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CLIMATE, WATER HARDNESS AND CORONARY HEART DISEASE*†

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GEOGRAPHIC variation in coronary heart disease mortality within the United States has been shown to be considerable [1]. These differences appear to be real, and not attributable to varying patterns of medical practice or death certification. Other workers [2–4] have shown that there are marked differences in coronary disease rates even within a given state. The reason behind these differences may be a key to the mystery of coronary disease etiology [5].

Many environmental factors have been proposed as possible explanations of these differences. These include various aspects of urbanization, population density and socio-economic status, altitude, air pollution and water supply. Even soil type has been found to have a possible association with death rates due to coronary heart disease [3].

SCHROEDER [6–8] has shown that a marked association exists between hardness of local water supplies and mortality rates from cardiovascular and coronary heart disease. MORRIS and his co-workers [9] found that two factors, "water characteristics" and "latitude", were distinctly and independently associated with cardiovascular mortality rates.

In addition to geographic variation in coronary disease rates, many studies have shown a marked seasonal (winter) increase in mortality and morbidity due to coronary disease. Most of these studies were done in the northern portions of Europe and

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the United States where winters tend to be harsh, and summer temperatures are moderate. ROSE [10] showed a high correlation between low temperatures and the winter excess of deaths in England. In contrast, the greatest number of cases of proven myocardial infarction in Dallas, Texas, occurred in the summer months, with the lowest number of cases in the winter months [11]. This was confirmed by DE PASQUALE and BURCH [12] in New Orleans. In Detroit, a sharp rise in deaths, particularly those due to cerebrovascular accident, was noted during each of two heat waves in 1962 and 1963 [13]. KUTSCHENREUTER [14], reporting on mortality from all causes in New York City, showed that there was a significant increase in mortality both during winter months with temperatures appreciably below normal, and during periods of excessively warm summer weather.

The present study was designed to assess the relative importance of climatic and water characteristics on geographic variations in coronary heart disease mortality rates. Although several studies have shown seasonal fluctuations in such rates, few attempts have been made to study comparative rates from areas with different climates. Age-adjusted death rates are available for white males, aged 45–64, for 163 Continental United States Standard Statistical Metropolitan Areas (SMSA) as defined by the U.S. Bureau of the Census for the years 1949–1951 [4]. Detailed information on the characteristics of the water supply [15, 16], the climate [17–19] and the population [20, 21] of many of these areas is also available. The data were complete for 116 of the 163 SMSA's considered. Of the remainder, most were excluded because relative humidity data were lacking.

DATA FOR ANALYSIS

Raw data

Age-adjusted death rates for arteriosclerotic heart disease including coronary heart disease (ISC 420) among white males aged 45–64 in the years 1949–1951 were presented by ENTERLINE and co-workers [4] for the SMSA's under study. Proportionate mortality due to coronary heart disease was determined for each SMSA by dividing the coronary death rate by the total death rate.

Thirty-five variables were originally included for study. These relate to the socio-economic composition of the populations and the geography, water hardness, and climate of the areas under study.

Socio-economic variables included total population, population density of the area, population density of the central city, median family income, median gross monthly rent, and median school years completed.

The geographic characteristics included the latitude, longitude, and elevation of the source of weather data for the area.

The water variables considered included the concentration of potassium, sodium, calcium, and magnesium, the total hardness, dissolved solids and specific conductance of the treated water supplies of the central city of the area.

Weather variables recorded included the mean maximum and minimum temperature, mean relative humidity and mean wind speed for each January and July of the 3 yr 1949–1951. These 2 months were chosen to represent the colder and warmer months of the year respectively. Mean yearly temperature, total rainfall, total snowfall, and total heating-degree days were also recorded for each year. Mean values of these variables as well as mean monthly temperature and mean daily and yearly temperature variations were determined for the 3 year covered by the mortality data.

Derived weather variables

In addition to analysis of the raw climatic data, it was thought desirable to include some measurement of thermal adaptability or thermal comfort [Ref. 22, p. 41]. For the present study, the Temperature–Humidity Index (*THI*), developed by THOM for the U.S. Weather Bureau, was considered to be the most practical [23] of available indices. One mathematical form of this index is shown in Equation 1.

$$THI = T - CI \tag{1}$$

where the "Comfort Index" (CI) is:

$$CI = 0.55\,(1 - RH)\,(T - 58) \tag{2}$$

T is air temperature (dry bulb) in degrees Fahrenheit, and RH is relative humidity. These formulae do not include measurements of either wind speed or heat radiation.

Studies discussed by TROMP [22] show that *THI* was an approximation of "effective temperature" for summer climatic conditions in the United States. KUTSCHENREUTER [14] showed that although the departure from normal summer temperature during heat waves correlated most highly with total mortality, the Temperature–Humidity Index (*THI*) also correlated highly.

The Temperature–Humidity Index (*THI*) is a reflection of the subjective evaluation of temperature based upon temperature and humidity. The extremes of the *THI* are subjectively the most uncomfortable. The Comfort Index (*CI*) represents the degree of ease of thermal adaptation of the body to extremes of temperature. Since *CI* increases in inverse relationship to humidity, a high humidity in hot or cold temperatures results in a low comfort index, positive in sign in hot temperatures and negative in sign in cold temperatures. A low index (disregarding sign) indicates a relatively more difficult adaptive process, whereas a high index is indicative of the conditions under which body temperatures can be regulated with the greatest ease. This is to say that at extreme temperatures, subjective comfort is less likely when the absolute value of the "comfort index" is low (the humidity is high) and more likely when the index is high (the humidity is low).

Figure 1 illustrates the pattern of change of *CI* for varying temperature and relative humidity. Subsequent graphical display of results will utilize this type of graph to permit simultaneous assessment of the relationships of temperature, relative humidity and *CI* to coronary mortality.

No known previous work has dealt with these indices in climates with low temperatures. These indices combining temperature and humidity have not previously been related to CHD mortality. To examine these factors in both the hotter and colder months for a given locality, a combined index was defined as the sum of the absolute values of the "comfort index" for both January and July. This combined index will be referred to as *CIABJJ*.

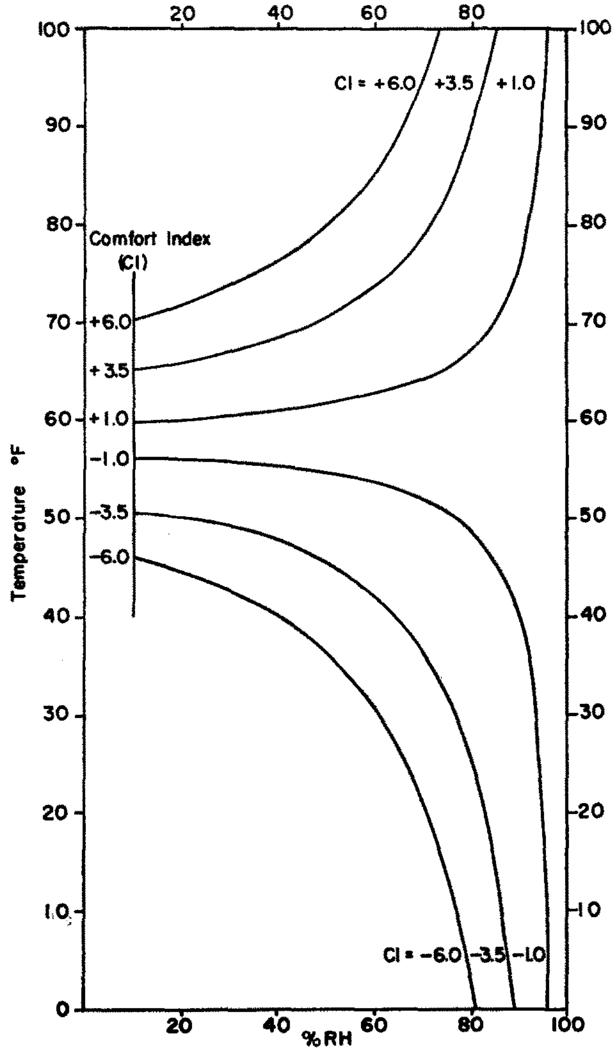

FIG. 1. "Comfort Index" in relationship to temperature and relative humidity.

Derived Weather Variables

(1) Temperature–Humidity Index (*THI*) developed by THOM for the U.S. Weather Bureau
$THI = T - CI$ (Comfort Index)

(2) Comfort Index (*CI*)
$CI = 0.55\,(-RH)(T-58)$
T=air temperature (dry bulb) in degrees Fahrenheit
RH=relative humidity

(3) *CI* (1)
Comfort Index (January)

(4) *CI* (7)
Comfort Index (July)

(5) *CIABJJ*
Combined Comfort Index (sum of absolute values of January and July comfort indices).

METHOD OF ANALYSIS

The degree of association between variables and the relative importance of each of the variables with respect to the CHD mortality indices were determined by means of a computer program for a stepwise correlation analysis. At each step in the analysis, the variable that correlated most highly with the CHD mortality index under consideration was selected, and variability due to this factor was removed. This was repeated until a predetermined level of significance ($p=0.2$) was reached. When desired, variables could also be selected in a predetermined order, before the remaining ones were automatically selected on the basis of their correlation with coronary disease mortality indices. The summary at the end of the analysis included a listing of the variables selected, in the order of their selection, the partial and multiple correlations at each step, the progressive reduction in variance, and the level of significance of each variable selected.

Tables 1 and 2 illustrate the method of the stepwise correlation analyses. The partial correlations indicate the strength and direction of the relationships to the

TABLE 1. SUMMARY OF THE STEPWISE CORRELATION ANALYSIS BETWEEN CORONARY DEATH RATES AND SEVENTEEN ENVIRONMENTAL VARIABLES

Group	Variable eliminated	Partial correlation	Multiple correlation	Reduction of total variance	Level of probability
Group A 46 areas with low mean annual temperatures, less than 53°F.	Education*	−0.1070	0.1070	0.0115	0.476
	Rent*	0.2889	0.3066	0.0940	0.051
	Income*	0.0401	0.3089	0.0954	0.795
	CIABJJ	−0.4790	0.5505	0.3030	0.001
	Potassium	−0.3689	0.6308	0.3979	0.014
Group B 40 areas with intermediate mean annual temperatures, 53.0–62.9°F.	Education*	−0.0473	0.0473	0.0022	0.770
	Rent*	0.0901	0.1017	0.0103	0.583
	Income*	0.3503	0.3630	0.1318	0.028
	Atmospheric pressure	0.5673	0.6412	0.4112	<0.001
	January relative humidity	−0.4433	0.7259	0.5269	0.005
	Potassium	−0.3076	0.7561	0.5716	0.068
	Population density, city	−0.2321	0.7712	0.5947	0.181
Group C 30 areas with high mean annual temperatures, 63° F. or more	Education*	−0.0309	0.0309	0.0010	0.870
	Rent*	0.0316	0.0442	0.0020	0.870
	Income*	0.0371	0.0577	0.0033	0.850
	CIABJJ	−0.6109	0.6126	0.3753	<0.001
	Population density, city	0.5271	0.7409	0.5489	0.004
	Hardness	−0.3038	0.7685	0.5905	0.132
	Area density	0.3719	0.8045	0.6472	0.067
	Mean July temperature	0.3311	0.8282	0.6858	0.115
	January temperature variation	−0.2849	0.8434	0.7113	0.190

*Pre-selected variable.

mortality indices. For any given line in the table, the effects of variables given above it have been eliminated. The multiple correlation indicates the strength of the cumulative effects of all variables listed to that point. The progressive reduction in variance indicates the proportion of variance explained by variables listed. It is the square of the associated multiple correlation.

The 116 metropolitan areas included in the study were divided into smaller groups on the basis of their mean annual temperature for the 3 yr considered. The other environmental variables were viewed within this primary context.

During the course of the study, the original list of 35 variables was gradually reduced to 17, of which 3 were eventually found to be good predictors of coronary heart disease death rates. Unless specifically desired in the analysis, variables were eliminated if they failed to fulfill the following two criteria for each of the 3 subgroups based on mean annual temperature: correlation with both coronary heart disease mortality and proportionate mortality of at least 0.15, and no strong association with any other environmental variables. When subjective judgment was required to

TABLE 2. SUMMARY OF THE STEPWISE CORRELATION ANALYSIS BETWEEN THE PROPORTIONATE RATIO AND SEVENTEEN ENVIRONMENTAL VARIABLES

Group	Variable eliminated	Partial correlation	Multiple correlation	Reduction of total variance	Level of probability
Group A 46 areas with low mean annual temperatures, less than 53°F.	Education*	−0.0141	0.0141	0.0002	0.925
	Rent*	0.3002	0.3006	0.0903	0.042
	Income*	−0.0077	0.3006	0.0904	0.960
	July relative humidity	0.3509	0.4499	0.2024	0.019
	Potassium	−0.3161	0.5311	0.2821	0.038
	Population density, city	−0.3308	0.6005	0.3606	0.032
Group B 40 areas with intermediate mean annual temperatures, 53.0–62.9°F.	Education*	0.1015	0.1015	0.0103	0.530
	Rent*	−0.0375	0.1081	0.0117	0.820
	Income*	0.0670	0.1270	0.0161	0.687
	July relative humidity	0.5110	0.5225	0.2730	0.001
	Winter precipitation	−0.3688	0.6098	0.3719	0.024
	Atmospheric pressure	0.4249	0.6966	0.4852	0.009
	Potassium	−0.3295	0.7356	0.5411	0.053
Group C 30 areas with high mean annual temperatures, 63°F. or more	Education*	0.3997	0.3997	0.1598	0.025
	Rent*	0.0414	0.4015	0.1612	0.829
	Income*	0.1244	0.4174	0.1742	0.524
	July relative humidity	0.6755	0.7423	0.5510	<0.001
	January mean temperature	−0.3960	0.7883	0.6214	0.040
	January temperature variation	−0.2924	0.8086	0.6538	0.149
	Hardness	−0.2771	0.8249	0.6804	0.182

*Pre-selected variable.

choose among several intercorrelated variables about equally correlated with both coronary mortality and proportionate mortality, we attempted to choose that variable which seemed most logically related to physiological processes.

Seven of the variables originally considered were only weakly related to coronary heart disease rates. Six of these (latitude, mean July wind velocity, mean annual temperature, annual heating-degree days, total snowfall, and the Temperature–Humidity Index for July) were eliminated from the final analysis, but mean July temperature was retained because of higher correlations between this factor and coronary rates in 2 of the 3 subgroupings of areas. Twelve other variables were excluded because of their high degree of association with variables that were retained.

From among the variables relating to the population and socio-economic aspects of the 116 metropolitan areas, median family income, median gross monthly rent, and median school years completed [21] were considered as a group. Despite their weak association with coronary rates, they were retained throughout the analysis, and variations in death rates related to these variables were removed arbitrarily prior to determining which of the remaining environmental variables were significantly associated with death rates due to coronary heart disease. The removal from the analysis of variability due to these socio-economic factors, minimizes differences between areas due to the availability and adequacy of medical care.

The population density of the entire area, and the population density of the central city or cities were recorded for each metropolitan area [20]. These were considered as potential indicators of risk in contrast to the income, rent, and education mentioned above. Initially, the total population of the area was considered. However, this factor was excluded from the analysis because, without some indication of the area or density involved, population figures alone are a poor measure of factors relating to the pressures of urbanization.

Initially, the elevation, latitude, and longitude of the local weather station were also recorded. However, although they were to varying degrees associated with mortality rates, they were eliminated from the final analysis because it was believed that by themselves they would have little, if any, direct relationship to mortality from coronary heart disease. Rather, the observed associations between elevation, longitude and disease are probably the result of mutual associations with other factors more directly related to disease incidence. For example, elevation and atmospheric pressure are very highly associated. Likewise, longitude and latitude are related to several of the climatic variables. Thus, the inclusion of elevation, latitude and longitude in addition to the other variables might tend to confuse or mask more meaningful relationships.

Eleven of the original climatic variables were eliminated from the final analyses for similar reasons. Five (mean July wind velocity, mean annual temperature, annual heating degree days, total snowfall and the temperature–humidity index for July) were only poorly associated with coronary heart disease mortality rates. Others were highly interrelated. Yearly temperature variation and the January Temperature–Humidity Index were related to the mean January temperature at the level of 0.9 or higher. The July Comfort Index (*CI* 7) was excluded from the stepwise correlation analysis because of its strong association with July relative humidity. With little variation in mean July temperature between cities, *CI* 7 varies inversely with *RH* 7. Likewise, July temperature and July precipitation were excluded in favor of July relative humidity (*RH* 7) with which they too were associated. Of the remaining climatic variables considered, total yearly precipitation was eliminated in favor of precipitation during the cooler months, October–April.

The water characteristics were examined to decide which should be eliminated from final analysis. Specific conductance showed lower correlations with coronary rates than did the other water variables. Analysis revealed that many of these water variables were highly intercorrelated. Therefore, among those originally considered, only total hardness, which is chiefly attributable to calcium and magnesium, and the concentrations of sodium and potassium were retained in the final analysis.

RESULTS

Differences among the 3 subgroups based on mean annual temperature were considered sufficiently important to indicate that separate analyses were required for each group. Table 3 shows some of the major climatic differences between the total sample and each of the three subgroups. Group A consists of cities with a mean annual temperature less than 53°F. Group C includes those with a mean temperature of at least 63°F. Cities with mean temperatures between these two values are in Group B. The coronary mortality rate was not significantly associated with mean annual temperature in these data.

Table 4 shows the correlations between the mortality indices and the eighteen environmental variables retained throughout the study, both for the entire 116 metropolitan areas, and the 3 sub groups based on mean annual temperature. Thus, for the 116 metropolitan areas, eight environmental variables are associated with age-adjusted mortality rates due to coronary heart disease at the 0.001 level of statistical significance. These are: potassium (K), hardness (*HD*), January relative humidity (*RH* 1), July relative humidity (*RH* 7), January temperature variation (*TV* 1), January comfort index (*CI* 1), combined comfort index (*CIABJJ*) and July atmosphere pressure (*AP*). However, only 4, all related to weather, are equally significantly associated with the proportion of total mortality that is due to coronary heart disease. These are: July temperature (*TA* 7), July relative humidity (*RH* 7), January temperature variation (*TV* 1) and combined comfort index (*CIABJJ*). To be considered specifically related to mortality due to coronary heart disease, the environmental variables should be correlated with both coronary heart disease rates and with the proportionate mortality ratios. A "coronary heart disease specific" factor is defined as one which has significant correlations of like sign with both CHD mortality and the proportion of total mortality due to CHD, and also a non-significant correlation or one of opposite sign with mortality rates due to all other causes combined.

CIABJJ (the sum of the absolute values of the January and July comfort indices) was the most consistent of the variables related to coronary heart disease rates. Likewise, July relative humidity (*RH* 7) was most consistently related to the proportion of total mortality due to coronary heart disease, regardless of differences in the mean yearly temperature of the different areas. Even when variability due to the three socio-economic variables (income, rent and education) was removed, these patterns remained unchanged.

For all areas combined, *CIABJJ* correlated most highly with coronary heart disease mortality rates. Therefore, during the stepwise correlation analysis, its contribution to the total variance was first to be removed after that related to the preselected

TABLE 3. MEANS AND STANDARD DEVIATIONS FOR CORONARY HEART DISEASE RATES, PROPORTIONATE MORTALITY RATIOS, MEAN ANNUAL TEMPERATURE, AND MEAN TEMPERATURE AND RELATIVE HUMIDITY FOR THE MONTHS OF JANUARY AND JULY, 1949–1951, FOR 116 METROPOLITAN AREAS AND EACH OF THREE SUBGROUPS BASED ON MEAN ANNUAL TEMPERATURE

Group	*N*	Coronary heart disease rate *ISC* 420	Proportionate mortality due to coronary disease	Mean annual temperature (°F)	Mean January temperature (°F)	Mean July temperature (°F)	Mean January relative humidity	Mean July relative humidity
Total	116 mean	570.63	0.350	57.1	39.2	76.8	0.74	0.71
	St. dev.	94.66	0.043	8.2	13.1	5.1	0.07	0.09
Subgroup A								
Mean annual temperature less than 53°F	46 mean	561.11	0.360	49.0	27.0	72.6	0.75	0.70
	St. dev.	77.61	0.034	3.1	7.7	2.6	0.06	0.08
Subgroup B								
Mean annual temperature 53.0–62.9°F	40 mean	568.56	0.347	58.0	41.4	77.0	0.72	0.72
	St. dev.	87.60	0.039	2.8	6.3	3.8	0.06	0.09
Subgroup C								
Mean annual temperature 63°F or more	30 mean	587.99	0.338	68.2	54.8	82.9	0.75	0.73
	St. dev.	121.39	0.055	3.4	6.7	2.4	0.08	0.10

TABLE 4. CORRELATION COEFFICIENTS BETWEEN THREE DISEASE VARIABLES AND EIGHTEEN ENVIRONMENTAL VARIABLES, FOR THE ENTIRE 116 METROPOLITAN AREAS, AND THE THREE SUBGROUPS BASED ON MEAN ANNUAL TEMPERATURE

Variable	All areas N=116			Group A Low mean annual temperature, N=46			Group B Intermediate mean annual temperature, N=40			Group C High mean annual temperature N=30		
	CHD*	CHD† Total	Other‡	CHD	CHD Total	Other	CHD	CHD Total	Other	CHD	CHD Total	Other
Income	0.026	0.289	—0.360	0.177	0.174	0.057	0.240	0.071	0.226	0.014	0.353	—0.512
Rent	0.005	0.295	—0.403	0.239	0.280	—0.050	0.055	0.017	0.033	—0.010	0.363	—0.558
Education	—0.092	0.227	—0.443	—0.107	—0.014	—0.143	—0.047	0.101	—0.221	—0.031	0.400	—0.654
Population density—City	0.245	0.049	0.216	0.331	—0.035	0.522	0.220	—0.003	0.295	0.470	0.120	0.352
Area	0.215	0.144	0.053	0.332	0.070	0.351	0.292	0.121	0.201	0.287	0.352	—0.196
Potassium	—0.335	—0.163	—0.187	—0.450	—0.277	—0.296	—0.354	—0.137	—0.255	—0.218	—0.120	—0.056
Sodium	—0.222	—0.261	0.151	—0.311	—0.125	—0.260	—0.174	0.108	—0.355	—0.340	—0.473	0.364
Total hardness	—0.386	—0.246	—0.098	—0.295	—0.189	—0.113	—0.466	—0.255	—0.252	—0.558	—0.607	0.270
January temperature	0.281	—0.109	0.476	0.342	0.046	0.403	0.422	0.238	0.181	0.351	0.120	0.222
July temperature	—0.068	—0.321	0.371	—0.131	—0.235	0.149	—0.212	—0.184	—0.015	—0.547	—0.491	0.134
January relative humidity	0.349	0.314	—0.022	0.352	0.311	0.106	0.129	0.005	0.196	0.545	0.544	—0.218
July relative humidity	0.414	0.438	—0.125	0.332	0.358	—0.036	0.244	0.463	—0.336	0.602	0.589	—0.212
January temperature variation	—0.344	—0.341	0.053	—0.494	—0.302	—0.311	—0.445	—0.115	—0.426	—0.419	—0.484	0.257
January comfort index	0.354	—0.010	0.441	0.453	0.229	0.335	0.399	0.223	0.199	0.392	0.187	0.168
July comfort index	—0.374	—0.544	0.334	—0.357	—0.412	0.077	—0.338	—0.475	0.230	—0.598	—0.595	0.230
Combined comfort index	—0.530	—0.325	—0.169	—0.516	—0.355	—0.244	—0.442	—0.414	0.013	—0.605	—0.490	0.061
Atmospheric pressure	0.507	0.311	0.190	0.466	0.355	0.160	0.617	0.397	0.267	0.493	0.463	—0.128
Winter precipitation	0.299	0.177	0.095	0.476	0.200	0.392	0.059	—0.104	0.229	0.405	0.476	—0.258

Critical values of r for given levels of probability:

	All areas	Group A	Group B	Group C
p=0.100	r_p=0.158	r_p=0.246	r_p=0.264	r_p=0.317
0.050	0.188	0.291	0.312	0.374
0.010	0.248	0.376	0.403	0.479
0.001	0.318	0.470	0.501	0.588

*Mortality due to coronary heart disease.
†Proportion of total mortality due to CHD.
‡Mortality due to all causes other than CHD.

socio-economic variables (education, rent and income) Table 1. *CIABJJ* was also the largest contributor to the variance of coronary heart disease rates in areas with high and low mean annual temperature. In the group with intermediate temperatures (B), atmospheric pressure was the major contributor, having a larger correlation than *CIABJJ*. These two variables are highly associated with each other. They may in truth be alternate descriptions of the same or similar climatic conditions.

After variability due to the combined comfort indices was removed, other factors less closely related to climate (hardness, potassium and population density of the central city) were the largest contributors to the residual variance in the four sets of areas. Total hardness and the concentration of potassium in the local water supplies were the most consistently large contributors. When variability associated with atmospheric pressure was removed from the group of cities with intermediate mean annual temperature (Table 1, part B), mean January relative humidity correlated more highly than the other remaining variables; thus its variability was next to be removed. This process was repeated until further reductions in the residual variance were insignificant.

Similarly, after variability due to the 3 socio-economic variables (education, rent and income) was removed, July relative humidity (*RH* 7) was the largest contributor to the total variance of the proportionate mortality ratios in both the total group and in all 3 subgroups (Table 2). After variability due to mean July relative humidity was removed, hardness and potassium were again the most consistent contributors to the residual variance.

When the stepwise correlation analysis was repeated, using only the three variables, combined comfort index, hardness and potassium, in addition to income, rent and education, not only did these variables account for up to 49 per cent of the total observed variance in mortality rates between areas due to coronary heart disease (Table 5), they also accounted for up to 59 per cent of the total observed variance in proportionate mortality ratios due to coronary heart disease (Table 6). It should also be noted that the 3 socio-economic factors had very little relationship to coronary heart disease rates, but they were significantly related to the proportionate mortality ratios. That is a result of their high correlation, particularly in the warmer areas, with all causes of death other than coronary heart disease.

As a final step, regression coefficients were determined for each group of cities for the three variables, combined comfort index and total hardness and the concentration of potassium in the local drinking water. Predicted rates of both coronary heart disease mortality and proportionate mortality due to coronary heart disease were determined for all 116 areas using these coefficients and the observed environmental data. Table 7 shows that these three variables alone did remarkably well in estimating these rates. The three environmental variables accounted for 41 per cent of the variance of CHD mortality rates and 22 per cent of the variance in proportionate mortality due to CHD. Both these percentages are highly significant statistically ($F_{3112}=26.23$ for CHD mortality and $F_{3112}=15.72$ for proportionate mortality).

Although the sum of the January and July comfort indices (*CIABJJ*) is consistently related to death rates due to coronary heart disease, there are interesting differences in the correlation of the separate factors which go into *CIABJJ* (Table 4). Where both the average summer (*TA* 7) and winter (*TA* 1) temperatures are low, the correlation of the January comfort index (*CI* 1) with coronary heart disease rates is stronger than

TABLE 5. SUMMARY OF THE STEPWISE CORRELATION ANALYSIS BETWEEN CORONARY DEATH RATES AND SIX ENVIRONMENTAL VARIABLES IN PRE-SELECTED ORDER

Group	Variable eliminated	Partial correlation	Multiple correlation	Reduction of total variance	Level of probability
Group A	Education	−0.1070	0.1070	0.0115	0.476
46 areas	Rent	0.2889	0.3066	0.0940	0.051
with low	Income	0.0401	0.3089	0.0954	0.795
mean annual					
temperatures,	*CIABJJ*	−0.4790	0.5505	0.3030	0.001
less than 53°F	Hardness	−0.2329	0.5838	0.3408	0.134
	Potassium	−0.3123	0.6365	0.4051	0.044
Group B	Education	−0.0473	0.0473	0.0022	0.770
40 areas with	Rent	0.0901	0.1017	0.0103	0.583
intermediate	Income	0.3503	0.3630	0.1318	0.028
mean annual					
temperatures,	*CIABJJ*	−0.4876	0.5815	0.3382	0.002
53.0–62.9°F	Hardness	−0.4859	0.7032	0.4945	0.002
	Potassium	−0.0163	0.7033	0.4946	0.925
Group C	Education	−0.0309	0.0309	0.0010	0.870
30 areas	Rent	0.0316	0.0442	0.0020	0.870
with high	Income	0.0371	0.0577	0.0033	0.850
mean annual					
temperatures,	*CIABJJ*	−0.6109	0.6126	0.3753	<0.001
63°F or more	Hardness	−0.3648	0.6771	0.4584	0.061
	Potassium	0.1230	0.6831	0.4666	0.553

TABLE 6. SUMMARY OF THE STEPWISE CORRELATION ANALYSIS BETWEEN THE PROPORTIONATE MORTALITY RATIO AND SIX ENVIRONMENTAL VARIABLES IN PRE-SELECTED ORDER

Group	Variable eliminated	Partial correlation	Multiple correlation	Reduction of total variance	Level of probability
Group A	Education	−0.0141	0.0141	0.0002	0.925
46 areas	Rent	0.3002	0.3006	0.0903	0.042
with low	Income	−0.0077	0.3006	0.0904	0.960
mean annual					
temperatures,	*CIABJJ*	−0.3253	0.4320	0.1867	0.031
less than 53°F	Hardness	−0.1063	0.4425	0.1958	0.500
	Potassium	−0.1574	0.4645	0.2158	0.322
Group B	Education	0.1015	0.1015	0.0103	0.530
40 areas with	Rent	−0.0375	0.1081	0.0117	0.820
intermediate	Income	0.0670	0.1270	0.0161	0.687
mean annual					
temperatures,	*CIABJJ*	−0.4718	0.4849	0.2352	0.002
53.0–62.9°F	Hardness	−0.2946	0.5491	0.3015	0.077
	Potassium	0.1706	0.5673	0.3219	0.322
Group C	Education	0.3997	0.3997	0.1598	0.025
30 areas	Rent	0.0414	0.4015	0.1612	0.829
with high	Income	0.1244	0.4174	0.1742	0.524
mean annual					
temperatures,	*CIABJJ*	−0.6393	0.7154	0.5117	<0.001
63°F or more	Hardness	−0.4035	0.7689	0.5913	0.036
	Potassium	0.0391	0.7693	0.5918	0.851

TABLE 7. OBSERVED AND PREDICTED AGE-ADJUSTED MORTALITY RATES PER 100,000 FOR WHITE MALES AGED 45–64 YR, IN 116 METROPOLITAN AREAS, GROUPED BY MEAN ANNUAL TEMPERATURE

Group A. Mean annual temperature less than 53°F

Area		Coronary disease mortality				Proportionate mortality			
		Observed		Predicted		Observed		Predicted	
		Rank	Rate	Rate	P/O*	Rank	Ratio	Ratio	P/O*
Albany	N	7	725.5	588.7	0.811	16	0.393	0.367	0.934
Portland	M	11	699.5	600.3	0.858	6	0.413	0.371	0.898
Rochester	N	17	652.2	593.0	0.909	4	0.423	0.369	0.872
Springfield	I	22	632.3	606.9	0.960	56	0.355	0.373	1.049
Sioux City	I	24	626.3	437.0	0.698	28	0.379	0.326	0.861
Cleveland	O	26	625.6	586.0	0.937	51	0.358	0.367	1.026
Bridgeport	C	27	618.3	596.2	0.964	17	0.393	0.370	0.942
Seattle	W	28	615.8	629.5	1.022	44	0.365	0.380	1.041
Indianapolis	I	29	615.8	584.4	0.949	58	0.354	0.367	1.037
Buffalo	N	31	612.9	588.9	0.961	76	0.339	0.368	1.086
Binghamton	N	32	612.8	594.2	0.970	25	0.383	0.369	0.965
Syracuse	N	34	610.3	578.2	0.947	36	0.371	0.364	0.982
Boston	M	37	606.0	574.3	0.948	50	0.358	0.363	1.012
Dayton	O	38	605.6	592.0	0.977	7	0.410	0.369	0.901
Milwaukee	W	39	604.3	572.9	0.948	39	0.370	0.363	0.981
Lansing	M	44	598.5	610.8	1.020	3	0.427	0.374	0.876
Pittsburgh	P	46	595.5	584.5	0.981	60	0.352	0.367	1.043
Providence	R	47	593.2	591.7	0.998	54	0.356	0.368	1.035
Allentown	P	49	588.6	578.1	0.982	29	0.377	0.365	0.968
Toledo	O	51	580.3	588.5	1.014	70	0.343	0.368	1.073
Duluth	M	53	578.8	557.9	0.964	23	0.384	0.358	0.932
Chicago	I	56	574.4	568.9	0.990	101	0.307	0.362	1.176
Hartford	C	57	573.3	598.7	1.044	38	0.370	0.370	1.001
Grand Rapids	M	59	571.0	597.7	1.047	15	0.397	0.371	0.934
Fort Wayne	I	60	571.0	581.9	1.019	26	0.381	0.367	0.962
Moline	I	62	569.1	556.6	0.978	13	0.401	0.358	0.894
Omaha	N	63	566.7	487.1	0.860	31	0.377	0.340	0.901
Youngstown	O	64	565.6	582.0	1.029	48	0.359	0.367	1.022
Detroit	M	69	563.4	584.8	1.038	75	0.339	0.366	1.080
South Bend	I	70	563.0	588.5	1.045	22	0.385	0.368	0.956
Sioux Falls	S	72	558.8	484.4	0.867	12	0.403	0.338	0.837
Portland	O	80	538.0	615.7	1.145	63	0.350	0.376	1.073
Minneapolis	M	81	537.2	512.3	0.954	41	0.368	0.344	0.935
Terre Haute	I	82	531.1	577.5	1.087	102	0.303	0.365	1.206
Columbus	O	83	528.5	581.8	1.101	78	0.338	0.367	1.084
Denver	C	84	527.0	486.5	0.923	81	0.337	0.336	0.996
Peoria	I	87	518.4	570.1	1.100	79	0.338	0.362	1.070
Des Moines	I	90	514.4	537.2	1.044	71	0.343	0.353	1.030
Akron	O	96	491.5	600.7	1.222	72	0.342	0.372	1.087
Salt Lake City	U	97	491.0	496.3	1.011	91	0.327	0.339	1.036
St. Joseph	M	99	482.8	511.8	1.060	69	0.344	0.347	1.008
Spokane	W	102	461.6	511.3	1.108	97	0.312	0.344	1.102
Madison	W	104	458.1	542.1	1.183	67	0.348	0.354	1.016
Green Bay	W	110	400.7	484.0	1.208	94	0.320	0.338	1.056
Pueblo	C	115	357.5	465.1	1.301	106	0.294	0.330	1.123
Lincoln	N	116	299.0	454.2	1.519	110	0.263	0.332	1.259

*Predicted ratio/Observed ratio.

TABLE 7 (continued).

Group B. Mean annual temperatures 53.0–62.9°F

Area		Coronary disease mortality				Proportionate mortality			
		Observed		Predicted		Observed		Predicted	
		Rank	Rate	Rate	P/O*	Rank	Ratio	Ratio	P/O*
Norfolk	V	4	753.7	608.0	0.807	5	0.420	0.364	0.867
Sacramento	C	6	730.6	561.6	0.769	74	0.340	0.339	0.997
Richmond	V	10	706.5	601.4	0.851	24	0.383	0.358	0.934
Charlotte	N	12	696.6	617.8	0.887	1	0.448	0.363	0.810
Greenville	S	14	692.2	634.8	0.917	35	0.374	0.366	0.978
Los Angeles	C	15	679.1	601.0	0.885	11	0.403	0.370	0.917
New York	N	16	677.4	577.8	0.853	21	0.387	0.342	0.884
San Francisco	C	19	639.4	652.0	1.020	57	0.355	0.379	1.069
Raleigh	N	25	626.2	620.3	0.991	34	0.375	0.362	0.963
Philadelphia	P	30	613.9	568.2	0.925	73	0.341	0.347	1.019
Little Rock	A	33	611.2	626.8	1.025	32	0.377	0.365	0.968
Harrisburg	P	35	607.8	598.6	0.985	27	0.381	0.349	0.914
Washington	D	36	607.7	537.2	0.884	47	0.359	0.335	0.933
Baltimore	M	45	598.1	578.8	0.968	93	0.321	0.348	1.084
Wilmington	D	48	590.1	593.2	1.005	52	0.357	0.352	0.987
Memphis	T	50	584.1	609.5	1.044	86	0.331	0.359	1.086
Chattanooga	T	54	576.7	589.4	1.022	77	0.339	0.354	1.047
Cincinnati	O	55	574.5	543.6	0.946	89	0.328	0.340	1.036
San Diego	C	58	572.7	514.0	0.898	55	0.355	0.346	0.974
Atlanta	G	61	570.1	629.6	1.104	68	0.346	0.369	1.065
Newark	N	66	564.2	573.5	1.017	88	0.329	0.341	1.038
Kansas City	M	67	564.1	550.8	0.976	62	0.350	0.344	0.983
Louisville	K	74	551.7	571.7	1.036	92	0.327	0.351	1.074
Tulsa	O	75	550.9	561.0	1.018	61	0.350	0.341	0.974
Evansville	I	76	547.5	545.3	0.996	84	0.332	0.342	1.029
Winston Salem	N	77	547.0	603.1	1.102	59	0.353	0.353	1.000
Wichita	K	78	543.1	533.7	0.983	46	0.363	0.332	0.914
Springfield	M	79	539.9	531.8	0.985	30	0.377	0.332	0.881
Greensboro	N	85	521.6	604.0	1.158	40	0.369	0.364	0.985
Oklahoma City	O	89	516.7	533.9	1.033	90	0.327	0.349	1.065
Roanoke	V	92	512.7	589.1	1.149	45	0.364	0.351	0.964
Fresno	C	93	507.5	522.9	1.030	103	0.298	0.329	1.103
St. Louis	M	94	498.3	574.1	1.152	107	0.291	0.356	1.223
Topeka	K	95	493.4	542.3	1.099	19	0.392	0.347	0.886
Amarillo	T	98	483.7	450.5	0.931	98	0.309	0.308	0.995
Nashville	T	100	477.4	595.5	1.247	104	0.294	0.356	1.212
Knoxville	T	103	460.8	577.7	1.254	105	0.294	0.355	1.210
Lubbock	T	111	399.6	403.9	1.011	87	0.330	0.307	0.930
Albuquerque	N	112	389.1	442.8	1.138	112	0.258	0.278	1.081
Lexington	K	114	364.9	571.2	1.565	111	0.263	0.348	1.324

*Predicted ratio/Observed ratio.

that for July (*CI* 7), 0.4532 and −0.3566, respectively. Conversely, where both summer and winter temperatures are relatively high, *CI* 7 correlates better with coronary heart disease rates than does *CI* 1 (−0.5985–0.3921).

When the individual climatic variables were compared for the 3 groups, the Temperature–Humidity Index (*THI*) always had a lower correlation with mortality rates than did the corresponding average temperature (*TA*). The latter correlation, in turn, usually was weaker than that for relative humidity (*RH*) (Table 4). Thus, for this set of data, *THI* is a poor predictor of CHD rates, and relative humidity is

TABLE 7 (continued)

Group C. Mean annual temperatures at least 63.0°F

Area		Coronary disease mortality				Proportionate mortality			
		Observed		Predicted		Observed		Predicted	
		Rank	Rate	Rate	P/O*	Rank	Ratio	Ratio	P/O*
Savannah	G	1	826.8	652.2	0.789	14	0.397	0.365	0.917
Charleston	S	2	825.6	671.0	0.813	43	0.366	0.373	1.018
Galveston	T	3	802.1	608.0	0.758	10	0.405	0.336	0.831
New Orleans	L	5	747.4	642.9	0.860	53	0.356	0.361	1.013
Baton Rouge	L	8	720.6	690.4	0.958	2	0.429	0.385	0.897
Montgomery	A	9	707.3	649.9	0.919	33	0.376	0.368	0.981
Augusta	G	13	693.2	644.3	0.929	66	0.348	0.365	1.048
Miami	F	18	646.5	594.3	0.919	18	0.392	0.340	0.866
Jackson	M	20	634.4	640.2	1.009	49	0.359	0.362	1.010
Dallas	T	21	633.2	561.1	0.886	9	0.405	0.340	0.840
Fort Worth	T	23	630.9	508.8	0.806	8	0.406	0.312	0.769
Columbus	G	40	603.4	653.3	1.083	96	0.315	0.367	1.163
Columbia	S	41	602.2	632.3	1.050	64	0.349	0.360	1.032
Mobile	A	42	599.9	676.2	1.127	42	0.368	0.374	1.018
Shreveport	L	43	599.1	625.8	1.045	20	0.388	0.357	0.918
Jacksonville	F	52	579.9	527.5	0.910	85	0.331	0.290	0.878
Macon	G	65	564.4	632.8	1.121	109	0.283	0.359	1.270
Corpus Christi	T	68	563.6	630.4	1.119	65	0.348	0.360	1.034
Tampa	F	71	560.3	577.9	1.031	82	0.336	0.326	0.968
Port Arthur	T	73	553.0	666.8	1.206	80	0.338	0.370	1.097
Houston	T	86	521.1	645.0	1.238	100	0.307	0.363	1.179
Birmingham	A	88	517.6	610.8	1.180	99	0.309	0.346	1.119
Orlando	F	91	512.9	596.3	1.163	95	0.316	0.331	1.048
Austin	T	101	475.7	569.3	1.197	83	0.334	0.336	1.006
Wichita Falls	T	105	446.6	509.2	1.140	37	0.371	0.315	0.850
El Paso	T	106	441.5	478.0	1.083	114	0.247	0.317	1.284
San Antonio	T	107	429.9	485.3	1.129	113	0.249	0.280	1.124
Phoenix	A	108	422.7	338.7	0.801	115	0.222	0.242	1.090
Laredo	T	109	405.5	420.6	1.037	116	0.205	0.243	1.186
Waco	T	113	372.7	500.3	1.342	108	0.285	0.297	1.041

*Predicted ratio/Observed ratio.

frequently better than average temperature. The interaction of relative humidity and temperature (*CI*) is frequently a better predictor of coronary rates than any single factor. As noted earlier, when the summer and winter comfort indices are combined (*CIABJJ*), even a better predictor of death rates due to coronary heart disease is obtained.

To explore these interactions further, the cities in the highest and lowest quartiles of coronary heart disease were plotted by January (Fig. 2) and July (Fig. 3) temperature, relative humidity, and comfort index. In both figures, cities with low coronary heart disease rates appeared to be those with a high absolute value (greater than 3.5) of the comfort index. During January, there was little variation in mean relative humidity, but mean temperatures were positively related to coronary rates. Figure 3 shows striking relationships in July. Cities with high coronary heart disease rates appeared to be those in which there was both a high average July temperature (greater than 77°F.) and high average July relative humidity (greater than 70 per cent). Low rates were concentrated where there was a high temperature and low relative humidity. When the mean July temperature was moderate, less than 77°F., there appeared to be

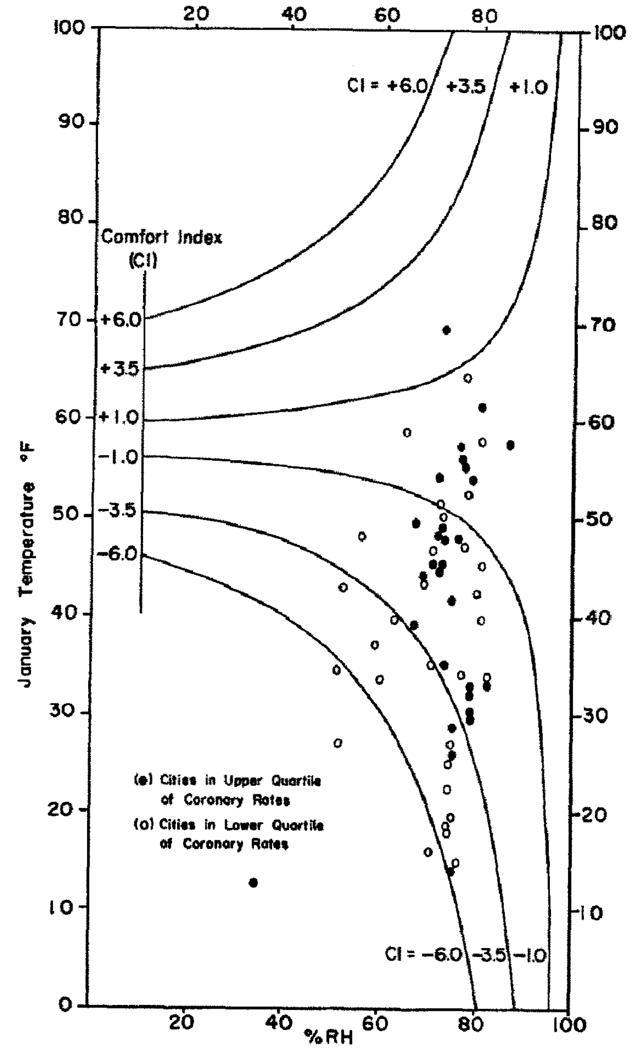

FIG. 2. Mean January temperature and relative humidity of cities in highest and lowest quartiles of coronary rates.

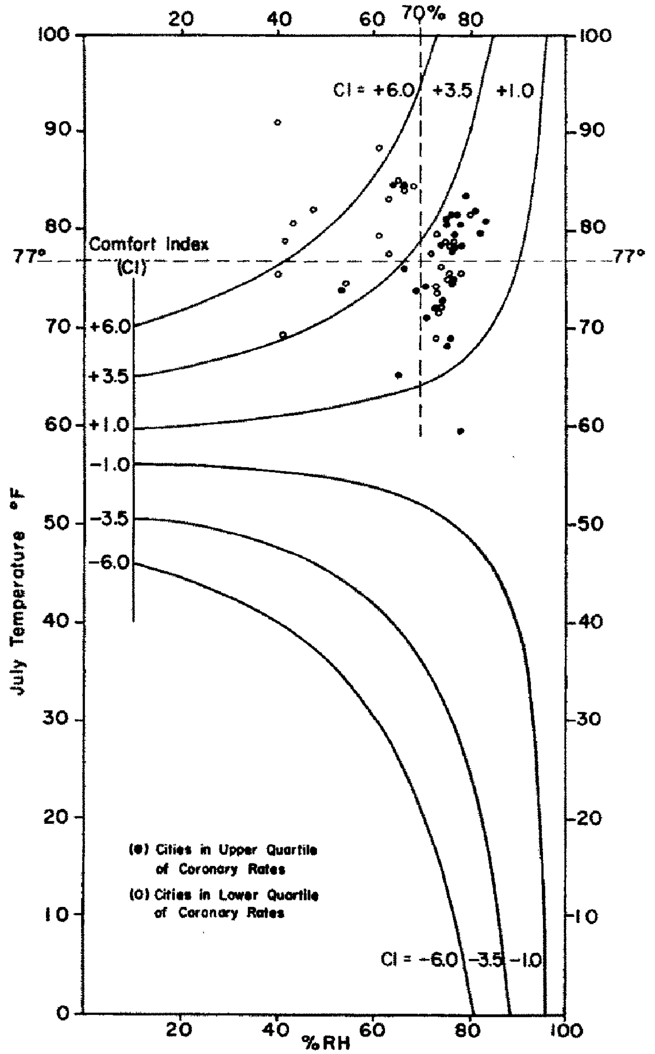

FIG. 3. Mean July temperature and relative humidity of cities in highest and lowest quartiles of coronary rates.

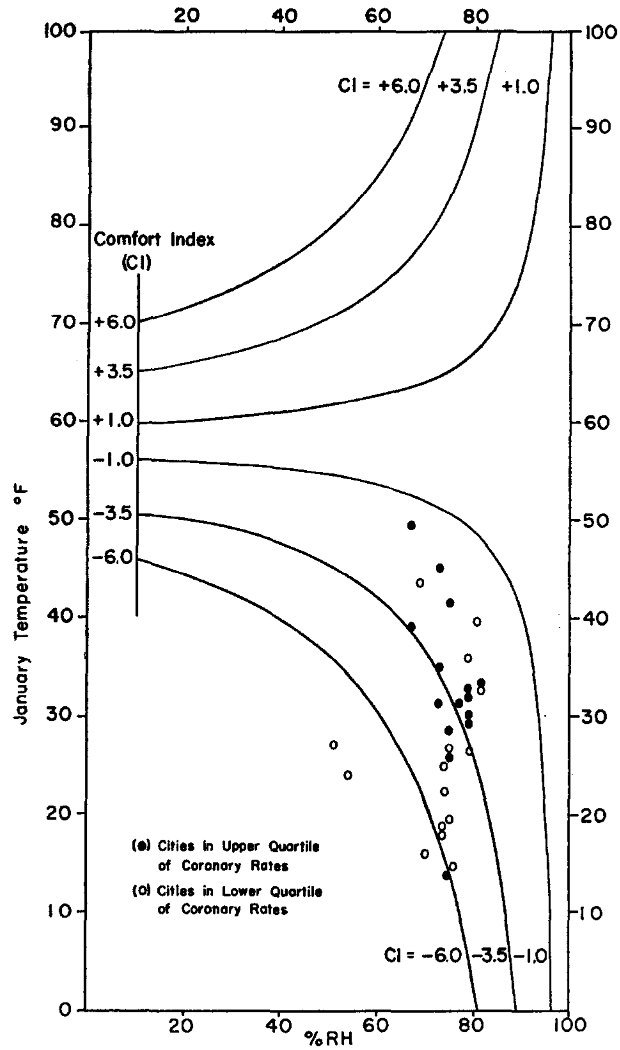

FIG. 4. Mean January temperature and relative humidity of cities in highest and lowest quartiles of coronary rates and having mean July temperature less than 77°F.

TABLE 8. OBSERVED AND EXPECTED FREQUENCIES OF THE DISTRIBUTION OF MEAN JULY TEMPERATURE BY TEMPERATURE, RELATIVE HUMIDITY, AND CORONARY MORTALITY RATES

Coronary rates	High temperature (>77°F)		Low temperature	Total
	RH>70 per cent	RH<70 per cent		
Lower 25 per cent	6* (10.75)†	11 (3.25)	12 (15.0)	29
Middle 50 per cent	23 (21.50)	0 (6.50)	35 (30.0)	58
Upper 25 per cent	14 (10.75)	2 (3.25)	13 (15.0)	29
Total	43	13	60	116

*Observed. χ^2 (d.f.=4)=30.34.
†Expected. p=0.001.

little relationship between these factors and death rates due to coronary heart disease (CHD). A chi-square test of the association between mean July temperature and relative humidity, and coronary mortality rates (Table 8) was significant at the 0.001 level of probability. The average coronary heart disease rates and proportionate mortality ratios for these climatic situations were as follows:

Mean July temperature	Mean July relative humidity	Number of cities	Mean CHD rate	Mean proportionate mortality ratio	Mean total mortality rate
All metropolitan areas		116	570.63	0.3498	1632.9
Greater than 77.0°F.	At least 70 per cent	43	610.07	0.3519	1733.1
Less than 77.0°F.	All	60	565.37	0.3588	1574.3
Greater than 77.0°F.	Less than 70 per cent	13	464.51	0.3015	1571.9

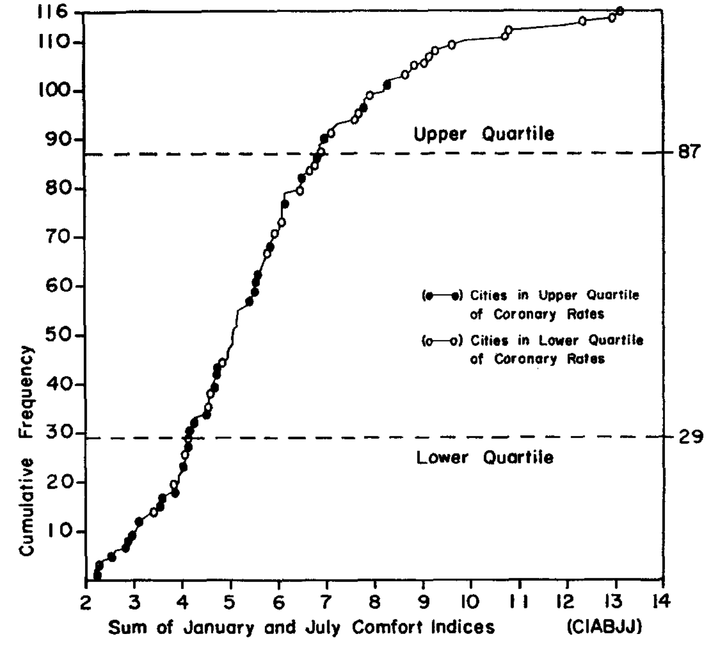

FIG. 5. Cumulative frequency curve of the sum of the January and July comfort indices, showing metropolitan areas having coronary rates in the upper or lower quartiles of mortality rates due to coronary heart disease.

When the January variables of only those cities with mean July temperature less than 77°F. were replotted (Fig. 4), the January comfort index can be seen to be of importance in distinguishing between those with high and those with low CHD rates.

Figure 5 shows that when the comfort indices for January and July were summed (*CIABJJ*), high mortality rates were associated with low values of *CIABJJ*, and low mortality rates were associated with high values of *CIABJJ*. Again, a chi-square test of association was significant at the 0.001 level of probability (Table 9).

TABLE 9. OBSERVED AND EXPECTED FREQUENCIES OF CORONARY MORTALITY RATES BY JANUARY PLUS JULY COMFORT INDICES (*CIABJJ*)

Coronary rates	*CIABJJ*			Total
	Lower 25 per cent	Middle 50 per cent	Upper 25 per cent	
Lower 25 per cent	4* (7.25)†	9 (14.50)	16 (7.25)	29
Middle 50 per cent	12 (14.50)	36 (29.00)	10 (14.50)	58
Upper 25 per cent	13 (7.25)	13 (14.50)	3 (7.25)	29
Total	29	58	29	116

*Observed.
†Expected.

χ^2 (d.f.=4)=24.84.
p=0.001.

DISCUSSION

Water characteristics

Investigations in several parts of the world have found significant negative correlations between death rates due to cardiovascular disease and some factor associated with the hardness of local water supplies. CRAWFORD and CRAWFORD [26], for example, have pointed out the higher CHD rates in a soft-water area (Glasgow) than in a hard-water area (London).

Despite the similarity in the direction of correlations in various studies between water hardness and CHD death rates, these studies have not agreed on the specific anions or cations that may be associated with cardiovascular disease. SCHROEDER [8] reported highly significant associations between death rates from arteriosclerotic heart disease in the United States and total hardness and the concentration of potassium and magnesium (but not calcium) in the local water supplies. MORRIS [9] using British data, reported correlations with calcium but not magnesium.

BIÖRCK [27] concluded that it seemed reasonable to regard the calcium content of the local water supply as an "indicator" of some other environmental factor which might be more directly related to CHD. SCHROEDER [8] also suggested that some quality of water "associated with, but other than, those measured may influence cardiovascular disease rates". MORRIS [9] found that other factors such as the amount of rainfall were associated with both hardness of local water supplies and cardiovascular mortality. LINDEMAN [28], in his study of the relationship between water hardness and cardiovascular deaths in rural counties of Oklahoma (minimizing geographic and environmental variables), found large variations among observed cardiovascular rates and also among levels of water hardness. However, he found no significant correlations between hardness and CHD as had been found over wider geographic areas in other studies in the United States and Great Britain. He also suggested that one or more other factors may be related both to water content and to an increase in cardiovascular disease.

In the present study, calcium, magnesium, and hardness were highly interrelated but they were not related to sodium or potassium. Total hardness was negatively related to mortality indices in the intermediate and warm areas whereas potassium had a significant, negative relationship to mortality in the cold areas only. Sodium content in water was found to be insignificantly related to CHD rates, even though various investigators have suggested relationships between sodium and hypertension, which in turn is related to coronary disease. The contribution of these ions to the total observed variance was less than that of the climatic factors. Differences in climate were most important among all of the factors studied, but when variability in rates due to these differences was removed, differences in water characteristics became of next greatest importance.

Climatic characteristics

The present study differs in one important respect from other epidemiological studies of the relation of climate to cardiovascular disease. Others have considered the effects of daily, monthly and yearly changes in weather on seasonal variations in disease incidence at one location. In contrast the present work is a study of the relationships between average climatic conditions in 116 metropolitan areas and disease mortality over a 3 yr period.

In the analysis of climatic factors in relation to CHD mortality, the single factor which seemed to be most consistently related to coronary heart disease rates was the "comfort index". Regardless of whether it was positive or negative, the greater the magnitude of the comfort index, the lower were both the CHD mortality rate and the proportion of total mortality due to coronary heart disease. The index was formulated from mean monthly temperature and humidity readings. The sum of the absolute values of this index for both seasonal extremes (January and July) was most highly related to CHD rates. Hot and humid areas had the highest annual rates of coronary heart disease, and hot, dry areas had the lowest rates of CHD, with other areas intermediate. The conclusion suggested is that chronic environmental discomfort (if not actual stress) is in some way associated with the development of coronary heart disease.

Since it can be shown that climatic and other environmental factors are related to CHD mortality, it would be of interest to determine whether this relationship is a result of the greater frequency of acute environmental stress (precipitating factors of coronary events) or if these factors provide a chronically stressful setting which promotes or accelerates the development of atherosclerosis.

Physical exertion or emotional stress, particularly when combined with adverse weather, has not infrequently been noted as a precipitating factor in myocardial infarction, and especially notable in angina pectoris. Seasonal fluctuations in CHD mortality corresponding to adverse weather conditions have been demonstrated in both hot and cold climates. The present data also point out differences in annual incidence of CHD mortality in the various climatic areas, thereby including all seasons.

Hypotheses to explain the differing seasonal and annual incidence rates may take 2 directions. The first is that the greater annual incidence of CHD in the hot, humid areas is a reflection of a greater number of acute stressful climatic events, each a potential precipitant of CHD. This hypothesis carries the presumption of equal degrees of underlying disease in all areas. Also, it would be presumed that the event awaits the precipitant, and in the absence of a sufficiently stressful precipitant, the coronary event would be delayed or avoided. This hypothesis implies that climatic stress is a precipitating factor and may have little, if any, relationship to etiology.

An alternative hypothesis to the "number of acute precipitants" theory is that *chronic* environmental stress is of importance in increasing susceptibility to CHD, and perhaps accelerating the underlying atherosclerotic process. Chronic stress may be no more than "discomfort", and not acute, severe challenges such as extremes of temperature or humidity. Such a hypothesis would presume that precipitating factors, though important, may be almost incidental in the larger consideration of the onset and development of the disease itself. When conditions within the arteries approach a critical stage, it seems likely that very little additional stress may be required to complete the pathologic process and to produce manifest symptomatic disease or death. However, it may well be true that both acute and chronic aspects of climatological stress may play a role in the production of observed differences in CHD rates in the various geographic areas.

SAUER [29, 30] and SYME [31] discuss the relationship of residential mobility and coronary heart disease mortality. Syme states that: "(1) migrants from states having low coronary death rates have higher death rates than those still living in the low-rate state; and (2) migrants from states having high coronary death rates have about the same rates as those still living in the high-rate states". This would suggest that the CHD-producing effect of a high-risk area is generated early in life and is permanent. Also, that this effect is modified at older ages, as evidenced by increasing rates in migrants from a low-risk area to a high-risk area. Such effects are more consistent with a "chronic" effect than a series of "acute" effects.

In addition to the association between "comfort" and coronary heart disease, another climatological factor, temperature variation (*TV* 1, *TV* 7, *YTV*), was found to be negatively correlated with coronary heart disease rates. Where there were large differences between average monthly maximum and minimum temperatures, or between mean January and July temperatures, coronary rates tended to be low. With large daily and seasonal variations, it would seem that periods of climatic stress might be severe, but would be of relatively shorter duration than in those climates with lesser daily change. Large fluctuations in daily temperatures are usually associated with large inverse fluctuations in relative humidity, thereby minimizing the amount of humidity (and resulting discomfort) when temperatures are high. When fluctuations are small, relative humidity is usually high, and the discomfort continues for a longer period.

Cultural aspects of urbanization also influence the climate to which man is exposed by providing heated homes and buildings in winter, and, with increasing frequency, air conditioning in summer. Thus, exposure to extremes of weather is reduced. Despite these moderating influences, factors related to temperature and relative humidity, and to the interactions between them, appear to be of significance to death rates due to coronary heart disease, both in cold climates during the winter and in warm climates during the summer.

The hot and humid summer of the southeastern United States presents a greater climatic stress than do either the relatively mild winters of that area or the cooler regions to the north. Therefore, it would seem reasonable that observed deaths due to CHD are most frequent during the summer months, and that annual death rates are higher than those of cooler or less humid areas. In the northern parts of the country where summers are mild, the colder winters represent the period of greater cardiovascular stress. However, in either extreme of temperature, an increasing humidity is associated with increasing risk of CHD.

BURCH and DE PASQUALE [25] present a discussion of the theoretical, experimental, and clinical aspects of the effect of hot and humid environments on man. Their studies show that the increased burden of thermoregulation imposed by hot and humid conditions may be analogous to a form of strenuous exercise. Such an environment "increases cardiac output, stroke volume, mechanical and physiologic cardiac work, and tension upon the walls of the ventricles". Under these conditions, cardiac work may increase even without exercise and without bodily movement. Furthermore, hot and humid climates discourage physical exercise. One might hypothesize that the increase in cardiac work without bodily exercise may be in some way a factor in the pathogenesis of coronary artery disease. The converse, that of the increase in effort associated with thermoregulation in cold, especially damp, cold climates may well be an analogous situation, and may in some way promote the development of atherosclerosis.

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