and its impact on future summer peak electric load. Adopting the second scenario, the estimated modifications in E (b_1 and b_2) are lower than those indicated for a_3. The real impact of the land-use change on E is suggested to be constrained by the maximum values obtained in the above two scenarios.

c. *Impact of doubling atmospheric CO_2 on the summer peak electric load*

Increased attention has been given to evaluating various potential economic implications related to doubling of the atmospheric CO_2 ($2 \times CO_2$; e.g., Cohen 1990). Tentatively, general circulation model (GCM) simulations indicate that $2 \times CO_2$ would result in a global average increase of several degrees Celsius in shelter temperature and would increase the air moisture (Schneider 1989). Various GCM $2 \times CO_2$ predictions for the eastern Mediterranean suggest that, toward the end of the next century, the increase in shelter temperature during the summer could be as high as 4°C with an associated increase in the specific humidity of 10%–15% (Segal et al. 1992b). Considering, however, the recent controversy about the accuracy of GCM predictions (Lindzen 1990) or, alternatively, the gradual onset of the impact, milder changes should also be considered. Table 3 illustrates various scenarios of $2 \times CO_2$ for which the 1987–88 relations of $E = E(C)$ [regression equation (4) in Table 1] for electric-load estimations were adopted. For eventual slight increase in T and T_w (1° and 0.75°C, respectively) due to $2 \times CO_2$, or alternatively in the early stage of the $2 \times CO_2$ impact, the increase in E is 70–80 MW. For intense increases of $\Delta T = 4$°C and $\Delta T_w = 3$°C, the anticipated increase in E is 280–325 MW, which is approximately 10% of the average summer peak electric load.

TABLE 2. Estimated changes in the peak-hours' electric load ΔE resulting from various range modifications in the shelter temperature ΔT and specific humidity Δq attributed to land-use change in the coastal plain of Israel [based on the regression equation (5) in Table 1]. The ΔE values in parentheses are percentages of the average summer peak electric load.

Case	ΔT (°C)	Δq (g kg^{-1})	ΔE87 (MW)	ΔE88 (MW)
a_1	−0.5	1.0	2 (0.07%)	5 (0.17%)
a_2	−0.5	2.0	23 (0.83%)	38 (1.29%)
a_3	−0.5	3.0	47 (1.72%)	71 (2.41%)
b_1	0.0	1.0	24 (0.88%)	52 (1.76%)
b_2	0.5	1.0	51 (1.86%)	61 (2.07%)

TABLE 3. Estimated changes in the peak-hours' electric load ΔE resulting from various increases due to $2 \times CO_2$ in the shelter temperature ΔT and the wet-bulb temperatures ΔT_w [based on regression equation (4) in Table 1]. The ΔE values in parentheses provide percentages of the average summer peak electric load.

ΔT (°C)	ΔT_w (°C)	ΔE87 (MW)	ΔE88 (MW)
1	0.75	70 (2.56%)	81 (2.74%)
2	1.5	140 (5.11%)	162 (5.49%)
3	2.25	209 (7.63%)	243 (8.24%)
4	3.0	279 (10.2%)	324 (10.98%)

4. Conclusions

As evaluated in this note, a conceptual analogy can be drawn between the effect of the meteorological conditions on the summer, early afternoon air-conditioning energy need in Israel and their effect on the outdoor biometeorological comfort feeling of human beings. It was assumed that (i) a functional relation exists between the electric load needed for air conditioning and biometeorological indices that express comfort feelings of human beings, and (ii) a functional relation exists between the electric load and meteorological parameters that are used in biometeorological indices. Preliminary bulk evaluations reported in this note indicate that high correlations are obtained when the first assumption is adopted. The highest correlations were obtained for the latter assumption.

Climate change has potential impact on the electric load needed for air conditioning. Climate change due to modification of land use was found to cause mild increase in the load. It was estimated that the potential impact of $2 \times CO_2$ is at most an increase of 10% of the peak-hours' electric load in Israel. It is most likely that, unrelated to climatic changes, the relative consumption of electric energy for air conditioning in Israel will increase gradually due to socioeconomic causes. Therefore, the relative impact of such climatic change on the future total load is likely to be somewhat higher than estimated in the present note.

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