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HEATING DEGREE–DAYS FOR ARID REGIONS

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Abstract—Arid regions generally have great temperature differences between day and night. Heating degree–days are indicative of the need to heat buildings. We show that the maximum and minimum temperatures are linearly related at high significance levels. Degree–day calculations using only maximum temperature records are presented and risk assessments are explained. Regional variations of monthly degree–days are mapped and their relations to local topography examined. © 1998 Elsevier Science Ltd. All rights reserved

1. INTRODUCTION

Precipitation and temperature records are indicators of regional climates. Temperature variations influence agriculture, architecture, power generation and use, melting of snow and the effects of freezing and icing on transportation systems, flowering and harvesting dates, electrical power for heating or cooling in large cities and air-conditioning services. All of these depend on daily temperatures and system design values.

In [1], a normal Gaussian distribution is assumed for the temperature-probability distribution function and calculations are performed to estimate the degree–days. Equations for mean monthly degree–days and standard deviations were obtained in [2]. It was observed [3] that heating degree–days are directly related to site-specific total energy use and heating-oil consumption for individual residences. Mean daily degree–hours may be expressed as a function of the standardized, truncated, normal distribution of the difference between the base and hourly mean temperatures [4]. For any country, predictions of future heating-energy demands depend on historical averages and also on anticipated climate [5].

Our main purpose here is to develop a simplified procedure for degree–day calculations based only on maximum temperatures in arid regions. Degree–days in the form of contour maps are presented for the Kingdom of Saudi Arabia (KSA).

2. DEGREE–DAY DEFINITION

The definition of degree–day requires truncation of a temperature series. A schematic of temperature changes is shown in Fig. 1. The actual temperature series may be treated statistically and probabilist-

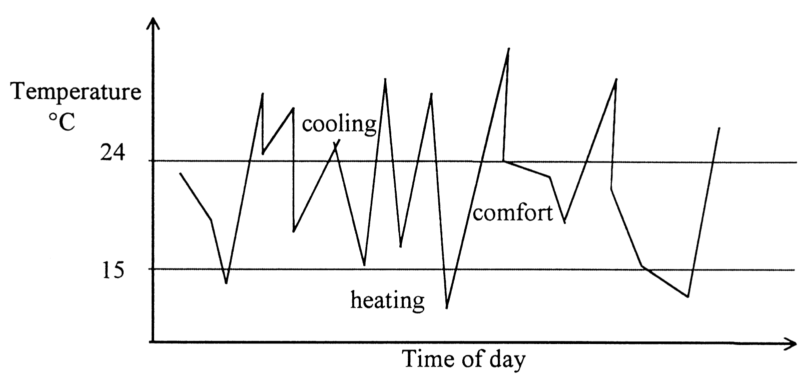

Fig. 1. Temperatures below which heating and above which cooling are required to maintain comfort temperatures vs time of day.

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ically in order to find the probability distribution function of the temperature at any station, in addition to low-order statistical parameters such as the mean, standard deviation, skewness coefficient, etc. The following definitions relate to Fig. 1. The method for calculating degree–days at any given truncation level from the monthly average ambient temperature is briefly presented in [6]. If the outside temperature T_o at time i is greater than the inside temperature T_i, the required temperature reduction by cooling is

$$T_{ci} = (T_i - T_o)^+ . \tag{1}$$

Similarly, the temperature rise needed for heating is

$$T_{hi} = (T_i - T_o)^- . \tag{2}$$

The temperature differences ($T_i - T_o$) are related to heat loss through insulation for a building. The recommended inside temperature T_i is a function of the time of day, use, degree of occupant activity, duration of occupation, presence of radiant heat sources, and outside conditions. Recommended indoor design conditions are given in [7].

An uninterrupted sequence of cooling (heating) amounts preceded and succeeded by at least one heating (cooling) amount is called the cooling (heating) duration. For a month, the summation of the daily cooling amounts is referred to as the monthly cooling degree–day (CDD) value in the literature and if the number of days in the month is m_d, then in general the cooling degree–day is defined as

$$CDD = \sum_{i=1}^{m_d} T_{c,i}, \tag{3}$$

which has the same unit as the temperature. In Eq. (3), i indicates the initial time of the cooling period. Similarly, the monthly heating degree–day is given by

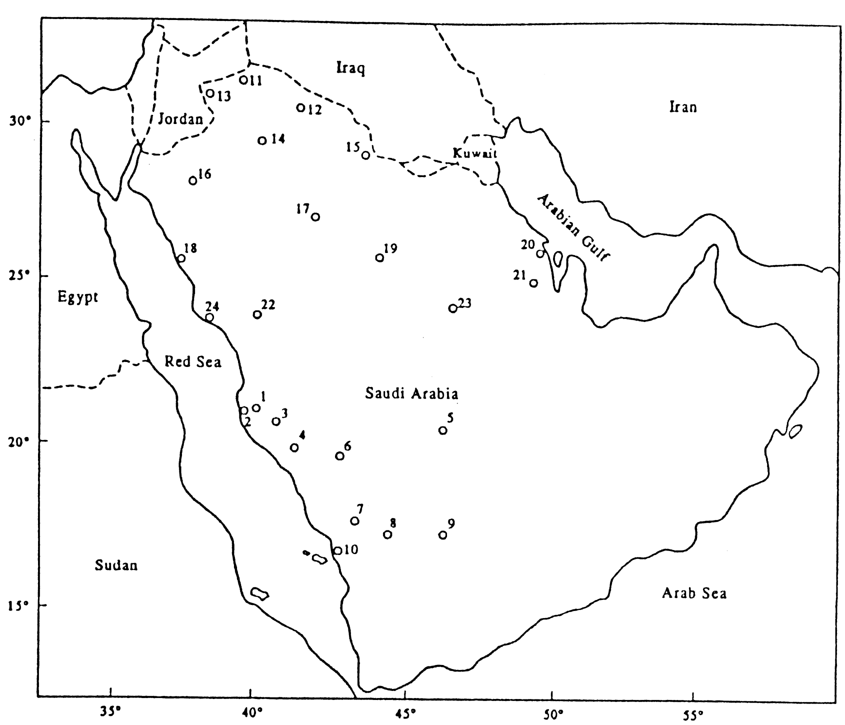

Fig. 2. Location map (after El-Shaarawi and Al-Masri [8]).

$$HDD = \sum_{i=1}^{m_h} T_{h,i}, \tag{4}$$

where m_h is the monthly number of days in the month.

3. APPLICATIONS

Tables of daily weather data, monthly means, maxima and minima, as well as yearly average temperatures are available from [8] for the Kingdom of Saudi Arabia and for 15 years. Station locations are shown in Fig. 2. It is obvious that measurements are made frequently along the Red Sea coastal plane and in the east at significantly inhabited locations.

Fig. 3 shows scatter diagrams of monthly maximum and minimum temperatures. It is apparent that the points lie close to a straight line. Thus, the regression line is

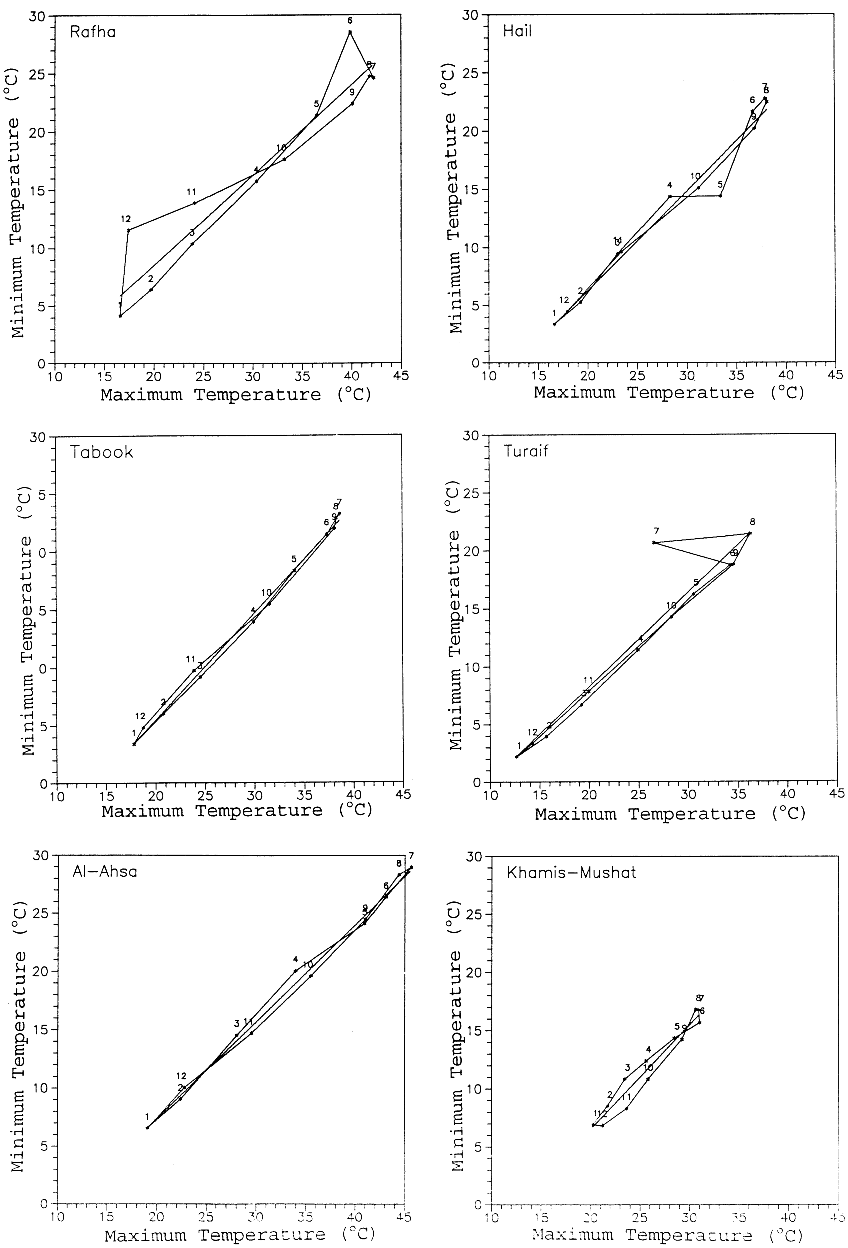

Fig. 3. Maximum–minimum temperature relations for several locations.

$$T_{min} = \alpha T_{max} + \beta, \quad (5)$$

where α and β are constants. In many calculations, the average temperature

$$\bar{T} = (T_{max} + T_{min})/2 \quad (6)$$

is used. Addition of T_{max} to both sides of Eq. (5) leads to

$$\bar{T} = aT_{max} + b, \quad (7)$$

where

$$a = (1 + \alpha)/2, \; b = \beta/2. \quad (8)$$

Following calculation of monthly *HDD*s from Eq. (4), we obtained the empirical *HDD*s fit

$$HDD = T_i - aT_{max} - b. \quad (9)$$

Table 1 shows the *a* and *b* coefficients for each one of the 24 stations considered in this study.

In order to obtain degree–day values at non-measurement stations, monthly *HDD* maps are prepared. These are shown in Fig. 4 and Fig. 5 for regional assessments. For these maps, 24 station locations are used as given in [8].

The maps of Fig. 4 and Fig. 5 lead to the following conclusions: (a) The highest monthly *HDD*s appear in the north and reflect cold climatic features of sub-tropical areas resulting from maritime and especially continental polar air masses. (b) From November to January, the monthly *HDD* area increases towards the south with increasing *HDD* values over the entire region. This result is caused by the penetration of Mediterranean air masses towards the equator during the winter period. (c) There are local patterns that overlie the general regional patterns at the Qurait and Turaif locations in the north,

Table 1. Degree-day coefficients for KSA stations.

Station No.	Station names	*a*	*b*	R^2
1	Makka	− 6.046	0.792	0.97
2	Jeddah	− 5.843	0.849	0.97
3	Taif	− 15.737	1.097	0.98
4	Al-Baha	− 13.306	1.015	0.93
5	Sulayel	− 11.583	0.912	0.99
6	Bisha	− 19.541	1.137	0.99
7	Khamis-Mushat	− 11.488	0.901	0.96
8	Nejran	− 16.209	1.044	0.99
9	Sharurah	− 13.607	0.946	0.97
10	Gizan	− 7.521	0.965	0.95
11	Turaif	− 8.023	0.814	0.91
12	Arar-Bedana	− 10.632	0.896	1.00
13	Gurait	− 10.820	0.764	0.99
14	Al-Jauf	− 13.359	0.946	0.89
15	Rafha	− 6.974	0.774	0.91
16	Tabook	− 12.989	0.922	1.00
17	Hail	− 10.832	0.855	0.98
18	Al-Wajh	− 10.910	1.026	0.91
19	Gassim	− 9.074	0.823	0.99
20	Dhahran	− 6.379	0.805	1.00
21	Al-Ahsa	− 9.219	0.832	1.00
22	Medina	− 9.592	0.886	0.99
23	Riyadh	− 10.994	0.901	0.99
24	Yanbo	− 17.614	1.159	1.00
	Average	− 11.179	0.919	0.97
	Maximum value	− 5.843	1.159	1.00
	Minimum value	− 19.541	0.764	0.89
	Standard deviation	3.650	0.112	0.03

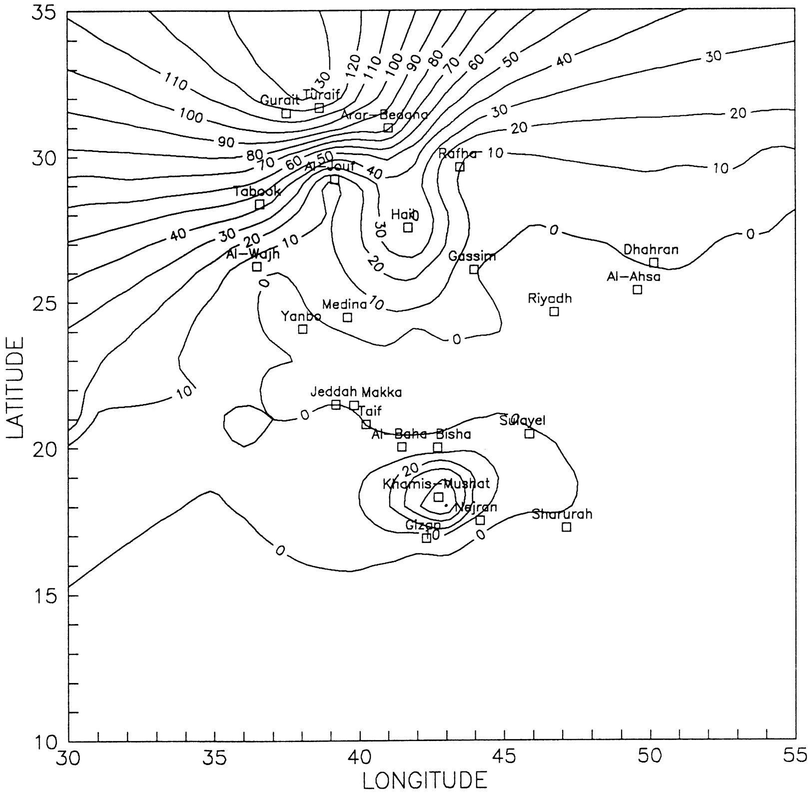

Fig. 4. Heating degree–day map for November.

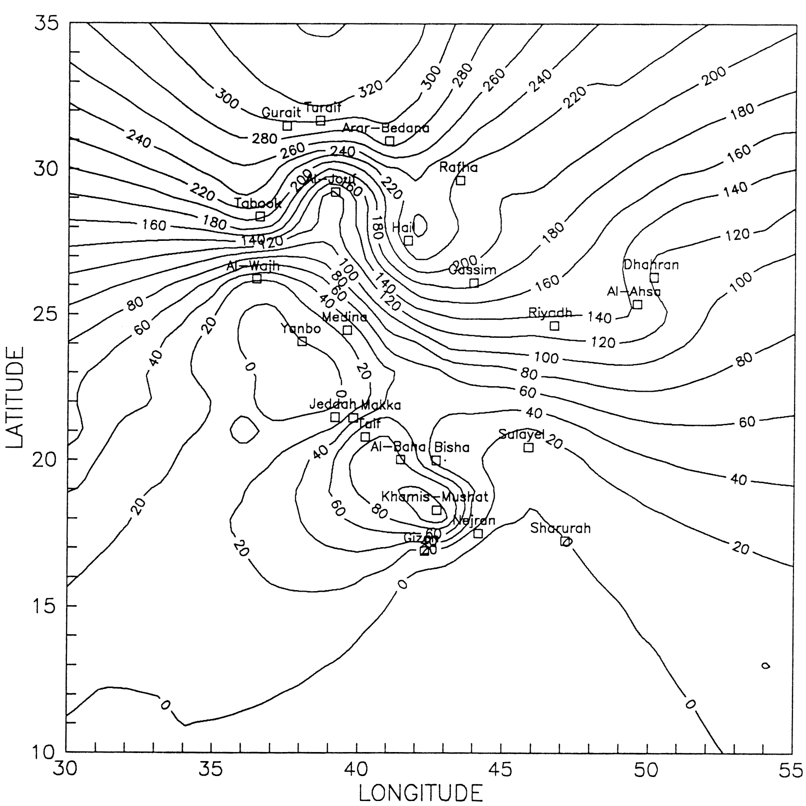

Fig. 5. Heating degree–day for January.

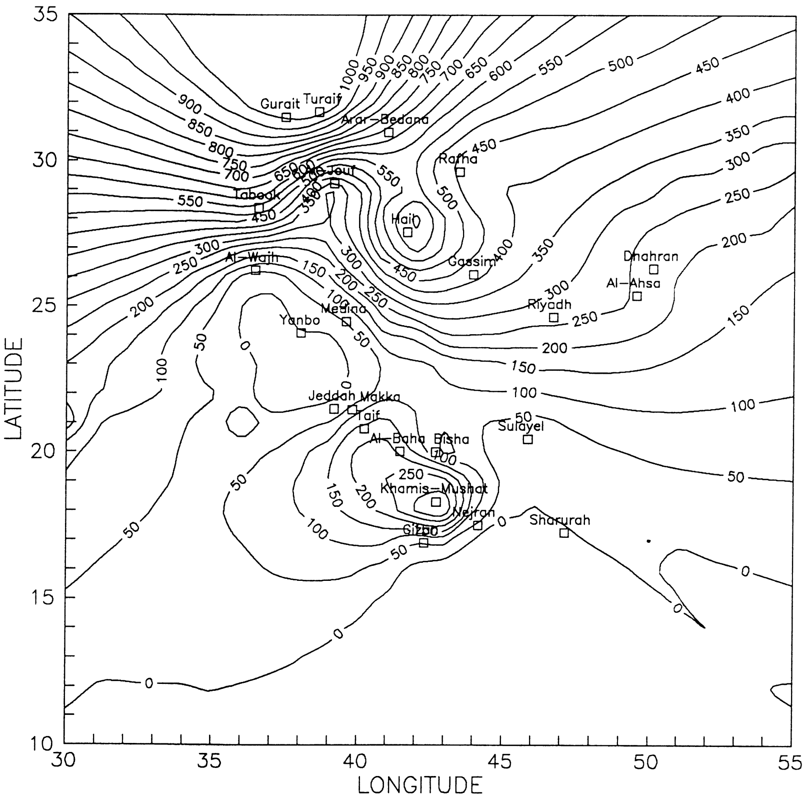

Fig. 6. Annual heating degree–day map.

at the Hail and Jauf areas in the middle and at the Khamis-Mushat locality in the south. In the middle area, excessive *HDD*s are due to the Sahara and continental arid-*HDD*s region climate with large temperature differences between day and night. Finally, in the Khamis-Mushat location, high *HDD* requirements are due to local topographic elevations reaching 2500 m and causing cooling of the moist air that rises from the Red Sea during the day. This locality receives one of the maximum rainfalls in the KSA [9,10]. (d) Starting from the Al-Wajh location along the Red Sea escarpment towards the south, contour lines run parallel to the Red Sea and reflect the Red Sea escarpment effect on the local climate and consequently on the monthly *HDD*s. However, towards the north of the Al-Wajh location, contours for each month are perpendicular to the Red Sea depression, which is caused, again, by penetration of a Mediterranean-type climate towards the south. (e) The Holy City of Makkah and the industrial city of Yanbo, as well as the trade center Jeddah, hardly need heating energy because these are areas with the lowest degree–days (cf. the maps). The similar annual *HDD*s in Fig. 6 are averages derived from five maps in previous figures.

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