Z. MIECZKOWSKI University of Manitoba

THE TOURISM CLIMATIC INDEX: A METHOD OF EVALUATING WORLD CLIMATES FOR TOURISM

In this essay a method of computing tourism climatic indices (TCIs) is described. These indices represent a quantitative evaluation of world climate for the purposes of international tourism. A series of rating systems is developed to provide a systematic basis for assessing the climatic elements that most affect the quality of the tourism experience. The problem of weighting climatic variables in the TCI formula is also discussed. Monthly TCIs have been computed for 453 meteorological stations throughout the world, and the results have been generalized in 12 monthly world maps.

L'article offre une méthode pour calculer des indices climatologiques touristiques (ICT), qui représentent une évaluation quantitative des climats mondiaux, destinée aux besoins du tourisme international. On développe une série de systèmes d'évaluation d'éléments climatologiques, fournissant ainsi une base systématique pour évaluer lesquels de ces derniers influencent le plus la qualité de l'expérience touristique vécu. L'article soulève aussi les problèmes réliés aux valeurs relatives, soient les poids, des variables qui entrent dans la formule de l'ICT. Des valeurs mensuelles ont été compilées pour 453 stations météorologiques à travers le monde, et les résultats sont présentés, en forme généralisée sur une base mensuelle, dans douze cartes mondiales.

This study belongs to a category of research that aims at the quantitative evaluation of natural or social phenomena by representing them in the form of indices. Heterogeneous components are assessed on specially devised rating schemes and weighted according to their relative importance. The numerical values of all the components are then summed as an index. A good illustration can be seen in the attempts to quantify the elusive notion of quality of life (cf Smith 1973; Coates, Johnston, and Knox 1977; Minnesota Department of Economic Research 1976; Boyer 1981). In various US cities and states, for example, quality of life indices have been devised to include such variables as climate, pollution, level of income, crime, availability of cultural and educational institutions, and the state of health care and social services. Another interesting example of the integration into a single index of heterogeneous variables, both natural and human, is the nordicity index computed for Canada by Hamelin (1980, 78–80).

The purpose of this essay is to propose a tourism climatic index (TCI), as a composite measure of the climatic well-being of tourists. Although climate is only one of the variables that cause tourists to travel, many tourists are entirely motivated by climatic considerations. Even those whose motives for travel are definitely non-climatic, as in educational or cultural tourism, have an interest in selecting times of the year when their climatic well-being is likely to be at its best. A TCI can provide this information, especially for international tourists who may not know much about the climatic conditions they can expect to encounter in various parts of the world at different times of the year. If tourists wish to visit a certain area, they can choose a time of the year when climatic conditions are at their optimum. Alternatively, if they have their vacations at a fixed time, they may select an area that then offers the most suitable climatic conditions.

TCIs also provide a second, indirect benefit, in that they may help to promote better use of climatic resources in various parts of the world. This is especially

The Canadian Geographer / Le Géographe canadien 29, no 3 (1985) 220–33

important for developing countries that have entered the international tourist market, in large part on the strength of their climatic attractions. The growth of tourism in some developing countries is already contributing to a more equitable distribution of wealth in the world. It may also bring benefits for developed countries, if acute seasonal pressures on valued natural and human environments can be alleviated by redirecting some of the tourism demand toward developing countries.

Classifications of Climate from a Human Point of View

Following the pioneering, nature-oriented classifications of climate by Köppen (1931), Thornthwaite (1931 and 1948), and Trewartha (1954), climatologists turned their attention to the evaluation of climate from the point of view of man. These human-oriented classifications have been interdisciplinary, combining applied climatology with the modern achievements of human biometeorology and bioclimatology. The work of the following is particularly relevant in the present context: Brazol (1954), for his map of isochrones of comfort months in Argentina; Maunder (1962), who developed a human classification of the climate of 22 stations in New Zealand; Burnet (1963), for his human climatic regionalization of seaside resorts in France; Terjung (1966), who applied his 'bioclimatic classification based on man' to the conterminous United States; Davis (1968), who applied his concept of maximum comfort to Great Britain; Gates (1973), who determined zones of comfort in relation to temperature and humidity as viewed by the people of the United States; and Kandror, Demina, and Ratner (1974), who developed a system of physiological-climatic regionalization of the Soviet Union based on annual frequencies of various types of weather.

In all these classifications, the aim was to evaluate the climatic comfort of the permanent residents of the investigated areas. The data were mainly annual or, in some cases, seasonal averages of various climatic elements such as temperature, humidity, rainfall, insolation, and wind. Then, in the 1950s and 1960s, the growth of tourism, especially international tourism, created a demand for a different type of human-oriented climate evaluation. Its prime concern was for the needs of temporary visitors who are not interested in annual climate but in climatic conditions during specific times of the year. Studies that fit this category have been carried out by Heurtier (1968), who investigated the 'touristic climate' of western and Mediterranean Europe for the period June–September, and Crowe (1976), who classified the climate of Canada's Northwest Territories for the purposes of tourism and recreation. As yet, however, there has been no attempt to develop a method for evaluating climate for tourism on a global basis. It is here that the concept of the tourism climatic index holds particular promise. The development of a TCI therefore constitutes the first step in an attempt to evaluate the climates of the world for the purposes of tourism. Since the feasibility and necessity of such a project have been discussed elsewhere (Mieczkowski 1983), attention in this essay will be focused on conceptual, methodological, and empirical issues.

Selecting and Rating Climatic Elements as Variables for the TCI Formula

It is scarcely necessary to remind geographers that climate results from complex interactions among a set of elements. Yet tourist agencies commonly report information on isolated elements, such as temperature or sunshine, and disregard other factors, thereby distorting the real climatic situation. The problem addressed in this essay is how to integrate into a single index all the climatic elements relevant to the tourism experience. This synthetic measure, the tourism climatic index, should reflect objective reality as closely as possible; that is, it should be based on a systematic assessment of the favourable and unfavourable effects that climate can be expected to have on an 'average' tourist visiting a particular locale at a particular time of year. It is also necessary to be able to summarize these various effects in a formula from which TCI values can be computed.

To construct such a formula, two conditions have to be satisfied. First, appropriate variables have to be determined, a procedure that requires an evaluation of the elements of climate in the context of tourist well-being. Temperature, humidity, precipitation, sunshine, and wind are the basic elements that have to be provided for, but of far greater importance than any single element is the complex parameter known as thermal comfort.[1] This has a decisive influence on national and international tourist flows, and largely controls the duration of the tourist season, especially in mid- and high-latitude regions.

Second, standardized rating systems have to be de-

vised to provide a common basis of measurement for the separate variables. For statistical convenience, a value of 5.0 has been assigned to the optimal condition in each case, scaling down to zero (and sometimes lower) in full or half units. The chosen variables are likely to differ in their importance to tourists, and will have to be weighted accordingly.

These procedures and their rationale will be described in this section of the essay, beginning with the concept of thermal comfort, followed briefly by other climatic elements.

THERMAL COMFORT VARIABLES

For the present purpose, the analysis of thermal comfort involves the simultaneous evaluation of two climatic elements, temperature and humidity. In reality, however, the level of thermal comfort is influenced by 6 factors, 4 of which are environmental (i.e. concerned with the thermal environment) and 2 human. They are: air temperature (dry-bulb); water vapour pressure or relative humidity of ambient air; mean radiant temperature; wind velocity; thermal resistance of clothing (clo value);[2] and activity level, which influences the amount of heat produced in the body.

Different combination of the six variables render different levels of thermal sensation. The relations are expressed in an equation for thermal comfort (Fanger 1970, 41 ff), but the equation will not be described here since it is not necessary to use it in full in the construction of the TCI formula. Only two of the variables, dry-bulb temperature (DBT) and relative humidity (RH), are considered to be essential; the others will be treated as constants. Thus, mean radiant temperature is assumed to equal dry-bulb temperature, and wind velocity is assumed to be zero. Thermal resistance of clothing is basically assumed to be 0.6–1.0 clo for the optimal comfort zone. For colder temperatures, however, seasonal dress has to be assumed, an approach taken by Kandror, Demina, and Ratner (1974). It weakens the assumption of 'constant' for the clothing factor but does not distort the values. Finally, an activity level equivalent to walking outdoors at a speed of 2.5–3.0 km/h, or about 2 mets, has been assumed to be appropriate for tourists.[3]

The decision to treat the two remaining factors, dry-bulb temperature and relative humidity, as the critical variables for thermal comfort is amply supported in physiological research. For some 50 years now, there have been attempts to correlate these two factors. In this narrower usage, thermal comfort expresses the reaction of the human body to the temperature–humidity relationship; it is also defined in terms that declare it to be a psychological parameter as well as a physiological one. According to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE 1974, 3), 'Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment.' This makes it difficult to measure, but, for practical purposes, thermal comfort means that a person is in a state of thermal neutrality in which it is impossible to tell if a warmer or cooler environment would be preferred. Hence, it is commonly assumed that thermal comfort equals thermal neutrality (Fanger 1970, 14).

The standards for thermal comfort are subject to change over time. Between 1914 and 1966 the optimal DBT increased by about 6c° for RH = 40 per cent (Rohles and Nevis 1973, 731), while the effective temperature for comfort increased from 18°c to 20°c between 1923 and 1941 (ASHRAE 1972, 136). According to Nevis (1973: 435), heating season design temperatures increased from 20°c in 1914 to 22.6°–25.6°c in 1973, and 'current US practice establishes the same comfort levels for heating and cooling at 25°c and 50% RH.' The reasons for these variations seem to be cultural and psychological; e.g. changes in clothing habits (a tendency to wear lighter clothing) and living and eating patterns, less outdoor work, better heating and cooling systems, and rising expectations of comfort.

The condition of thermal comfort does not represent any specific combination of temperature and humidity. Rather, there is a comfort zone, or zone of contentment, that can be determined empirically by physiological research using a large number of subjects. If people were thermally equal, one research subject would suffice, but human thermal sensations are subjective, so it is impossible to satisfy everyone in exactly the same thermal environment. It is also unrealistic to try to establish hard-and-fast bioclimatic norms. The task is rather to identify certain zones of objective thermal conditions, based on combinations of DBT and RH, and to determine the subjective thermal sensations that are more or less applicable to these conditions. To achieve this aim, physiologists have conducted tests in artificial thermal conditions with large numbers of healthy subjects (in some

cases, well over one thousand). The optimal conditions of the thermal comfort zone, or the 'modal comfort envelope' as it has come to be called by ASHRAE, are those that yield the highest possible percentage of favourable thermal sensations. The percentage of dissatisfied subjects in this zone is normally between 5 and 20 per cent.

In the 1960s and early 1970s, particularly important physiological research into thermal comfort zones was undertaken in the ASHRAE Environmental Test Chamber at Kansas State University. The results of these experiments have been accepted as the basis for the rating system of thermal sensations or thermal comfort, which constitutes the most important component of the TCI formula. At the same time, certain modifications were required, because the ASHRAE experiments were oriented to the needs of the heating and air-conditioning industry. They therefore refer to indoor conditions, not outdoor climates, and the subjects were at rest or engaged in light sedentary activities.

It has been discovered that thermal comfort or discomfort, indoors or outdoors, is not a function of the body's core temperature but is largely influenced by skin temperature (Danilova 1977; Krawczyk 1979). This averages about 33°C in conditions of thermal neutrality (ASHRAE 1972, 132), and so a correlation between an average skin temperature of 33°C and the sensation of thermal comfort can be assumed (Fanger 1974: 314). It has been found, for instance, that an average skin temperature of 33°–34°C is comfortable for a sedentary subject with an activity level of 1 met; a higher skin temperature under the same circumstances means discomfort. However, if levels of activity are increased, the subject may feel comfortable with a lower skin temperature (ASHRAE 1972, 132 and 138; Fanger 1974, 314). Danilova (1973, 165) suggested a comfort range of 31°–33°C for light work outdoors.

Three Soviet researchers, Kandror, Demina, and Ratner (1974) went a step further, devising a parameter called 'average weighted skin temperature' which correlates well with levels of thermal sensation (thermal comfort) rated in points. This led them to conclude that human thermal condition can be adequately characterized by the level of average weighted skin temperature which reflects the thermal content in the 'envelope' of the body, assuming that the temperature level of the 'core' of the body remains stable (i.e. is not subject to extreme meteorological influences or intensive muscular activity). According to their results, an average weighted skin temperature of 31°–33°C is closest to the optimal thermal sensation in air temperatures above 0°C (Kandror, Demina, and Ratner 1974, 91–2). Even with temperatures below freezing, the average weighted skin temperature drops insignificantly to 31–32°C (Kandror, Demina, and Ratner 1974, 84). The slightly lower skin temperatures in the Soviet tests arise from the fact that their subjects were engaged in light work outdoors, whereas the Western researchers tested their subjects in conditions of rest indoors.

Measurement of thermal comfort: In the physiological literature the degree of thermal comfort (or discomfort) is measured by the comfort index, a numerical parameter defined as the 'psychophysiological sensations of the average person in terms of temperature and humidity' (Terjung 1968, 119). In turn, this composite measure makes use of the concept of effective temperature (ET), which, in a simplified way, is a single index of dry-bulb temperature and relative humidity.[4] When drawn on a psychrometric chart, as in Figure 1, the lines of effective temperature represent lines of equal physiological thermal sensation. In other words, effective temperature means the temperature that is really experienced. The Russian term is *oshchushchayemaya temperatura*, literally 'temperature really felt.' Some 60 years of research have now gone into this notion, but the most recent adjustment of the official arrangement of ET lines occurred in 1972 (ASHRAE 1974). The rating system of thermal sensations (thermal comfort) for the TCI formula is based on these modified standards.

The comfort index has proved a reliable measure of the degree of comfort, especially in the range of RH 30–70 per cent. In more general terms, researchers agree that the optimum of comfort for a lightly dressed, seated person lies around 20°–27°C DBT and between 30 and 70 per cent RH, although 20–80 per cent RH seems to be tolerable (Heurtier 1968, 86). The reliability of the comfort index decreases toward the extremes of RH, which may be regarded as intrinsically uncomfortable. That is, very high RH and very low RH induce discomfort at almost any temperature (Terjung 1966, 151; Heurtier 1968, 86).

Low air humidity levels are reputed to cause discomfort by drying the nasal mucus, although this has not been confirmed by researchers experimenting with low

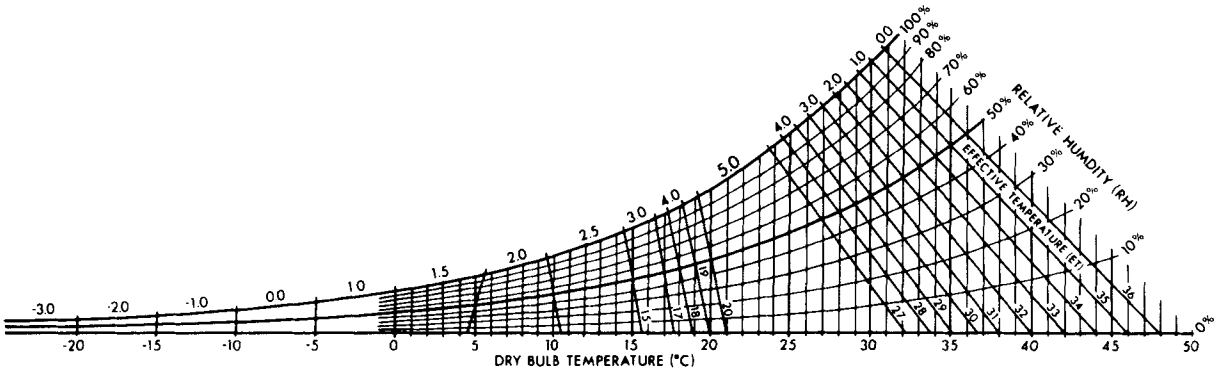

Figure 1
Thermal comfort rating system for the tourism climatic index, modified from ASHRAE (1972) standards of effective temperature

humidities (Elkins and Longley 1968; McIntyre 1978). On the contrary, Anderson, Lundqvist, and Jensen (1974, 323) came to the startling conclusion 'that there is no physiological need for humidification of the air.' High air humidity seems to have a greater influence on the level of thermal comfort, especially at higher temperatures. It impedes the dissipation of body heat, thus creating the condition called hyperthermia (overheating). The experiments of Griffiths and McIntyre (1973, 463) indicate that a temperature of 28°C constitutes a kind of threshold, when the research subjects find high RH 'more oppressive, more moist and less comfortable.' In my opinion, however, 28°C should not be regarded as a universal threshold but rather as an indicator of a transition zone that lies below this value. I suggest that DBTs of 24°–28°C define this transition zone. Below this range the majority of people sweat little or not at all when lightly dressed and in sedentary positions; increases in RH have little effect on them.

The available research on effective temperature leads to the conclusion the RH plays a more important role at high temperatures than at low. This is reflected in Figure 1 in the decreasing slopes of the ET lines from right to left. Gregorczuk and Cena (1967, 145), using the pre-1972 ET standards, even suggested that the influence of RH on sensations of warmth is applicable only for ETs over 10°C, with extreme discomfort starting at 28°C ET. ETs over 31°C create stressful conditions for the body, and ET 35°C constitutes the upper limit of human tolerance.

At the same time, the left side of the psychrometric chart cannot be ignored completely. At temperatures between approximately 0°C and 10°C there is a slight negative correlation between temperature and humidity. Terjung (1966, 153) puts it this way: 'The ET lines which in the warmer portions of the continuum tend to emphasize and reinforce the effect of high temperature and high moisture, tend to do the opposite from about 8°C dry-bulb on towards the colder portions of the chart.' The practical experience that wet cold is more uncomfortable than dry cold leads me to the conclusion that between about 0° and 8°C DBT, the sensible warming of temperature is reduced by high humidity. Below 0°C DBT the RH loses its influence on comfort, as long as the negative effect of humidity on the insulating power of clothes in low temperatures is not allowed for. For this range the measure of comfort, discounting the effects of wind, is exclusively and directly dependent on DBT. Indeed, the decreased importance of RH in temperatures characteristic of mid-latitude climates has induced some authors to ignore it for regionally limited studies. For example, Camuset (1975: Annexe E, 2–3) used a simple (certainly too simple) formula of a modified climatic index (CI) computed for major French cities and resorts: CI = monthly hours of insolation × monthly mean temperature / monthly rainfall.

Thermal comfort rating system: In summary, to establish the rating system by which to assess the level of thermal comfort for the TCI, the two variables of dry-bulb temperature and relative humidity were selected and the ASHRAE thermal comfort standards were reviewed (ASHRAE 1972; Rohles and Nevis 1973; Rohles 1974). Following from this, the 1972 ASHRAE standard for

optimal comfort (thermal neutrality) was accepted as the optimal rating zone, although some modifications were required, for three reasons. Radiant temperature, although treated as a constant here, influences the level of thermal comfort outdoors, especially in hot air, where it increases the DBT.[5] Personal standards of comfort accept rather lower temperatures outdoors than they do indoors (Ambler 1968, 295). The production of body heat is greater for a person walking slowly than for a sedentary one.

On Figure 1, the adjusted ASHRAE thermal neutrality zone constitutes the optimal zone for the TCI, with a rating of 5.0 points. The rating scale then decreases progressively on both sides of the optimal zone, according to an arbitrarily assigned set of ordinal values. The boundaries between the rating zones are the ET lines derived from the ASHRAE comfort chart (ASHRAE 1972, 137). The scale ranges down to −3.0. It is divided into half-point cohorts between 1.0 and 5.0, and one-point cohorts between −3.0 and 1.0.

A final observation about the ETs pertains to their usefulness for rating adjustments to various levels of recreational activity. Although these variations were not taken into account here, Terjung suggested that the sloped of ET lines become more horizontal with increased activity (Terjung 1966, 147). Kandror, Demina, and Ratner (1974, 52) are of the opinion that the ET concept is useless in this respect; they stress the impossibility of using it for various types of work. I think that a more practical solution lies in shifting the rating zones as the production of body heat increases with increased activity levels, thus producing different thermal comfort requirements. Different environmental conditions may contribute to change, as well; e.g. the rating scale for beach activities could be shifted by one unit to the right, reflecting the changed thermal requirements.

Rating thermal comfort for the TCI: The final step in this procedure was to decide on the most appropriate measures of thermal comfort or ET from the standpoint of tourists. Two indices were therefore developed; both depend on monthly normals of DBT and RH.

The first measure, the daytime comfort index, combines the variables of maximum daily DBT and minimum daily RH. Both usually occur between 1200 and 1600 hours, which is also when tourists tend to be most active outdoors. For this reason, the daytime comfort index is considered to be the single most important indicator of their climatic well-being. It carries a weight of 40 per cent in the TCI formula.

The second measure, the daily comfort index, employs two different variables – mean daily DBT and mean daily RH. This index carries only 10 per cent in the TCI formula because it reflects conditions of thermal comfort over the full 24 hours, including the night hours when most tourists stay indoors. It is therefore considered to be a less valid measure than the daytime comfort index, although it does allow for the possible effects of lower night-time temperatures. Hounam (1967, 156), for one, regards diurnal variation as an importnat comfort factor: 'The physiological effect of a cool night / hot day sequence is important in daytime comfort because after a comfortable night one is better able to stand up to an uncomfortable day.'

To obtain the indices, the values of monthly normals for the desired pair of variables are plotted on Figure 1. Thus, for example, the combination of a temperature normal of 28°c with 30 per cent RH gives the optimum rating (index) of 5.0. The same DBT with 40 per cent RH gives an index score of 4.5, and with 70 per cent RH, only 3.5.

OTHER CLIMATIC ELEMENTS IN THE TCI

Precipitation: Precipitation has a significant effect on the climatic comfort of tourists, both through the total amounts that fall and through their distribution in time. Persistent light or moderate rain, though producing a relatively small total amount, is more difficult to endure than a thunderstorm with a concentrated period of heavy rain. While it is sometimes impossible for sightseers to resume an activity immediately (e.g. it is not possible to continue game viewing in African national parks after a heavy rainfall on lateritic soils, since the roads remain impassable for a relatively long time), these situations are exceptional. The rule is that if such thunderstorms occur only a few times in a month, they do not constitute a major discomfort for tourists. Yet the same amount of precipitation distributed evenly throughout a month in the form of light persistent rain may significantly diminish holiday enjoyment. The same holds true on a daily basis. Thus, the number of days with some minimal precipitation has to be taken into account, although there are different opinions about what that minimum should be. Heurtier (1968, 83) used

Table 1
Precipitation variable

Rates	Mean monthly precipitation
5.0	0.0–14.9 mm
4.5	15.0–29.9 mm
4.0	30.0–44.9 mm
3.5	45.0–59.9 mm
3.0	60.0–74.9 mm
2.5	75.0–89.9 mm
2.0	90.0–104.9 mm
1.5	105.0–119.9 mm
1.0	120.0–134.9 mm
0.5	135.0–149.9 mm
0.0	150.0 mm or more

a standard of >1 mm, Danilova (1976, 107) >3 mm, and Hofer (1967, 444) >5 mm for the purpose of determining the number of days per month on which precipitation is a negative factor in human perception of comfort.[6]

For the purpose of constructing the TCI, the choice of precipitation variables was narrowed to three: the amount of precipitation, the mean number of days with precipitation >1 mm, and the percentage of precipitation during daytime hours (0900–2100). Unfortunately, the last two variables had to be dropped later, because it was found that data were not available, especially in a number of developing countries. In the upshot, only the absolute amount of precipitation has been included in the formula, in accordance with the rating scale in Table 1. For monthly precipitation >150 mm, a value of −1.0 is assigned for each additional 60 mm of precipitation. This rating system reflects the progressive disadvantage of increasing precipitation for tourists' enjoyment. The precipitation factor has also been assigned a weight of 20 per cent in the TCI formula, in recognition of its substantial effect on tourist well-being.

Sunshine: Sunny conditions are generally regarded as positive factors in human climatic comfort, since they are associated with the health benefits of moderate ultraviolet radiation. They are also necessary for sunbathing and improve the results of photography, both of which are important aspects of the tourism experience. At the same time, insolation is not without negative features, such as the danger of sunburn and skin cancer associated with ultraviolet rays, the discomfort resulting from overheating connected with the combination of direct solar radiation and high air temperatures, and the increase in indirect radiation which contributes to heat load with high air temperatures. As well, there are the sundry health hazards listed by Rosen (1979, 76): 'Excessive sunshine ... can increase gastric excretion, increase protein metabolism, lower blood pressure, increase hemoglobin content and number of erythrocytes, increase the fraction of vitamin D and histamines, and increase calcium, magnesium, and phosphate levels in the blood.'

Conversely, some authors have argued that cloudy skies with warm temperatures should not be regarded as a source of discomfort, even in seaside resorts. Burnet (1963, 61) used the example of the Basque Riviera of northern Spain and southwestern France, located in the contact zone between the Pyrenees and the Atlantic Ocean. Semi-clouded skies often occur there in conjunction with warm temperatures and, according to Burnet, constitute one of the attractions of the region. Dammann (1964: 114) came to a similar conclusion with respect to the long-range effects of 'good weather' as a negative factor in climotherapy.

These arguments underline the point that sunshine should not be viewed as unequivocally beneficial for tourism. Still, as far as most tourists are concerned, sunshine is a positive feature and has been so treated in the TCI formula. Like precipitation, it is given a weight of 20 per cent, and, in general, the more sunshine the better the rating. Only for stations (mainly located in desert climates) where high amounts of sunshine are combined with temperatures exceeding skin temperature (about 33°C) will a negative effect be recognized. For temperatures between 33° and 36°C, 10 points are to be deducted from the total monthly index score, and in those rare situations where temperatures exceed 36°C the deduction is to be increased to 20 points. In this way indirect radiation (which has otherwise been ignored) can be taken into account.

The selection of an appropriate measure of insolation for the TCI formula posed some difficulty. Initially, influenced in part by Heurtier (1968, 77–8), I thought that the percentage of possible total sunshine would be best, since it is the inverse indicator of the degree of cloudiness. However, this variable has two critical deficiencies. First, it is given rather rarely in meteorological statistics. The common measure is mean monthly hours of sunshine, and so an additional computation

Table 2
Insolation variable

Rates	Mean monthly hours of sunshine per day
5.0	10 hrs or more
4.5	9 hrs – 9 hrs 59 min
4.0	8 hrs – 8 hrs 59 min
3.5	7 hrs – 7 hrs 59 min
3.0	6 hrs – 6 hrs 59 min
2.5	5 hrs – 5 hrs 59 min
2.0	4 hrs – 4 hrs 59 min
1.5	3 hrs – 3 hrs 59 min
1.0	2 hrs – 2 hrs 59 min
0.5	1 hr – 1 hr 59 min
0.0	less than 1 hr

would be required to convert that into a percentage, using the length of daylight hours from astronomical tables. Second, and more important, tourists are interested in the absolute number of sunshine hours per day, and relative figures have less importance to them; e.g. during short winter days a high percentage of sunshine may translate into fewer sunshine hours than are experienced on summer days with a lower sunshine percentage. With this in mind, I have adopted mean monthly hours of sunshine per day as the insolation variable. The variable is calculated by dividing the mean monthly hours of sunshine by the number of days in the relevant month. The rating scale in Table 2 was then developed.

Wind: Wind is a complicated factor to evaluate for the TCI. Authors of regional studies, where there is little spatial variation in wind speed, have eliminated it from consideration by assuming some constant value. For example, Heurtier (1968, 76) assumed a constant wind speed of 4 m / s in his study area. This closely resembles Serra's (1953) estimate that the average wind speed in Europe is slightly greater than 4 m/s.

These precedents to the contrary, it would be a mistake not to include wind as a variable in the TCI formula. It plays a critical role, because it accelerates the transfer of heat by turbulence and by evaporative cooling. At cooler temperatures, wind increases the chill sensation by removing the heated layer of air near the skin; at warmer temperatures, between 24°–26°c and 33°c (skin temperature), it pleasantly cools the body by the same action, removing the overheated, saturated layer of air and so restoring the function of evaporative cooling. When air temperature exceeds the comfort skin temperature, wind increases the heat load by adding convective heat to the body, thus contributing to a still more unbearable feeling of discomfort.

These considerations gave rise to three conclusions of importance to the construction of a rating system for wind speed.[7] First, wind is a basically negative variable that should normally be associated with lower ratings as wind speeds increase. This is especially valid for cold and temperate climatic conditions (in the latter case, excluding the hottest months with mean maximum temperatures greater than 24°c). A negative evaluation should also be applied against hot climates with mean maximum temperatures greater than 33°c. Danilova (1976, 107) regards winds over 6 m / s (i.e. over 20 km / h) as uncomfortable in any weather conditions.

Second, for cold climatic conditions it seems desirable to have another system based on wind chill rating, in which average monthly wind speeds are integrated with monthly mean daily temperatures. It was also concluded that windspeeds of over 5 m / s (or about 18 km / h) need not be taken into account in the rating system, because they produce no significant further deterioration in human thermal condition (Kandror, Demina, and Ratner 1974, 116).[8]

Third, since increased wind speeds may be beneficial under some conditions, yet another rating system should be constructed for areas with trade winds and other areas when monthly mean maximum temperatures are immediately below the mean comfort skin temperature. Such areas may lie in hot climatic zones as well as in temperate zones.

With these points in mind, four separate wind rating schemes were devised (Table 3). The first, the so-called normal system (column 3), in which the lowest mean

Table 3
Wind Rating Scales

Wind speed (km / h)	Beaufort scale	Normal system	Trade wind system	Hot climate system
<2.88	1	5.0	2.0	2.0
2.88–5.75	2	4.5	2.5	1.5
5.76–9.03	2	4.0	3.0	1.0
9.04–12.23	2	3.5	4.0	0.5
12.24–19.79	3	3.0	5.0	0
19.80–24.29	4	2.5	4.0	0
24.30–28.79	4	2.0	3.0	0
28.80–38.52	5	1.0	2.0	0
>38.52	6	0	0	0

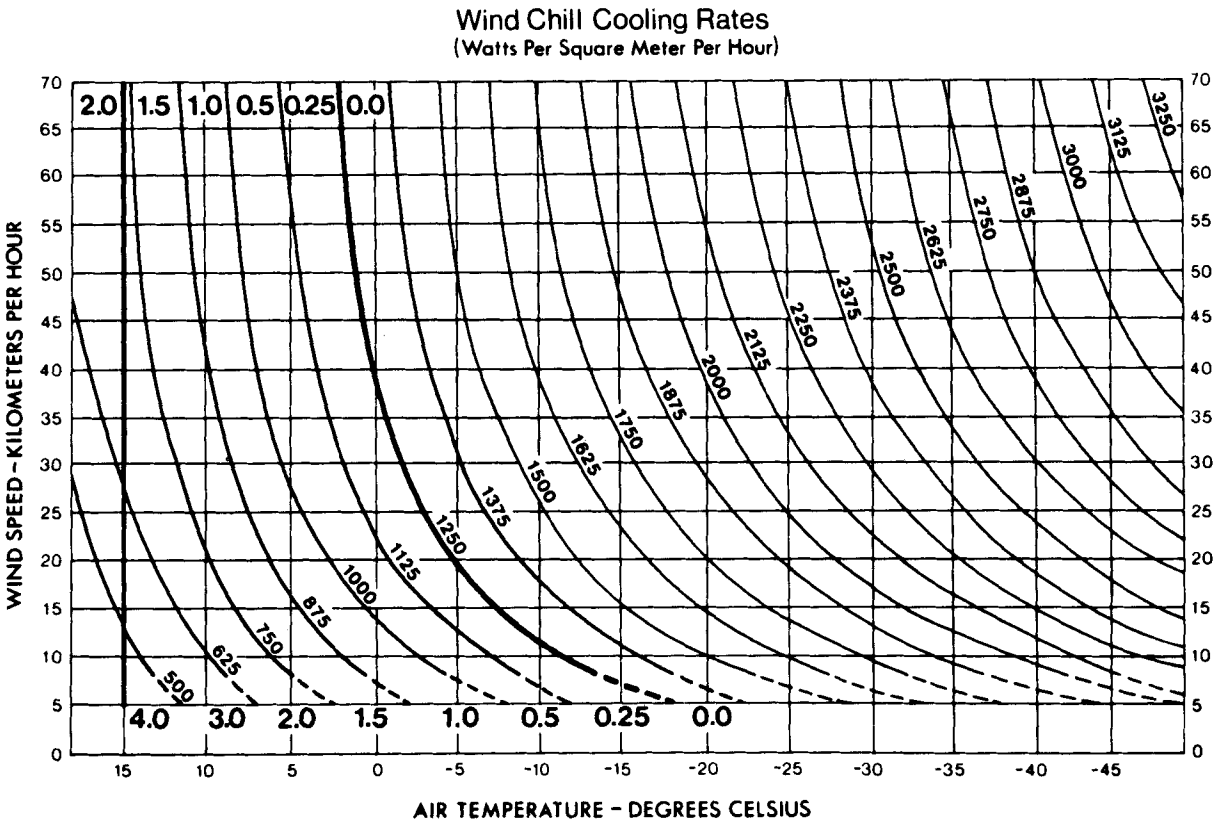

Figure 2
Wind chill rating system for the tourism climatic index, modified from a nomogram prepared by Environment Canada

monthly wind speeds are assigned the optimum value of 5.0, is intended to apply to those months in which the mean daily maximum temperature is between 15° and 24°c. The trade wind system (column 4) recognizes the pleasant effect that evaporative cooling can have at higher temperatures (i.e. between 24° and 33°c); on this scale, the optimum value is set at a moderate wind speed. Next, under the hot climate system (column 5), in which mean daily maximum temperatures exceed 33°c, any wind is considered to be uncomfortable; here, the lowest mean monthly wind speeds are again assigned the maximum rating, but the value is only 2.0. Finally, in consideration of the negative effect of wind at low temperatures, a wind chill nomogram has been prepared (Figure 2). It is meant to be applied to months in which the mean daily maximum temperature is less then 15°c and the mean wind speed is greater then 8 km / h (about 2 m / s); at lower wind speeds the 'normal system' still applies.

The TCI Formula

THE FINAL SET OF VARIABLES

Two criteria governed the final selection of variables for the TCI formula. One was the theoretical considerations of tourist well-being that have just been reviewed; the other was the availability of appropriate data on a worldwide basis. On purely theoretical grounds, an initial list of 12 variables was compiled. A questionnnaire was then circulated to the meteorological services of well over 100 countries, in an attempt to fill gaps in the published record of meteorological statistics. This was only partially successful, so it was necessry to omit 5 of the

Table 4
Monthly TCIs for Edmonton, Toronto, and Sydney

Meteorological station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Edmonton	20	25	37	39	73	77	83	80	69	55	40	21
Toronto	27	29	38	50	69	86	86	88	76	56	38	29
Sydney	82	76	76	75	65	50	55	61	74	77	79	84

Table 5
A Classification Scheme for Mapping TCIs

Numerical value of indices	Code	Descriptive category	Mapping category
90–100	9	ideal	excellent
80–89	8	excellent	
70–79	7	very good	very good and good
60–69	6	good	
50–59	5	acceptable	acceptable
40–59	4	marginal	
30–39	3	unfavourable	unfavourable
20–29	2	very unfavourable	
10–19	1	extremely unfavourable	
9–−9	0	impossible	
−10–−20	−1	impossible	

original variables, chiefly because of a lack of data for some developing countries.

The 7 remaining variables, all of them monthly means or normals, are: 1) maximum daily temperature (°C); 2) mean daily temperature (°C); 3) minimum daily relative humidity (percentage); 4) daily relative humidity (percentage); 5) precipitation (mm of rain); 6) daily duration of sunshine (hours); and 7) wind speed (m / s or km / h). The first 4 variables relate to the thermal comfort of tourists, with variables 1 and 3 being combined in the daytime comfort index and variables 2 and 4 in the daily comfort index.

THE TCI FORMULA

When the several variables are weighted in accordance with the relative importance that they are believed to bear in tourist well-being, the following formula is derived (the sunshine variable is based on monthly normals; all other variables are monthly normals): TCI = 4CID + CIA + 2R + 2S + W, where CID = daytime comfort index, composed of T_1 = maximum daily DBT and RHmin = minimum daily RH; CIA = daily comfort index, composed of T_2 = mean daily DBT and RHa = mean daily RH; R = precipitation in mm of rain; S = daily hours of bright sunshine; and W = wind speed in m / s or km / h. In numerical terms, with an otimal rating of 5.0 for every variable, the formula takes on the following expression: TCI = 2[(4 × 5) + 5 + (2 × 5) + (2 × 5) + 5] = 100.

APPLICATIONS OF THE TCI

Although the full results cannot be presented here, TCIs have been computed for every month for the 453 meteorological stations for which data have so far been obtained. In illustration of the method, monthly indices for three individual stations are provided in Table 4.

Indices can also be mapped to bring out global and regional patterns of climatic conditions for tourism. However, this means that the TCI data must undergo a further transformation, since it is necessary to group the index scores in accordance with some classification scheme. An example is provided in Table 5. This represents a first approach to the problem, and the actual classes employed in the table need to be subjected to rigorous analysis to determine whether they are, in fact, appropriately scaled to the realities of tourist well-being.

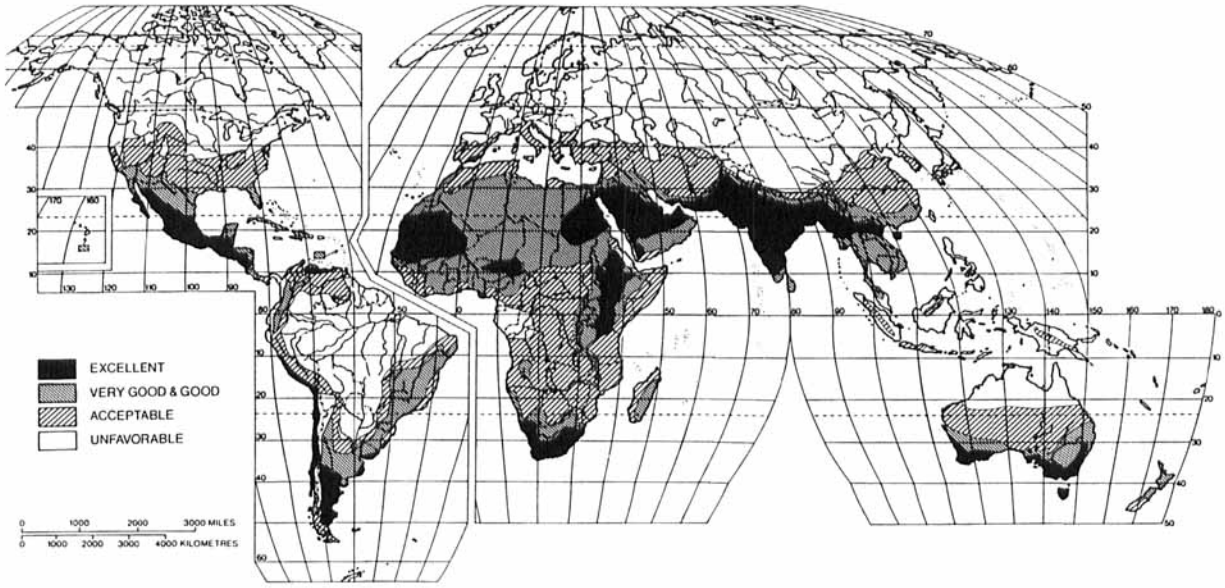

Figure 3
Tourist climatic conditions for January

Nonetheless, the scheme serves the immediate purpose of demonstrating the utility of the TCI for mapping on a world scale. Sample maps have been prepared for every month, but only the January map is presented here to illustrate the technique (Figure 3). The 453 meteorological stations in the data file represent all climatic regions and subregions, so their individual scores have been generalized into regions on the basis of Trewartha's climatic regionalization, as published in all recent editions of *Goode's World Atlas*.

Discussion

In terms of the methodological issues raised by the construction of the TCI, there are two that merit discussion: the rating systems and the weighting of the rated variables.

RATING SYSTEMS

The ratings, which constitute evaluations of climatic variables for the purposes of tourism, represent comparative rather than absolute values, but they are derived from a consistently applied method. Although the results are stochastic, not causal, they can nonetheless be regarded as nomothetic (Bishop 1978, 149–51) and therefore scientifically objective and valid. In particular, the biomedical research results, on which the evaluation of thermal comfort for tourists has been based, have established parameters of human thermal comfort (or discomfort) with respect to temperature and humidity according to the preferences of a majority of healthy adults. There is a considerable degree of agreement among independently conducted research projects, sometimes involving well over 1,000 research subjects. With respect to variables 5–7, in contrast, there is little available research, so an empirical-judgmental method had to be used in the development of rating systems. The literature was of some use, but only in general terms (Maunder 1962, 8–9).

Human thermal sensations (variables 1–4) and the other climatic elements (variables 5–7) do not render themselves well to a discrete method of rating. In reality, when making evaluations of human climatic sensations or preferences, we are dealing with continua rather than with sharply defined limits or thresholds. In the TCI rating systems, however, the transition from one level of response to another has had to be collapsed into the conventional form of artificial limits. The zones within these limits constitute the best known approximations to the

opinions of a majority of people about thermal comfort, or, in the case of variables 5–7, my own judgment.

Another important methodological issue is how to rate different recreational activities, since their climatic requirements vary widely. Two extreme examples are beach activities, which require little or no clothing, and high-mountain recreational activities, which often require warm clothing. Because each of these activities depends on special climatic data sets for their evaluation, the rating systems presented in this essay have considered only sightseeing – the most common tourist activity. Individual recreational activities could be allowed for by shifting the rating values according to the varying climatic requirements. Such modifications could be made rapidly with an appropriate computer program.

THE ISSUE OF ARBITRARINESS OF WEIGHTS

To open this discussion, it is appropriate to quote Maunder (1962, 5): 'Unfortunately, in deciding both what to include, and how important the elements are in relation to total climate, one is forced to rely primarily on personal experience and observations for there is no measurable basis for deciding such issues. Nevertheless, some choice of elements and some weighting of the elements chosen must be decided upon, even though it is realized that there will be many who will disagree.'

The prospect of disagreement certainly applies to the TCI proposed here, especially with reference to the decision to assign the highest weight (50 per cent of the total TCI value) to thermal comfort. Auliciems, for one, reflects a different view: 'The primary and most significant weather element associated with increased "pleasantness" was increased sunshine – accounting for some 20 per cent of the variance. Unrelated to sunshine, increasing temperature had a secondary influence on the perception of "pleasantness". And the perceived degree of "pleasantness" was reduced by increasing cloudiness, humidity, and wind speed' (in Rosen 1979, 81).

The most basic reason for expecting disagreements to occur, as the extract from Auliciems reveals, is that human response to climatic elements is partly a matter of perception. This means that the variables in the TCI are psychological as well as physiological. Ambler (1968), for example, has observed that we feel warmer as soon as we walk into a sunny area, before the sun really starts to 'work.' Similarly, sunshine is especially appreciated after long spells of overcast conditions, so its weight is greatest in cool seasons (Auliciems 1976). Yet, when Ambler (1968, 296) compared the apparent warming effects of sunshine in India and England, he came to the conclusion that bright sunshine in India was equivalent to about 10°F (6°C), whereas in England it was equivalent to only 5.5°F, 'in spite of the fact that the sun was lower than in India and therefore radiating over a greater area of the body.'

This evidence of subjectivity aside, most writers on the subject agree that thermal comfort is the single most important factor in the evaluation of climate from the perspective of human well-being (e.g. Terjung 1966, 1973; Heurtier 1968, 526). In general, if there is disagreement it is most likely to be about the best numerical values for the assigned weights (Maunder 1962, 8).

Another point that should be apparent is that the weightings adopted here (and probably the rating systems as well) will not suit every tourist. Since the desired benchmark was the 'average tourist,' the TCIs do not provide directly for individual climatic preferences. At the same time, the system has an inherent flexibility which allows it to be adapted. This follows the example of Heurtier (1968), who provided for individual weighting adjustments in his formula for climatic well-being. Thus, if a tourist attaches special value to sunny skies but is not troubled by wind, the weight of the 'insolation' variable could be increased from 2 to 3 and that of the 'wind' variable reduced from 1 to 0. This, of course, would require new indices to be computed, and the individual meteorological stations would acquire different TCI values. Here, again, a computer program could provide instant information.

In summary, the arbitrariness of numerical representations is as much an issue in the weighting procedures as it is in the rating systems. Because the weights for the TCI formula have been derived by value judgments, an element of arbitrariness, and thus subjectivity, has been introduced. For this reason, the final scores of the TCIs should not be regarded as mathematically precise, absolute quantities. At best, they are reasonable approximations. Their sole purpose is to express a comparative evaluation of climates from the tourist's point of view. In other words, the indices show, in quantitative terms, the relative merits or demerits of an area as compared with

other areas of the world for each of the twelve months. Their value is further enhanced by the fact that this method of evaluating the world's climates is designed to be applied with complete consistency.

Notes

1 Heurtier (1968, 81) argues that the term 'comfort' is not appropriate because it is used for indoor situations. He suggests 'thermal well-being' (*bienêtre thermique*) instead.

2 One clo is the unit of thermal insulation of clothing that will maintain a resting-sitting person, whose metabolism is 58 W / m^2, indefinitely comfortable when $T = 21°C$, RH < 50 per cent and $v = 10$ cm / s (Gagge, Burton, and Bajett 1941).

3 The level of activity is measured in met-units, where 1 met = 58 W / m^2 (50 kcal / m^2h). Sedentary activity corresponds to 1 met, standing to 1.4 met, slow walking (3 km / h) to 2 mets, walking at 5 km / h to 2–6 mets, and running at 10 km / h to 8 mets (Fanger 1974, 314). According to Kandror, Demina, and Ratner (1974, 24), people walking 2.5 to 3 km / h produce 150–200 kcal / h, which is equivalent to 1.8–2.4 mets.

4 There are other examples of temperature being correlated with humidity. The US National Weather Service uses a temperature-humidity index (THI) which gives a numerical indication of human comfort. At THI 70, about 10 per cent of the population is uncomfortable, at THI 75, half the population is uncomfortable, and at THI 80, just about everyone is uncomfortable (Maunder 1970, 197; Gates 1973, 94–5). In Canada the combined effects of temperature and humidity are now expressed by 'humidex', a number indicating a degree of comfort. A humidex of 20–29 is comfortable, 30–39 indicates some discomfort, and 40–45 is uncomfortable for everyone (*Winnipeg Free Press* 21 August 1976).

5 When clothed, people experience less radiant heating than when nude, especially in hot desert conditions.

6 Some authors find even the number of rainy days an inadequate indicator for purposes of tourism. Friedrich (1960) argues that Austria has an average of about 50 per cent rainy days but only 10–20 per cent hours with rain, a phenomenon tht is even more pronounced in most low-latitude climates.

7 Other possible variables have not been included, most notably the frequency of strong winds, either as a percentage or a frequency of duration of wind above a certain speed. Also significant is the average number of days with gusts over 39 km / h (6 on the Beaufort scale). Unfortunately, such data are not available on a world-wide basis, so mean monthly wind speed had to stand as the only feasible variable.

8 There is a disagreement about the wind speed beyond which there is little additional chilling effect. Terjung (1966, 150) suggests a cut-off value at 72 km / h or 20 m / s. Indeed, an analysis of his nomogram (Terjung 1966, 151) makes clear the gradual nature of the phenomenon and, thus, the subjectivity of the issue.

References

AMBLER, H.R. 1968 'Thermal comfort in hot temperate climates' *Journal of Tropical Medical Hygiene* 71, 294–6

ANDERSON, I.B., LUNDQVIST, G.R. and JENSEN, P.L. 1974 'Human response to 78 hour exposure of dry air' *Archives of Environmental Health* 29, 319–24

ASHRAE 1972 *Handbook of Fundamentals* (New York: American Society of Heating, Refrigerating and Air Conditioning Engineers)

— 1974 *Thermal Environmental Conditions for Human Occupancy* (New York: American Society of Heating, Refrigerating and Air Conditioning Engineers)

AULICIEMS, A. 1977 'Weather perception – a subtropical winter study' *Weather* 32, 312–16

BISHOP, P. 1978 'Human geography: a nomothetic science?' *Area* 10, 149–51

BOYER, R. 1981 *Places Rated Almanac* (Chicago: Rand McNally)

BRAZOL, D. 1954 'Bosquejo bioclimatico de la Republica Argentina' *Meteoros* 4, 381–94

BURNET, L. 1963 *Villégiature et tourism sur les Côtes de France* (Paris: Librairie Hachette)

CAMUSET, F. 1975 'Concentration ou étalement? Plaidoyer pour la survie des vacances' Université d'Aix-Marseille, unpublished thesis

COATES, B.E., JOHNSTON, R.J. and KNOX, P.L. 1977 *Geography and Inequality* (New York: Oxford University Press)

CROWE, R.B. 1976 *A Climatic Classification of the Northwest Territories for Recreation and Tourism* (Toronto: Environment Canada)

DAMMANN, W. 1964 'Die Schwule als Klimfaktor' *Berichte zur Deutschen Landeskunde* (Bad Godesberg) 32(1), 100–9

DANILOVA, N.A. 1973 'Klimat Pribaltiki i prodolzhitelnost perioda blagopriyatnogo dla turizma' in J.A. Kovalev et al eds *Geografia i turism. Voprosy geografii* (Moskva: Mysel) 93, 164–76

— 1976 'Klimaticheskiye uslovia prigorodnogo otdykha na Yevorpeyskoy territorrii SSR' in *Rekreatsionaya geografia* (Moskva: Moskovskiy filial GOSSSR) 106–9

— 1977 *Priroda i Nashe Zdorovye* (Moskva: Mysl)

DAVIS, N.E. 1968 'An optimum summer weather index' *Weather* 23, 305–17

ELKINS, R. and LONGLEY, M. 1968 'Effects of humidity on health' *Proceedings*, Conference of the American Gas Association Inc

FANGER, P.O. 1970 *Thermal Comfort* (Copenhagen: Danish Technical Press)

— 1974 'Assessment of man's thermal comfort in practice' *British Journal of Industrial Medicine* 30, 313–24

FISHBURN, P.C. 1964 *Decision and Value Theory* (New York: Wiley)

FRIEDRICH, W. 1960 'Neue meteorologische Erkenntnisse für die Fremdenverkehswerbung' *Berichte zur Landesforschung und Landesplanning* 4, 48–50

GAGGE, A., BURTON, A. and BAJETT, H. 1941 'A practical system of units for the description of the heat exchange of man with his environment' *Science* 194, 428–30

GATES, M. 1973 *Man and His Environment: Climate* (New York: Harper and Row)

GONZALEZ, R.R., NISHI, Y. and GAGGE, A.P. 1974 'Experimental evaluation of standard effective temperature. A new biometeorological index of man's thermal discomfort' *International Journal of Biometeorology* 18, 1–15

GREGORCZUK, M. and CENA, K. 1967 'Distribution of effective temperature over the surface of the earth' *International Journal of Biometeorology* 11, 145–9

GRIFFITHS, I.D. and MCINTYRE, D.A. 1973 'Subjective response to relative humidity at two air temperatures' *Archives des Sciences Physiologiques* 27, 456–69

GRIFFITHS, J.F. 1976 *Climate and the Environment* (Boulder, Colorado: Westview Press, Inc)

HAMELIN, L. 1980 *Nordicité canadienne*, Collection Géographie, Cahiers du Québec 55 (Montréal: Hurtubise HMH)

HEURTIER, R. 1968 'Essaie de climatologie touristique synoptique de l'Europe occidentale et Mediterranéene pendant la saison d'été' *La Météorologie* 7, 71–107 and 8, 519–66

HOFER, K. 1967 'Klimabehaglichkeit und Kurort' *Wiener Medizinische Wochenschrift* 16, 444–6
HOUNAM, C.E. 1967 'Meteorological factors affecting physical comfort' *International Journal of Biometeorology* 11, 151–62
KANDROR, I.C., DEMINA, D.M. and RATNER, Y.M. 1974 *Fiziologicheskye principy sanitarno-klimatologicheskogo rayonirovanya territorii SSSR* (Moskva: Meditsina)
KÖPPEN, W. 1931 *Grundriss der Klimakunde* (Berlin: Walter de Gruyter Company)
KRAWCZYK, B. 1979 'Proba okreslenia zwiazku pomiedzy srednia temperatura skory czlowieka a temperatura radiacyjmo – ekwiwalentno – efektywna' *Problemy bioklimatologii uzdrowiskowej* 3(2), 66–72
LAMB, H.H. 1972 *Climate: Present, Past and Future*, Volumes 1 and 2 (London: Methuen and Co)
MCINTYRE, D.A. 1978 'Response to atmospheric humidity at comfortable air temperature: a comparison of three experiments' *Annals of Occupational Hygiene* 21, 177–90
MAUNDER, W.J. 1962 'A human classification of climate' *Weather* 17, 3–12
— 1970 *The Value of Weather* (London: Methuen)
MIECZKOWSKI, Z. 1983 'The feasibility and necessity of climatic classification for purposes of tourism' *Proceedings*, International Geographical Union Commission for Tourism and Leisure, Lodz Symposium, 315–31
MINNESOTA DEPARTMENT OF ECONOMIC RESEARCH 1976 *Quality of Life: Measurement of the State of the States* (Minneapolis: Department of Economic Research, Minnesota Research Bulletin No. 2)
NEVIS, R.G. 1973 'Engineering applications of comfort data' *Archives des Sciences physiologiques* 27, 433–9
PETERS, M. 1969 *International Tourism: The Economics and Development of the International Tourist Trade* (London: Hutchinson)
ROHLES, F.H., JR 1974 'The modal comfort envelope and its use in current standards' *Human Factors* 16, 314–22
ROHLES, F.H., JR. and NEVIS, R.G. 1973 'Thermal comfort: new directions and standards' *Aerospace Medicine* 44, 730–8
ROSEN, S. 1979 *Weathering. How the Atmosphere Conditions Your Body, Your Mind, Your Moods – and Your Health* (New York: M. Evans and Co)
SERRA, L. 1953 'Le vent en France et ses possibilites d'utilization' *La Météorologie* 4ème series, 32, 273–92
SMITH, D.M. 1973 *The Geography of Social Well-Being in the United States* (New York: McGraw Hill)
TERJUNG, W.H. 1966 'Physiological climates of the conterminous United States: a bioclimatic classification based on man' *Annals of the Association of American Geographers* 56, 141–79
— 1968 'World patterns of the distribution of the monthly comfort index' *International Journal of Biometeorology* 12, 119–51
THORNTHWAITE, C.W. 1931 'The climates of North America according to a new classification' *Geographical Review* 21, 633–55
— 1948 'An approach toward a rational classification of climate' *Geographical Review* 38, 55–94
TREWARTHA, G.T. 1954 *An Introduction to Climate* (New York: McGraw-Hill)

Observations

A NEW FEATURE FOR *THE CANADIAN GEOGRAPHER*

The Editor

The Canadian Geographer is introducing a new feature, titled 'Observations.' It is designed to make productive use of pages found at the ends of articles that, in the past, have ended up at least half blank. An Observation may consist of a display in the left-hand column (eg map, table, graph, photo, quote) and a related commentary of up to 300 words in the right-hand column, or it may be a research-related statement or provocative essay of up to 500 words. Its objective may be to interpret patterns or trends, raise questions, present problems, pose hypotheses, or advance arguments.

The first example of an Observation appears on page 273 of this issue. It is anticipated that two to four of these could appear in each issue of the *Geographer*.

Please send submissions to the Editor, following the 'Instructions for Contributors' that appear in the spring 1985 issue (vol 29, no 1) on pages 94–6.