EVALUATION OF THERMAL ENVIRONMENT IN SHELTERS

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Occupational Health

EVALUATION OF THERMAL ENVIRONMENT IN SHELTERS

Douglas H. K. Lee, M.D.
and
Austin Henschel, Ph.D.

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Occupational Health Research and Training Facility
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FOREWORD

On 23 October, 1962, the Chief, Research Branch, Division of Health Mobilization, Office of the Surgeon General, requested the Division of Occupational Health to conduct a study on the effects of extremes of the environment on shelter occupants, desired by the Director of Research, Office of Civil Defense.

On 5 November, 1962, the authors met with the Director of Research and several of his assistants in Washington, and presented an outline of the study they were prepared to undertake under three headings:

Scope of Study

State physiological and clinical effects of environmental factors in quantitative terms, and the relative contributions of each, in a form which will guide planners as to the significance of various combinations.

Will not try to estimate what conditions may occur or comment on methods of ameliorating conditions, unless there is an overriding physiological or clinical aspect.

Sets of Variables to be Considered

A. Environmental conditions: temperature, humidity (in various aspects), air movement, radiant heat, clothing, approximation of persons.

B. Human factors: activity, age, acclimatization, functional impairment, disease, hydration, diet, normal variation.

C. Significant effects: comfort, sensations of distress, functional failures, physiological crises, exacerbation of existing disease, infectious disease, water requirements, clothing requirements.

Approach

A. Establish zones of effect for standard person on a psychrometric chart.

B. Establish quantitative adjustments to be made for departure from standard person.

C. Establish quantitative adjustments to be made for variations in environment other than temperature and humidity.

D. Prepare tables of significant effects for each zone.

These proposals were discussed in some detail and accepted as the basis for contract negotiation. The formal contract was signed on 21 March, 1963.

The contract was further amended on 7 June, 1963, to provide for the supply of 500 copies of the final report and an annotated bibliography.

In June, 1963, the authors presented an outline of the report being developed, at a seminar on "Physiological Aspects of an Austere Environment", conducted by the Research Directorate of the Office of Civil Defense.

This document constitutes the final report under the contract. The annotated bibliography will be presented separately.

EVALUATION OF THERMAL ENVIRONMENT IN SHELTERS

SUMMARY

Various schemes which have been advanced for expressing the significance of a given set of environmental conditions as a single number, or as a semi-quantitative simple phrase, are reviewed, including the katathermometer, wet bulb-globe thermometer, effective temperature, operative temperature, EP index, P_4SR index, heat stress index, and psychrometric plots.

An index of relative strain is developed, similar to that used by Belding and Hatch in their heat stress index, but based on Burton's wet clothes formula for the calculation of actual and relative cooling demands. A chart is developed in which relative strain lines are drawn on a psychrometric chart for standard conditions of activity, clothing, air movement, and radiant heat transfer most likely to be found in shelters. A table is provided for adjusting the reading on the chart for certain non-standard conditions of activity and air movement.

The significance of each zone for a standard "average" person is expressed in graphic form for such considerations as comfort, discomfort, distress, failure, performance, and tolerance. Further charts indicate the significance of each zone for such non-standard states as cardiopulmonary disease, metabolic disturbances, gastrointestinal upsets, psychological abnormalities, dermatological complaints, infancy, middle age, old age, acclimatization, limited water supply, and obesity.

The report seeks to present the best judgment of the authors on the evidence available at this time. As knowledge of thermal physiology and the effects of clinical disorders upon heat responses is extended, improvements will undoubtedly become possible; but for the present it is believed that the estimates presented here will permit optimum management of the shelter situation.

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BACKGROUND

Over the sixty years since Haldane reported on the Cornish tin miners (1) there have been numerous attempts to devise a system whereby the significance of a given set of environmental conditions could be expressed as a single number, or at least a semi-quantitative simple phrase. Efforts have centered around the thermal aspects of the environment because it was believed that the well-known physical laws governing heat exchange would permit a relatively simple and reliable formulation to be established. It still seems reasonable to concentrate on the thermal aspects, but it is clear that a formulation cannot be simple and accurate at the same time, and that a workable scheme must necessarily be something of a compromise.

VARIABLES INVOLVED

Three sets of variables are involved in assessments of significance:

1. Environmental conditions:

   temperature, humidity, air movement, noise, clothing, contiguity, radiant heat.

2. Human factors:

   activity, age, acclimatization, functional efficiency or impairment, disease, hydration, nutrition, individual variability within any one of these sub-classes.

3. Significant effects:

   comfort - discomfort, sensations of distress, functional failures, physiological crises, pathological developments, exacerbation of pre-existing disturbances, infections, water needs, clothing needs.

Clearly it would be impossible, or at least impracticable, to set up a scheme giving full expression to all of these variables - even if the necessary quantitative data were available. Some selection must be made, and some condensation effected in the presentation of data if the results are to be comprehensible.

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CHARACTERISTICS OF A PREDICTIVE SCHEME

In making a selection of variables to be included, and in judging the adequacy of any particular method, the requirements of an ideal predictive scheme should be borne in mind. These have been set out elsewhere (2) as follows:

A. Permits read-in of data on the primary stress factor. Involves:

(1) Establishment of true stress factor or constant accompaniment

(2) Recognition of variability in nature and effectiveness of factor

(3) Development of accurate measurement of factor and equivalences of variants

B. Permits read-in of modifying effect of other environmental conditions. Involves:

(1) Recognition of factors having modifying effects, and quantitative relationship

(2) Measurement of incidence of modifying factors

(3) Establishment of any interaction between modifying factors.

C. Permits read-out of predicted effects on standard individual. Involves:

(1) Recognition of important effects

(2) Establishment of quantitative relationship between effect and primary stress

(3) Measurement of effects

(4) Determination of biological (or social) significance of effects, if possible as single integrated value.

D. Permits adjustment of prediction to non-standard individuals. Involves:

(1) Establishment of characteristics which affect responses

(2) Measurement of characteristics

(3) Determination of quantitative effects of these characteristics upon responses.

E. Indicates limits of confidence. Involves:

(1) Errors in measurement of primary and modifying factors

(2) Sampling errors in time and place

(3) Uncertainties in quantitative relationship

(4) Errors in measurement of response

(5) Individual variability

(6) Uncertainty in integration of different responses to give inclusive measure of strain.

F. Is applicable to various time-distributions of exposure. Involves:

(1) Response development on commencement of exposure

(2) Response decay on cessation of exposure

(3) Sets developing as result of exposure or absence of exposure

(4) Application of cyclical, intermittent or graduated exposure.

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EXAMPLES OF PAST PREDICTIVE SCHEMES

Attempts to provide predictive schemes fall roughly into three groups:

(1) Instrumental methods sought a device which would respond to the major environmental variables conjointly and in a fashion comparable to man's.

(2) Physiological methods, at the other extreme, set up charts or tables based on measured human responses, from which a given combination of environmental conditions could be evaluated.

(3) More attention has been given recently to formulation methods, which seek to base evaluation on the difficulty of maintaining a thermal balance in a given environment.

Some of the better known examples follow.

Katathermometer

In its earliest and simplest form (3) it was an alcohol thermometer, with a bulb measuring 1.5 x .75 in. and two marks engraved on the stem corresponding respectively to 100 and 95°F. The time taken for it to cool between these two marks, after it had been heated to a higher temperature, was measured. From this time, and the amount of heat lost from the katathermometer in cooling (the "factor" engraved on the stem), the "cooling power" of the air was determined. When the kata was used dry, the cooling power indicated the combined effect of air temperature, radiant heat, and air movement; when the bulb was wrapped with a wet sock, the cooling power included the effect of humidity as well.

Because the shape, dimensions, and thermal properties of the kata differed markedly from those of the human body, it fell into disuse. A silvered version in three ranges (100-95; 130-125; 150-145°F) has frequently been used to measure turbulent air movements. (4).

Wet Bulb-Globe Thermometer

Minard and co-workers (5) developed a simple index of combined effects of temperature, humidity, radiant heat, and air movement, which is obtained by combining dry bulb temperature (DBT), wet bulb temperature (WBT), and conventional dry globe thermometer temperature (GBT) in the following fashion:

For indoor use: WBGT = .7 (WBT) + .3 (GBT)

For outdoor use: WBGT = .7 (WBT) + .2 (GBT) + .1 (DBT)

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A comprehensive table of evaluations seems not to have been published, but the following practice has been reported for U. S. Marine Corps training centers:

WBGT	82 to 84.9	Green flag.	Alert for possible curtailment of drill.
WBGT	85 to 87.9	Yellow flag.	Active drill curtailed for new (less than four weeks) recruits.
WBGT	88 to 89.9	Red flag.	Active drill stopped for all recruits, except those in last quarter of 12 weeks training may continue routine training.
WBGT	90 and over		All training stopped.

We have found the globe thermometer to give unreliable readings in gusty wind, or in the vicinity of hot surfaces of limited extent, so that we would not expect the WBGT to be very accurate in many industrial situations. The significance of a given value for WBGT needs to be considered in terms of the activity of the person exposed, his clothing, degree of acclimatization, etc.

Effective Temperature

The earliest and most widely known scheme for indicating the thermal significance of environments based upon physiological reactions, is the "Effective Temperature" scheme, developed by a research team in the American Society of Heating and Ventilating Engineers.(6) Test subjects were exposed serially to atmospheres with different temperatures, humidities, and air movements, and asked to rate their comparative sensations of warmth or coolness. From a large number of records two nomograms were drawn up indicating the combinations which produced comparable sensations: (a) on normally clothed persons, and (b) on persons stripped to the waist. The latter is seldom used. For simplicity of understanding the significance of any combination is expressed as the temperature of a still, saturated atmosphere which would produce the same effect. For example, normally clothed persons exposed to a dry bulb temperature of 76°F, a wet bulb temperature at 62°F, and an air movement of 100 ft/min, on the average expressed the same sensations as when they were exposed to "still" air (actually an air velocity of 25 ft/min) with both dry and wet bulb temperatures at 68°F. The "effective temperature" of the former atmosphere is, therefore, said to be 68°F. From the appropriate nomogram, (Fig. 1), the "effective temperature" of any combination of dry bulb temperature, wet bulb temperature, and air movement can be determined.

Figure 1. **NOMOGRAM FOR DETERMINING CORRECTED EFFECTIVE TEMPERATURE FOR CLOTHED PERSONS.** From Bedford (4).

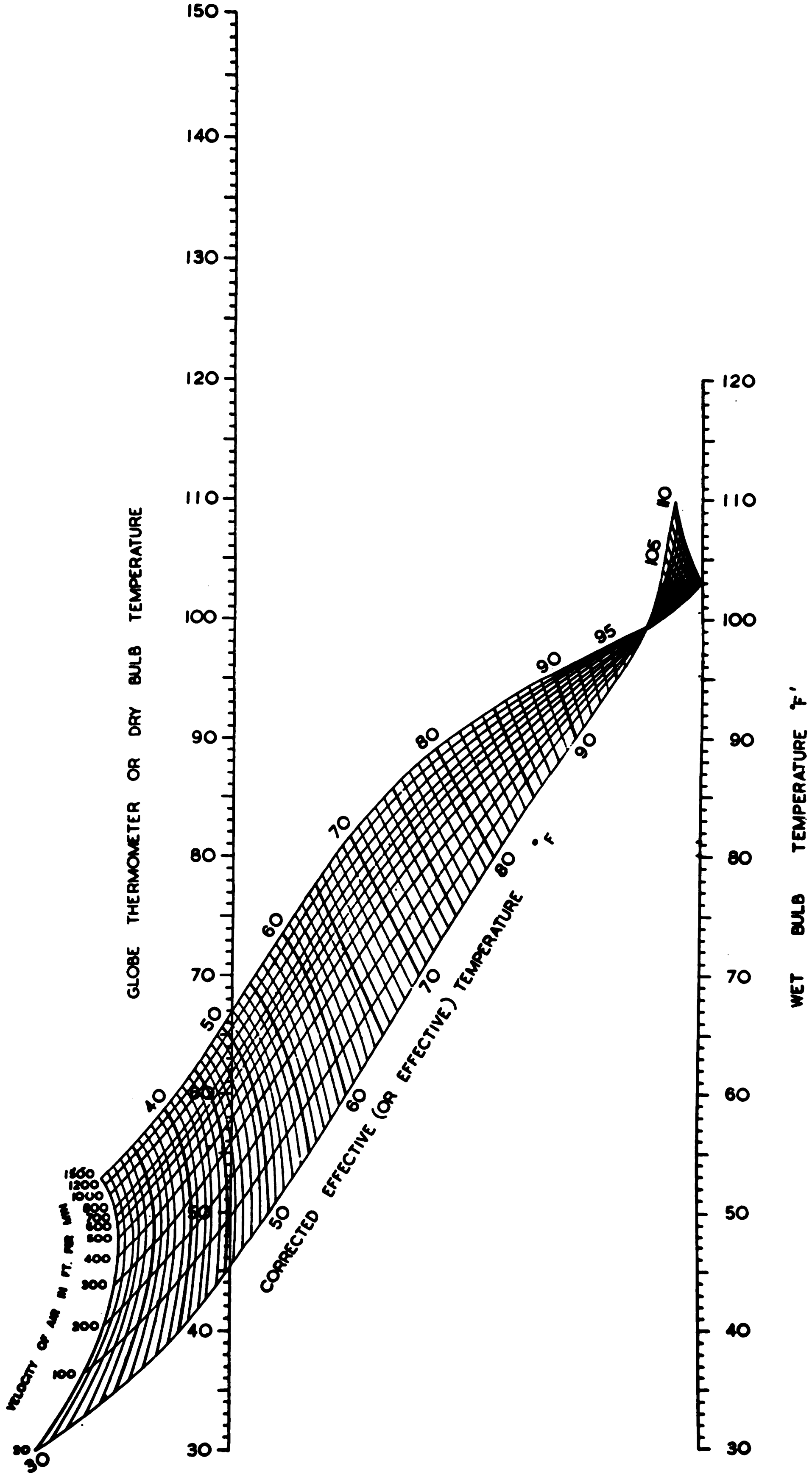

CHART SHOWING NORMAL SCALE OF CORRECTED EFFECTIVE (OR EFFECTIVE) TEMPERATURE

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This, like any other scheme, has certain limitations. Most of these were clearly recognized by the authors, but have not always been observed by users or critics.

(1) The basic observations were made on a specific group of subjects -- healthy, young, white men and women, living under the current American conditions of climate, housing, clothing, etc. The results are not necessarily representative of other groups, and should not be applied with abandon to inhabitants of England, let alone to Eskimos or African pigmies.

(2) The observations relate only to sedentary conditions, although some later modifications were drawn up to make the scheme applicable to greater activities.(7)

(3) The scheme applies only to persons clad as described. Heavy clothing could be expected to reduce the effect of air movement still further.

(4) The original scheme applies only to situations in which the mean black body temperature of the surroundings is substantially the same as the air temperature. It has been shown by Bedford (4), however, that the scheme can continue to be used where the temperatures of the surrounding surfaces differ from air temperature, provided that they are fairly uniform, if the globe thermometer temperature is substituted for the air temperature.

(5) It does not apply at air movements below 25 ft/min.

(6) It is not reliable at the upper end of the scale -- E.T. above 90°F -- since sensations of heat cease to be very good guides under conditions as hot as this.

(7) The scheme in its original form gives too much weight to changes in humidity at the lower end of the scale. The lines have recently been revised (8), but the entire nomogram has not yet been redrawn. The nomogram and the revisions are given as separate figures (Figs. 1 and 2).

The effective temperature scheme was based upon sensations of warmth and coolness, but there was superimposed upon it later a scale to indicate the proportion of the test population that could be expected to be comfortable at various effective temperatures. Some indication of the variation in preferences of different populations is given in Fig. 3. The scheme provides no scale for evaluating the physiological significance of stresses above or below the comfort zone.

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Operative Temperature

Workers at the Pierce Laboratory of Hygiene (12) early entered the field of formulation with the "operative temperature," which expressed the combined effect of air temperature, wall temperature and air movement as the temperature of still air (and walls) which would permit the same rate of heat loss.

$$t_o = \frac{K\,t_w}{1 + K} + \frac{1}{1 + K}\left[t_a \sqrt{\frac{V}{V_o}} - t_s\left(\sqrt{\frac{V}{V_o}} - 1\right)\right]$$

where K is ratio of radiation to convection constants

t_o is standard operative temperature

t_w is mean black-body temperature of walls

t_a is air temperature

V is rate of air movement

V_o is standard air movement (15 ft/min)

t_s is temperature of skin

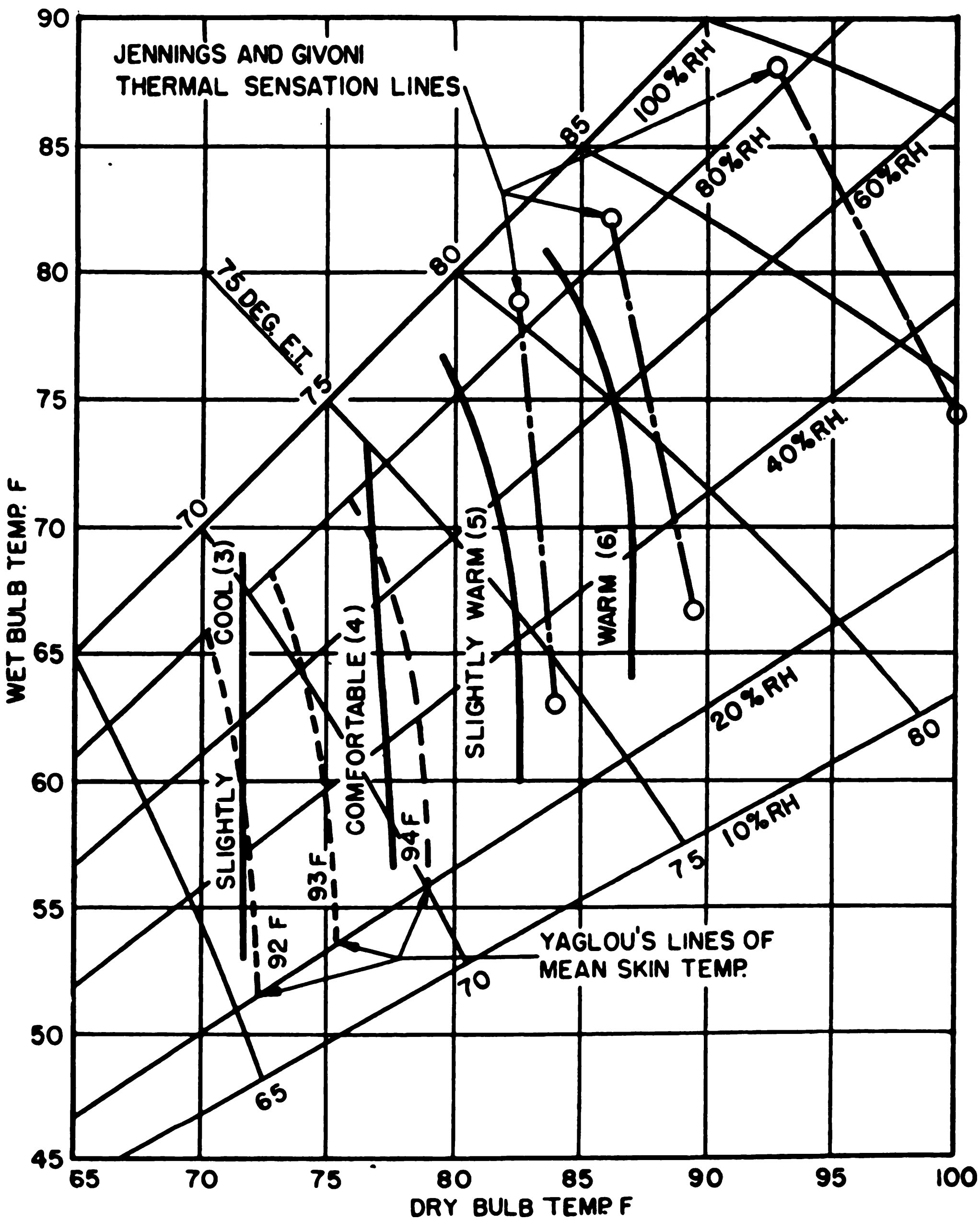
The proponents of this scheme deliberately omitted any expression of humidity from the equation on the grounds that: (a) humidity is not a factor in heat loss under cold conditions; (b) that if the humidity is changed under hot conditions, the unevaporated sweat passively increases the extent of the water film on the skin and does not put an extra burden on the body. In spite of this defense, the omission of humidity was felt to be a weakness, and the scheme was never widely adopted.

EP Index

Robinson and co-workers (13) devised an index of environmental significance based on the combined response of rectal temperature, pulse rate, skin temperature, and sweat rate. The concept of relative strain, that is the deviation from normal as compared with the maximum deviation that the body can tolerate without breaking down, was used here for the first time, although not clearly labelled as such. The relative strains for pulse rate, skin temperature, rectal temperature, and sweat loss were established for a variety of conditions, and the results expressed on dry bulb v wet bulb temperature grids (Fig. 4). Unfortunately, this scheme, in common with most physiological methods of prediction, does not furnish any basis for extrapolation to sets of conditions other than those used in the original experiments.

Figure 2. EFFECTIVE TEMPERATURE LINES REPORTED BY DIFFERENT INVESTIGATORS

Thin continuous lines--original ET lines (11); thick continuous lines--Koch, Jennings and Humphreys (8); dash lines--Yaglou's lines of mean skin temperature (9); dash-dot lines--Jennings and Givoni thermal sensation lines (10). All of the newer lines show considerably less slope with humidity than the original ET lines.



JENNINGS AND GIVONI
THERMAL SENSATION LINES
YAGLOU'S LINES OF
MEAN SKIN TEMP.
75 DEG. E.T.
100% RH
80% RH
60% RH
40% RH
20% RH
10% RH
SLIGHTLY COOL (3)
COMFORTABLE (4)
SLIGHTLY WARM (5)
WARM (6)
92 F
93 F
94 F
WET BULB TEMP. F
DRY BULB TEMP. F

Figure 3. DISTRIBUTION OF COMFORT SENSATIONS IN DIFFERENT POPULATIONS (11).

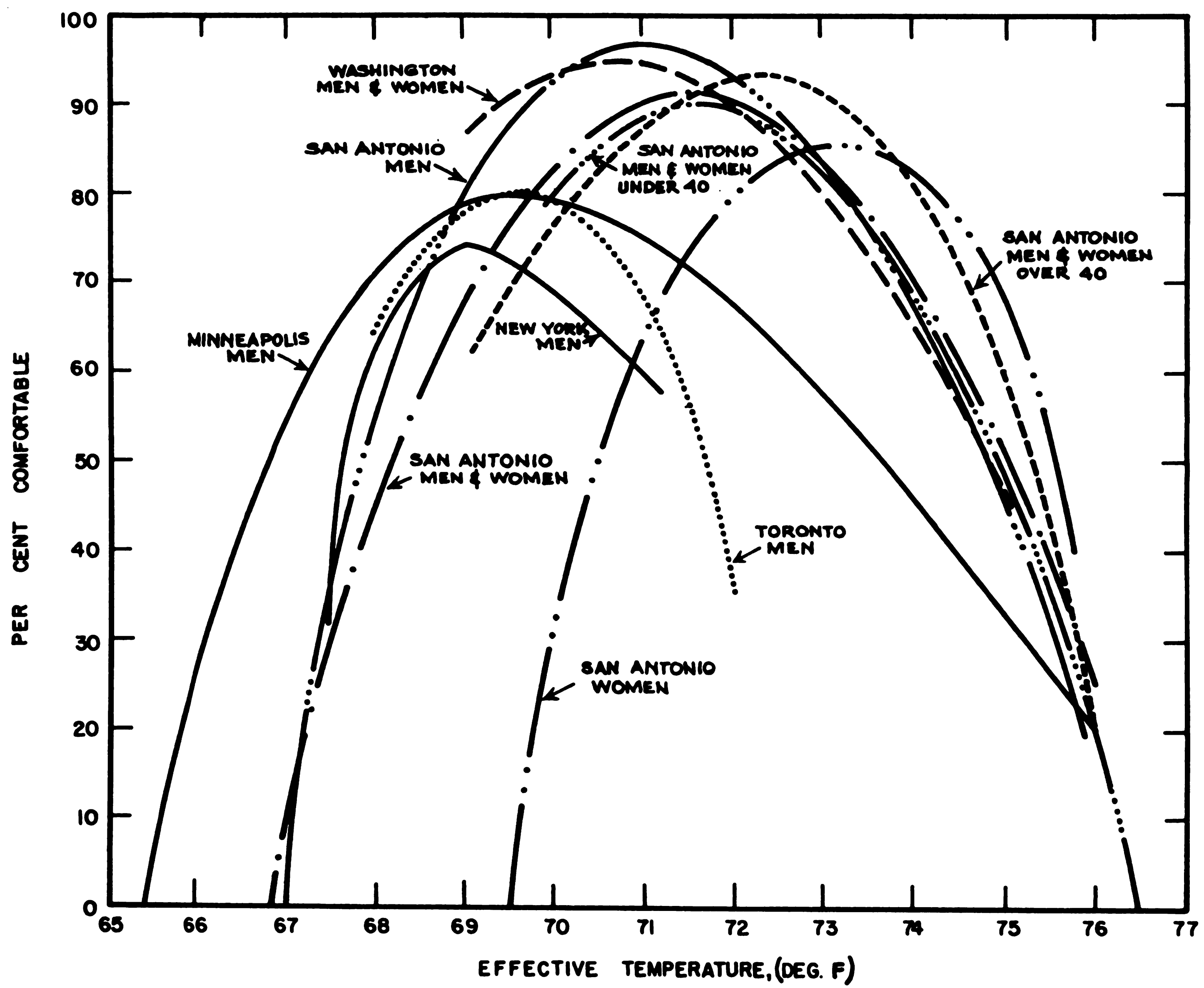
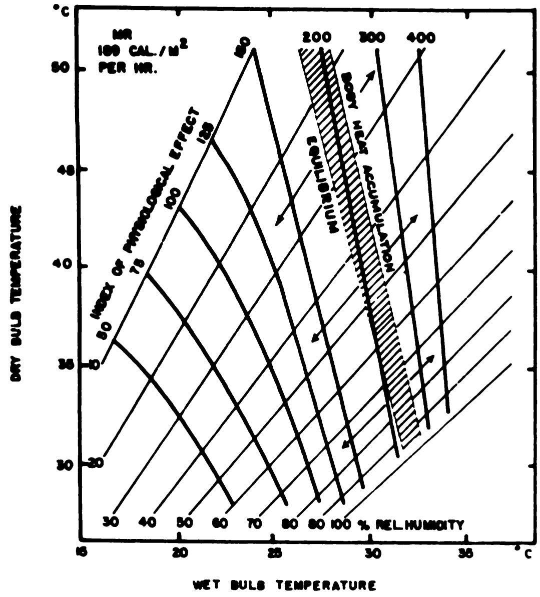
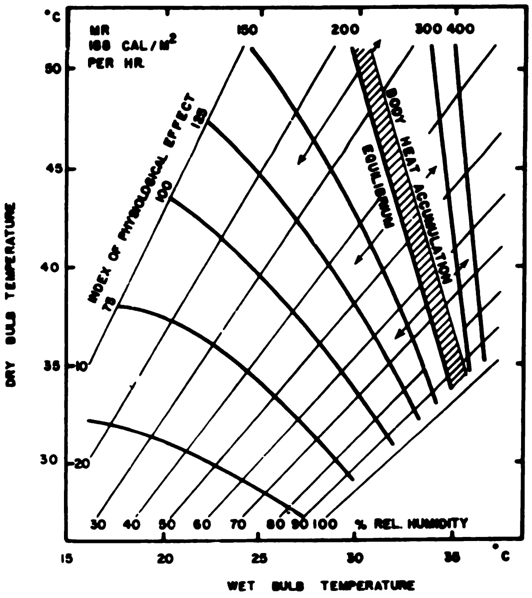
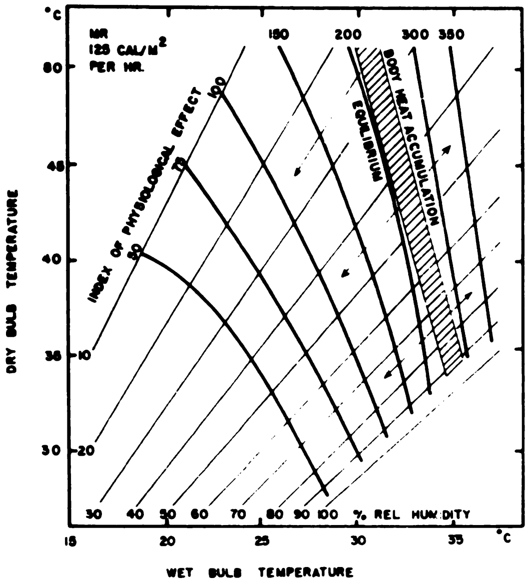

WASHINGTON MEN & WOMEN
SAN ANTONIO MEN
SAN ANTONIO MEN & WOMEN UNDER 40
SAN ANTONIO MEN & WOMEN OVER 40
MINNEAPOLIS MEN
NEW YORK MEN
SAN ANTONIO MEN & WOMEN
TORONTO MEN
SAN ANTONIO WOMEN
PER CENT COMFORTABLE
EFFECTIVE TEMPERATURE, (DEG. F)
0
10
20
30
40
50
60
70
80
90
100
65
66
67
68
69
70
71
72
73
74
75
76
77

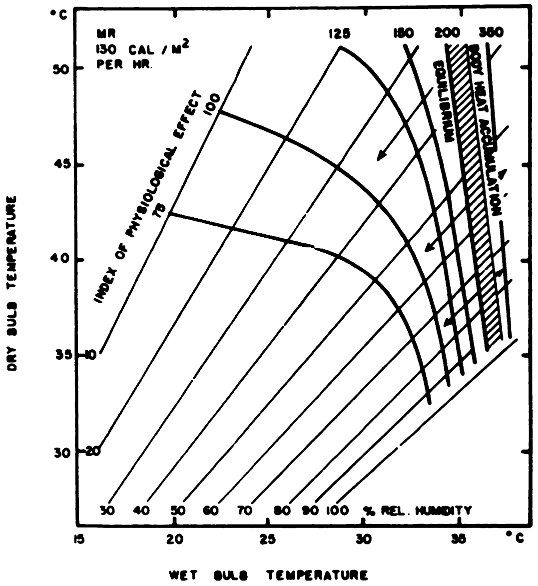
Figure 4. **EP INDEX OF PHYSIOLOGICAL EFFECT OF ENVIRONMENTAL CONDITIONS.** From Robinson et al (13).

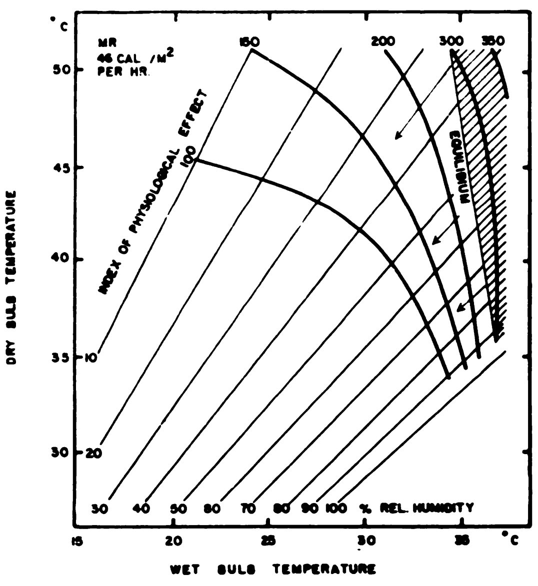
Upper left: clothed men walking at 5.6 km/hr up 2.5% grade; upper right: men in shorts doing same work; middle left: clothed men walking at 4.5 km/hr on level; middle right: men in shorts doing same work; lower: men in shorts sitting at rest.


MR
189 CAL./M²
PER HR.
INDEX OF PHYSIOLOGICAL EFFECT
50
75
100
125
150
200
300
400
EQUILIBRIUM
BODY HEAT ACCUMULATION
DRY BULB TEMPERATURE
WET BULB TEMPERATURE
30 40 50 60 70 80 90 100 % REL. HUMIDITY
°C


MR
168 CAL./M²
PER HR.
INDEX OF PHYSIOLOGICAL EFFECT
75
100
125
150
200
300 400
EQUILIBRIUM
BODY HEAT ACCUMULATION
DRY BULB TEMPERATURE
WET BULB TEMPERATURE
30 40 50 60 70 80 90 100 % REL. HUMIDITY
°C


MR
125 CAL/M²
PER HR.
INDEX OF PHYSIOLOGICAL EFFECT
50
75
100
150
200
300 350
EQUILIBRIUM
BODY HEAT ACCUMULATION
DRY BULB TEMPERATURE
WET BULB TEMPERATURE
30 40 50 60 70 80 90 100 % REL HUMIDITY
°C


MR
130 CAL / M²
PER HR.
INDEX OF PHYSIOLOGICAL EFFECT
75
100
125
150
200
350
EQUILIBRIUM
BODY HEAT ACCUMULATION
DRY BULB TEMPERATURE
WET BULB TEMPERATURE
30 40 50 60 70 80 90 100 % REL. HUMIDITY
°C


MR
46 CAL. /M²
PER HR.
INDEX OF PHYSIOLOGICAL EFFECT
100
150
200
300
350
EQUILIBRIUM
DRY BULB TEMPERATURE
WET BULB TEMPERATURE
30 40 50 60 70 80 90 100 % REL. HUMIDITY
°C

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P_4SR Index

McArdle and co-workers (14) developed a nomogram whereby the significance of different atmospheric conditions is expressed in terms of the sweat loss they induce. With a later modification (15) it was made applicable to various combinations of clothing and levels of activity (Fig. 5.) For conditions which are hot enough to induce moderate sweating, but not sufficiently severe to overtax the sweating capability, the index works fairly well. Care is necessary, however, in applying it to people who differ markedly in training or acclimatization from those used by the authors.

Heat Stress Index (HSI)

Belding and Hatch (16) explicitly tackled the concepts of stress and strain. On the former, they reported: "Heat stress is considered to exist whenever, despite vasomotor adjustment, metabolic heat production exceeds the combined losses by radiation and convection." Strain they regarded as the probable consequence of exposure to stress, and by a sequence of reasoning that is not quite clear, hit upon expressing strain as the ratio between: (a) the rate at which evaporative cooling is needed to balance the stress, and (b) the maximum rate at which evaporative cooling can be maintained in that particular environment.

$$\text{Strain} = \frac{\text{Evaporative cooling required}}{\text{Maximum evaporative cooling possible}}$$

As will be seen later, this ratio would be better termed "relative strain".

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For quantitative expressions the authors had recourse to data obtained on military subjects by Nelson et al. (17), with the following result:

$$\text{Strain} = \frac{M + 22(t_w - 95) + 2\sqrt{V}(t_a - 95)}{10.3\ V^{0.4}\ (42 - p_a)}$$

where M is metabolic rate in BTU/hr

t_w is temperature of walls °F

t_a is temperature of air °F

V is rate of air movement in ft/min

p_a is vapor pressure of air in mm hg (obtainable from dry and wet bulb temperatures)

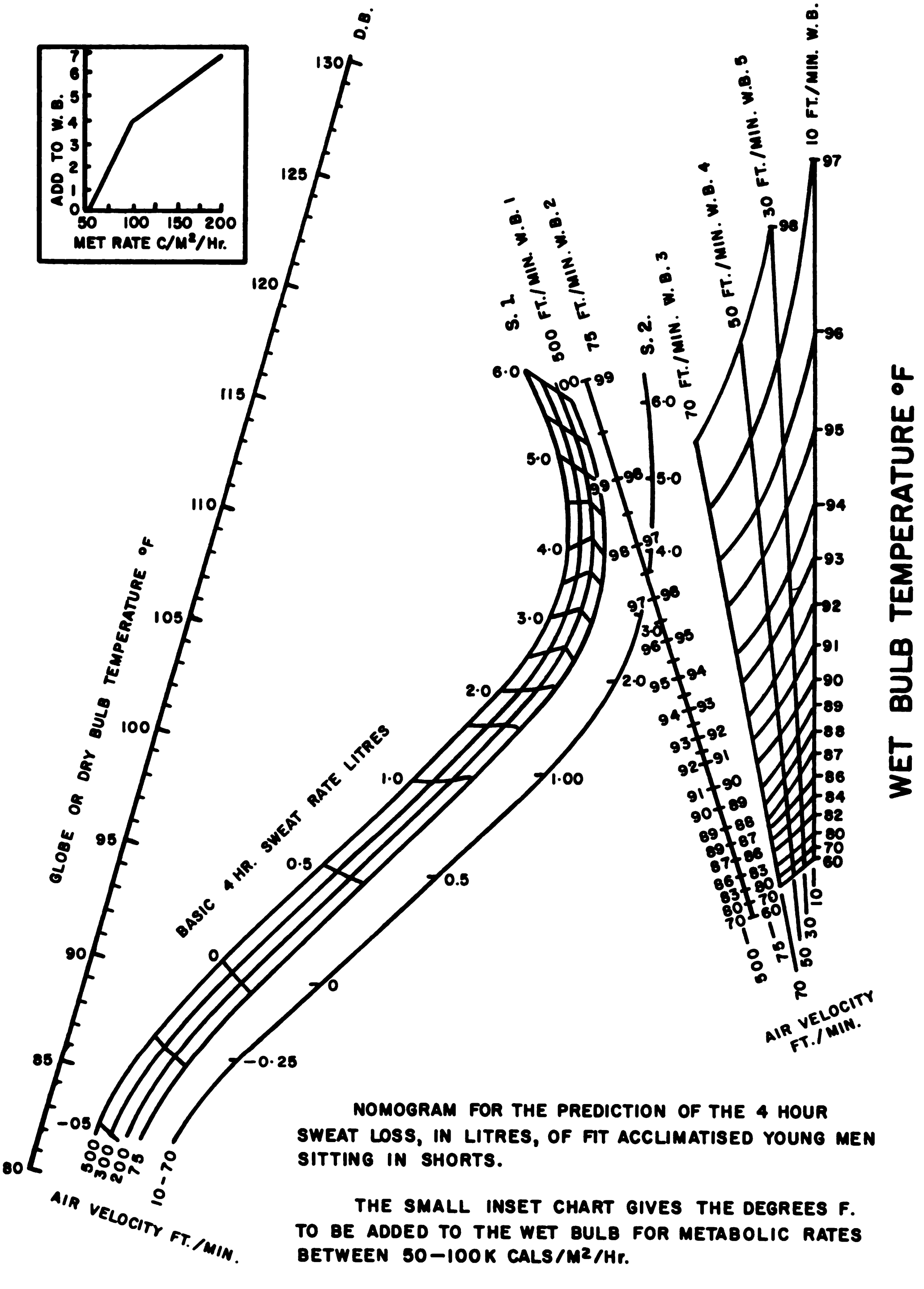
As the vapor pressure of the air decreases or as the rate of air movement increases, the value of the denominator will increase. The authors placed a constraint upon this value of 2400 BTU/hr, on the grounds that the body cannot maintain a rate of sweating which will permit greater cooling than this.

A chart was provided for determining the HSI value for a given set of conditions (Fig. 6), and a table (Table 1) for determining the significance of the value obtained.

Figure 5. **NOMOGRAM FOR THE PREDICTION OF THE 4-HOUR SWEAT LOSS OF FIT, ACCLIMATIZED YOUNG MEN, SITTING IN SHORTS (14).**

Locate point of intersection of wet bulb temperature and air velocity lines at right side of diagram. Join this to the globe or dry bulb temperature reading on the left side of the diagram. The point at which this transverse line cuts the air velocity line in the center of the diagram indicates the basic 4-hour sweat rate. The nomogram may be used for higher rates of work by adding to the wet bulb temperature reading the amount indicated by the small chart at top left. (The appropriate figure for the metabolic rate can be obtained by reference to the table on p. 21 of the text).

THE NOMOGRAM FOR THE PREDICTION OF 4-HOUR SWEAT RATE (P4SR)

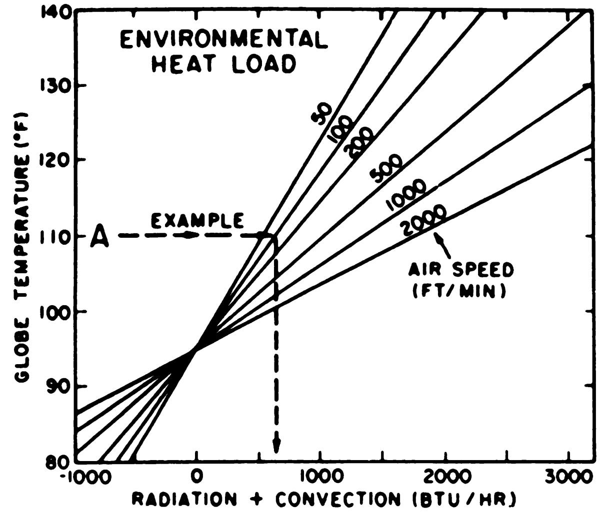


NOMOGRAM FOR THE PREDICTION OF THE 4 HOUR SWEAT LOSS, IN LITRES, OF FIT ACCLIMATISED YOUNG MEN SITTING IN SHORTS.

THE SMALL INSET CHART GIVES THE DEGREES F. TO BE ADDED TO THE WET BULB FOR METABOLIC RATES BETWEEN 50—100K CALS/M²/Hr.

Figure 6. **FLOW CHARTS FOR DETERMINING HEAT STRESS INDEX (16).**

Example: Globe temperature 110°F, dry bulb temperature 90°F, wet bulb temperature 75°F, air speed 100 ft/min, metabolism 600 BTU/hr. For solution follow broken lines. HSI = 90.



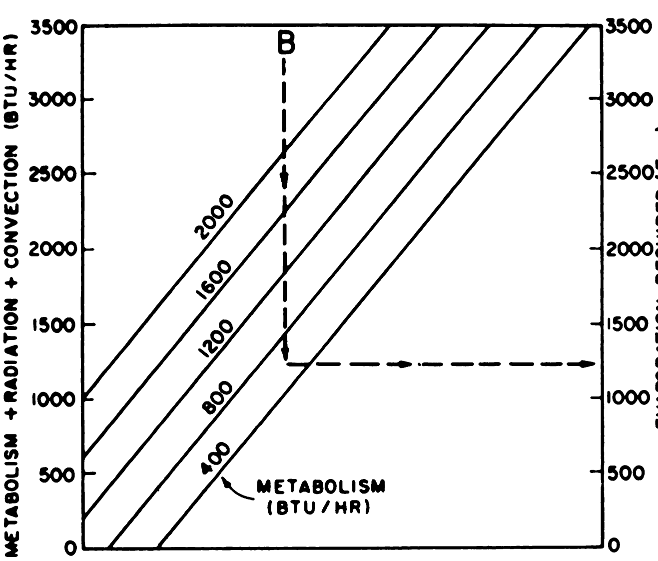
ENTER A. Drop vertical line from intercept of globe temperature with air speed; thus get combined radiation and convection heat load. Extend vertical line to

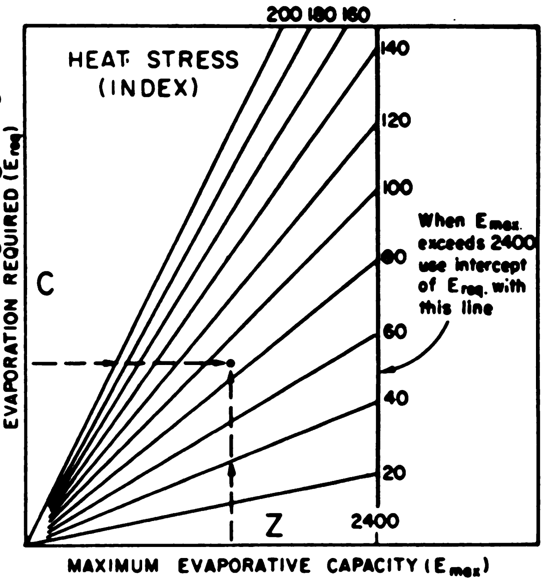
ENTER B. At intercept with metabolism, draw horizontal line; obtain total heat load in terms of evaporation required for heat balance (Ereq). Extend horizontal line to ENTER C.

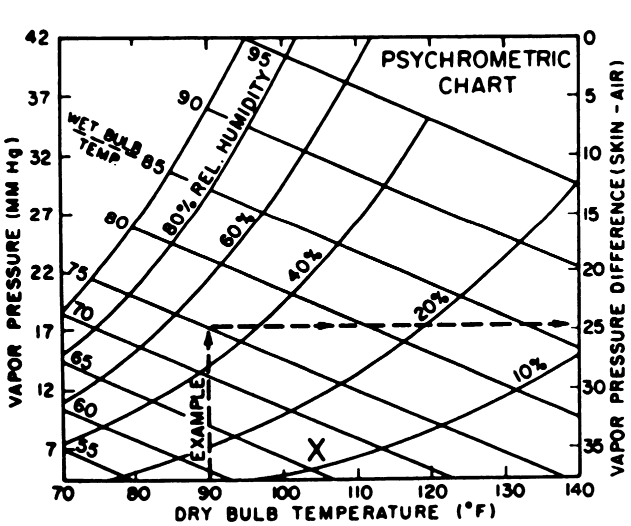
ENTER X. Draw horiz. line from intercept of db and wb temperature; obtain vapor pressure gradient between saturated skin at 95 F and ambient air. Extend line to

ENTER Y. At intercept with air speed draw vertical line; obtain maximum evaporation from wet skin at 95 F (Emax). Extend line to

ENTER Z. Move to intercept with horiz. line from C. (If Emax exceeds 2400, enter Z at 2400). READ HEAT STRESS INDEX VALUE.







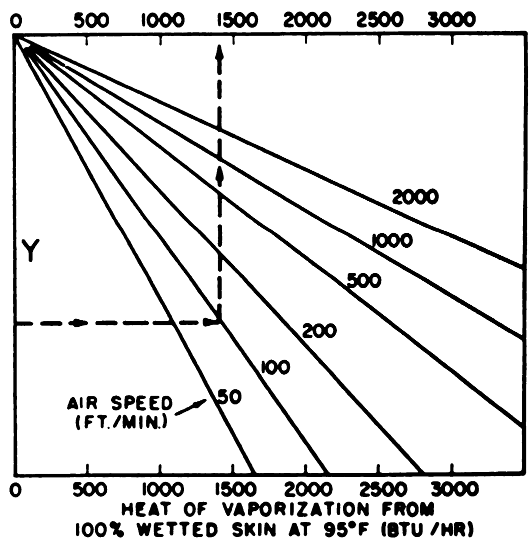


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Table 1 - Evaluation of Values in Belding and Hatch H.S.I.

Index of Heat Stress	Physiological and Hygienic Implications of 8-hr Exposures to Various Heat Stresses
-20 -10	Mild cold strain. This condition frequently exists in areas where men recover from exposure to heat.
0	No thermal strain.
+10 20 30	Mild to moderate heat strain. Where a job involves higher intellectual functions, dexterity, or alertness, subtle to substantial decrements in performance may be expected. In performance of heavy physical work, little decrement expected unless ability of individuals to perform such work under no thermal stress is marginal.
40 50 60	Severe heat strain, involving a threat to health unless men are physically fit. Break-in period required for men not previously acclimatized. Some decrement in performance of physical work is to be expected. Medical selection of personnel desirable because these conditions are unsuitable for those with cardiovascular or respiratory impairment or with chronic dermatitis. These working conditions are also unsuitable for activities requiring sustained mental effort.
70 80 90	Very severe heat strain. Only a small percentage of the population may be expected to qualify for this work. Personnel should be selected (a) by medical examination, and (b) by trial on the job (after acclimatization.) Special measures are needed to assure adequate water and salt intake. Amelioration of working conditions by any feasible means is highly desirable, and may be expected to decrease the health hazard while increasing efficiency on the job. Slight "indisposition" which in most jobs would be insufficient to affect performance may render workers unfit for this exposure.
100	The maximum strain tolerated daily by fit, acclimatized young men.

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This scheme was a distinct advance on previous proposals in expressing the unmeasurable strain as a dimensionless ratio between definable quantities. It is unsatisfactory in that it does not include the effect of clothing, and ignores physiological reactions other than sweating. Attempts have been made more recently to meet some of these objections (18), but the practical application awaits further development.

Psychrometric Plots

As a supplemental device to the various indices in determining the acceptability of environmental conditions, it is sometimes useful to have a psychrometric chart on which are plotted those combinations of temperature and humidity which have been found to have equivalent effects, as revealed by estimates of "comfort," limiting physiological responses, threatened physiological breakdown, etc. The more illuminating of these lines of equal effect are given in Figs. 7 and 8. The conditions of activity, air movement, and clothing applicable to each are shown in the appropriate box.

BASIC FORMULATION

DEFINITION

For many years one of us (D.H.K.L.) has insisted in teaching and writing that, if physiologists use physical terms in a physical connotation, they should conform to the usage of physicists. Stress is defined in the Handbook of Chemistry and Physics (23) as "the force producing or tending to produce deformation in a body, measured by the force applied per unit area". Strain is defined as "the deformation resulting from a stress, measured by the ratio of the change to the total value of the dimension in which the change occurred".

When the concepts contained in these definitions are applied to the case of a living organism exposed to heat, the term "stress" should clearly refer to heat gain imposed on the living system, and "strain" to the changes in the living system resulting from the application of that stress. It is unfortunate that in at least one field of physiology, the essential difference between these terms has been completely lost. The authors agree completely with Belding and Hatch on this point.

Figure 7. **REPORTED TOLERANCES FOR LIGHTLY AND NORMALLY CLOTHED MEN.**

The chart may be used in one of two ways: (1) to determine the warmest conditions at which a given activity may be carried out without exceeding given tolerances -- select box which comes closest to describing the activity and tolerance in mind, and then see what combinations of temperature and humidity correspond to this limiting line; (2) To determine what activity can be carried out under given atmospheric conditions, locate point corresponding to prevailing temperature and humidity and then see what activities describe the lines passing near that point. Numbers in circles correspond to the following references in the bibliography: 1--(19); 2--(12); 3--(20); 4--(13).

REPORTED TOLERANCES FOR LIGHTLY AND NORMALLY CLOTHED MEN

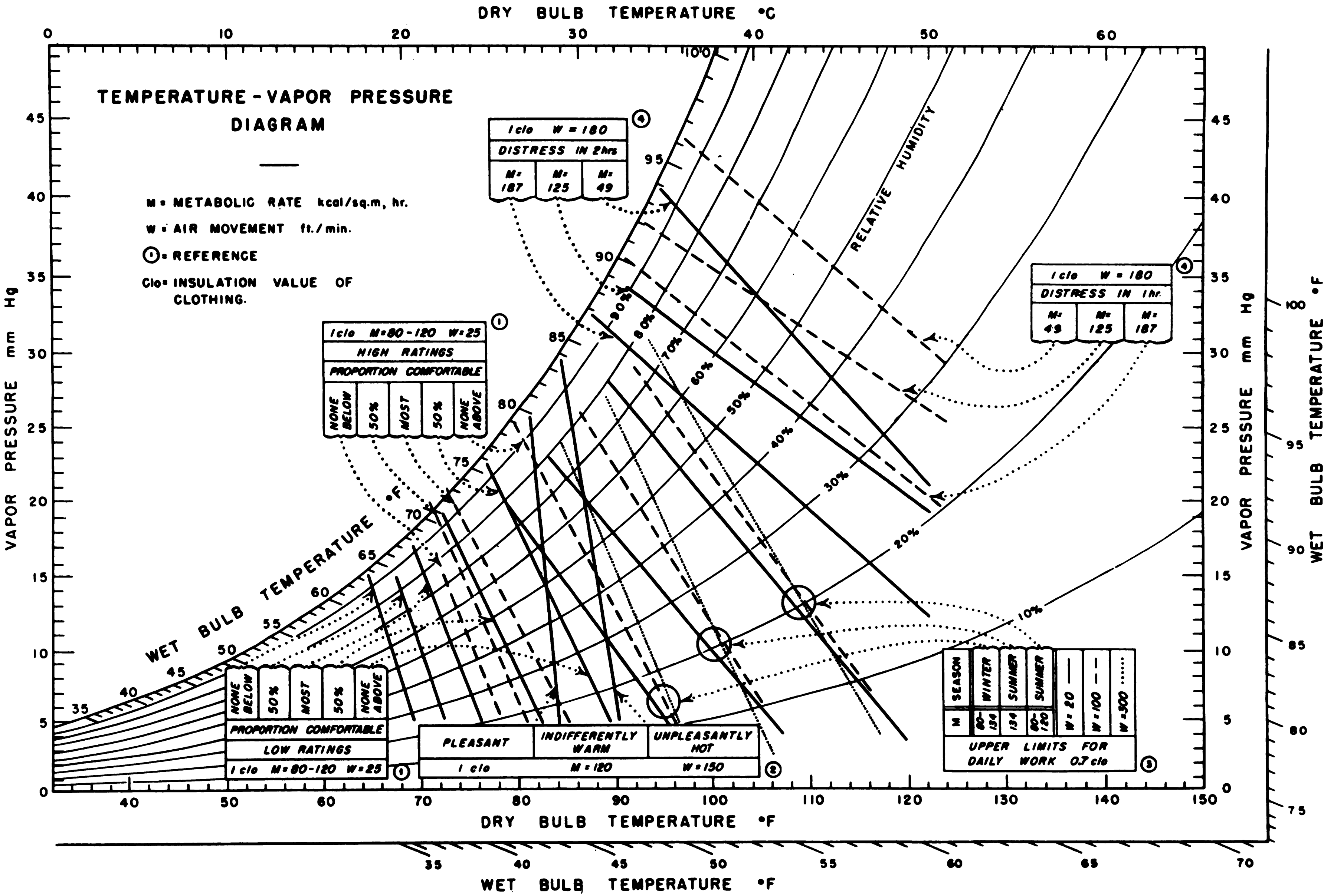
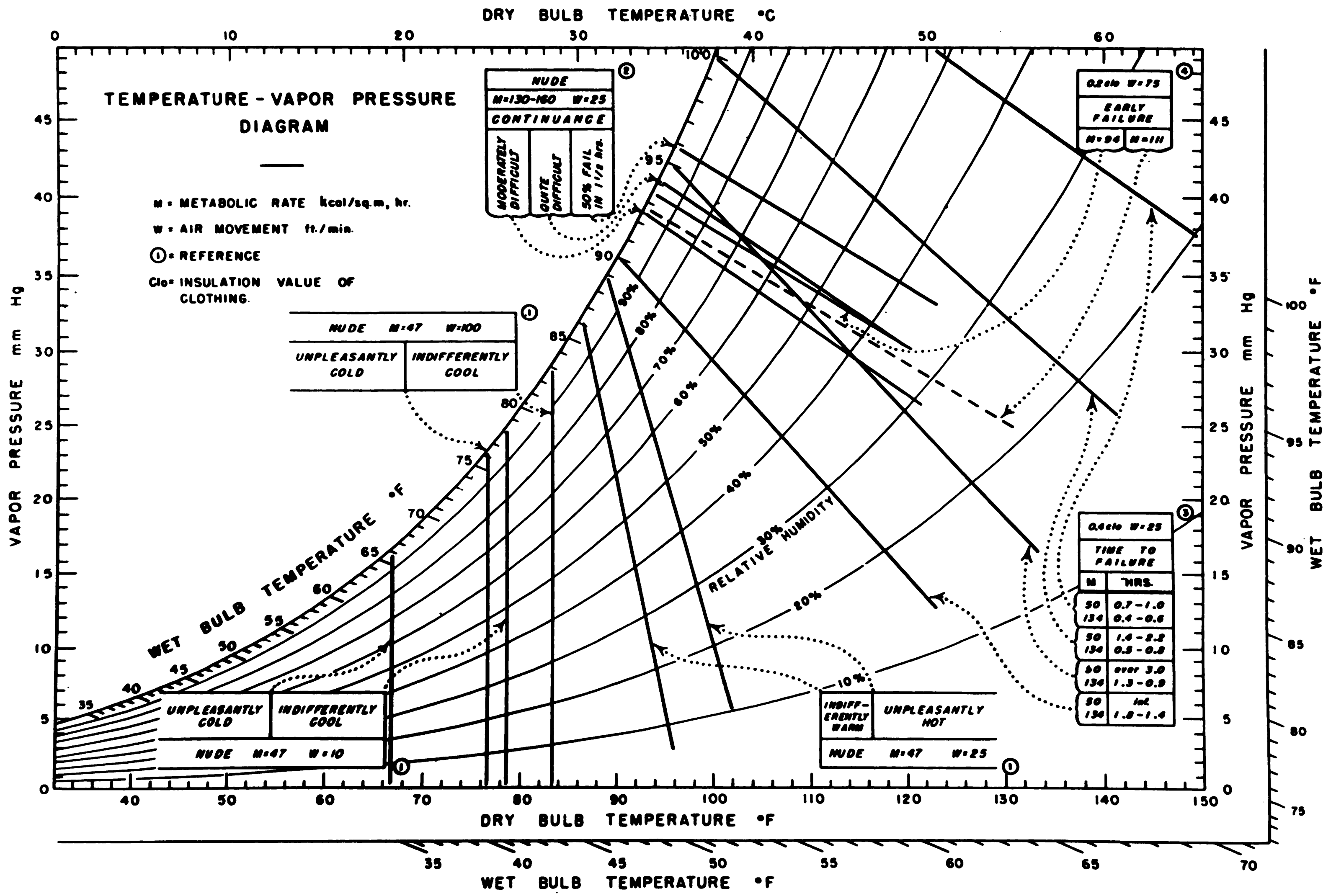


Figure 8. **REPORTED TOLERANCES FOR NUDE AND PARTIALLY CLOTHED MEN.**

The chart may be used in one of two ways: (1) to determine the warmest conditions at which a given activity may be carried out without exceeding given tolerances -- select box which comes closest to describing the activity and tolerance in mind, and then see what combinations of temperature and humidity correspond to this limiting line; (2) To determine what activity can be carried out under given atmospheric conditions, locate point corresponding to prevailing temperature and humidity and then see what activities describe the lines passing near that point. Numbers in circles correspond to the following references in the bibliography: 1--(12); 2--(21); 3--(20); 4--(22).

REPORTED TOLERANCES FOR NUDE AND PARTIALLY CLOTHED MEN



SHELTER ENVIRONMENTS

When one goes beyond the concepts to dimensions of the terms, and modes of quantitative expression, one runs into some difficulty with the term "force". Even in physical systems there are difficulties when one deals with other than mechanical forces and work energy. Mechanical force is energy/distance and has the dimensions mlt^{-2}, but temperature, which is often regarded as a "force", is energy/entropy and has its own dimension (24). For our purposes, we will follow our own earlier practice, similar to that of Belding and Hatch, and use energy intensity, that is energy transfer per unit surface area per unit time, as the "force". As we will eventually be concerned with the ratio between two such expressions of intensity, it matters little whether certain dimensions are included in the original selection or not.

RELATIVE STRAIN

The evaluation of a thermal environment as a ratiohas been an attractive concept these last twenty years, but ideas differed as to what should go into the ratio. As we have seen, Robinson (13) used the observed response of four functions in comparison with the maximum response that the body could make without breaking down. A Quartermaster group (25) proposed the ratio of the opportunity for heat loss to the heat produced by metabolism (less heat loss from the lungs). One of us (D.H.K.L.) starting from the tendency of lines of equal effect, plotted on a psychrometric chart (Fig. 7), to change slope with increasing stress, sought to express strain as the ratio between the threatened rate of heat gain and an empirically derived expression of the opportunity for evaporative compensation (26).

Belding and Hatch cut the Gordian knot by using the ratio between: (a) the rate at which evaporative cooling is needed to balance the stress, and (b) the maximum rate at which evaporative cooling can be maintained into that particular environment. It replaced the author's empirical expression of evaporative possibility with a rational one.

This resulted in an index which at least expressed the concept of strain as a deformation resulting from stress, postulated a direct relationship between this measure of strain and the applied stress, andwas dimensionless. It departed from the narrow physical definition of strain in comparing the extent of deformation with the maximum deformation possible without system breakdown, instead of with the normal dimensions of the system.

However, it is precisely the ratio of deformation produced to the maximum permissible deformation that we wish to know. The conflict with physical practice can be resolved if we will change our nomenclature somewhat, and term this ratio the "relative strain". The present authors feel that this is in any case a better term, since it is the relativity that we wish to emphasize, and we will use it hereafter.

SHELTER ENVIRONMENTS

FORMULATION

The Belding and Hatch index of relative strain had the disadvantage that it was based upon the reactions of nude subjects, and did not provide for the effects of clothing. The proponents took the view that not enough was known about the effects of clothing for this consideration to be included in the quantitative expressions. Some concession was made to the marked effect of clothing under conditions of high radiant heat in a later paper (18), but the allowance was empirical. It is not clear why they elected to ignore Burton's equations (27), which do provide terms of clothing effects. It is true that the expressions used by Burton can be regarded as no more than first order approximations, and that the appropriate values for the constants should be explored over a wider range of conditions than those used in the Pierce Laboratory experiments (12) on which they were based. But they do provide a basis for dealing rationally with clothing effects, and if incorporated into the expressions constituting the ratio should permit more satisfactory application to a wider range of circumstances.

First Formulation

On these assumptions the present authors made their first modification to the HSI by substituting the following expression for that advocated by Belding and Hatch:

$$\text{Relative Strain} = \frac{M + \dfrac{5.55(t_a - 35) + RI_a}{I_a + I_c}}{\dfrac{5(44 - p_a)}{r_a} \cdot \dfrac{I_a}{I_a + I_c}}$$

where M is metabolic rate in kcal/sq m, hr

t_a is air temperature in °C

R is mean radiant heat incidence in kcal/sq m, hr

I_a is insulation of air in clo units

I_c is insulation of clothing in clo units

P_a is vapor pressure of air in mm hg

r_a is resistance of air to outward passage of water vapor expressed as equivalent cm still air

SHELTER ENVIRONMENTS

This expression reduces to

$$\text{Relative strain} = \frac{M(I_a + I_c) + 5.55(t_a - 35) + RI_a}{5(44 - p_a) \cdot I_a/r_a}$$

And according to Burton, $I_a/r_a = 1.5$

Explanation of Terms

M, the metabolic rate, is the same as in the Belding and Hatch formula.

The bracket (t_a - 35) corresponds in the centrigade scale to the (t_a - 95) in the Belding and Hatch formula, but the square root of the air movement in the former is here replaced by a more complicated expression, the inverse of two quantities I_a and I_c. I_a expresses the effect of changing air movement as did the square root of ambient air velocity, but I_c introduces the further effect of clothing in modifying the rate of air movement over the skin. The relationship between I_a and V is given in the following table:

Standard Values for I_a (28)

Insulation clo units	0.1	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.85
Velocity of air movement miles/hr	51.0	22.7	11.9	4.85	2.39	1.27	0.85	0.57	0.49	0.34
ft/min	4,500	2,000	1,050	425	210	120	75	50	35	30
cm/sec	2,280	1,015	534	216	107	61	28	25	18	15

The value of I_c for dry conventional clothing is given approximately by the mean thickness of the clothing ensemble from the skin surface to the outer margin of nap, including any intervening air space up to .6 cm. (For detailed explanation of the reasoning behind these expressions, see 29, 30.)

The coupling of I_a with the datum for incident thermal radiation provides for the fact that part of the heat derived from absorption of radiation is swept away by movement in the ambient air.

The bracket (44 - p_a) corresponds to the (42 - p_a) in the Belding and Hatch formula, but the fractional power of the air movement is again replaced by an inverse expression of resistivity.

SHELTER ENVIRONMENTS

The modifying fraction $I_a / (I_a + I_c)$ in the denominator is designed to compensate for the probable evaporation of sweat at the surface of the clothing instead of at the skin surface. As pointed out by Belding in an earlier publication (31), part of the heat removed by evaporation is, under these circumstances, taken from the ambient air rather than the skin-clothing system.

Further Modification

To test the relative applicability of the two formulas -- that of Belding and Hatch and the one just derived from Burton's equations -- one can substitute reasonable values for all of the variables except temperature (t_a) and vapor pressure (p_a), plot lines for various values of relative strain on a temperature/vapor pressure grid, and see to what extent the predictions correspond to experience.

Since we are ultimately concerned especially with conditions likely to prevail in shelters, we can postulate the following standard values:

M = 100 kcal/sq m,hr (walking at 2 mi/hr)

I_c = 1 clo (standard business suit)

I_a = 0.4 (ambient air movement 100 ft/min, air movement caused by body movement 110 ft/min)

R = 0 (wall temperature = air temperature)

The above formula based on Burton's dry clothing equations then reduces to:

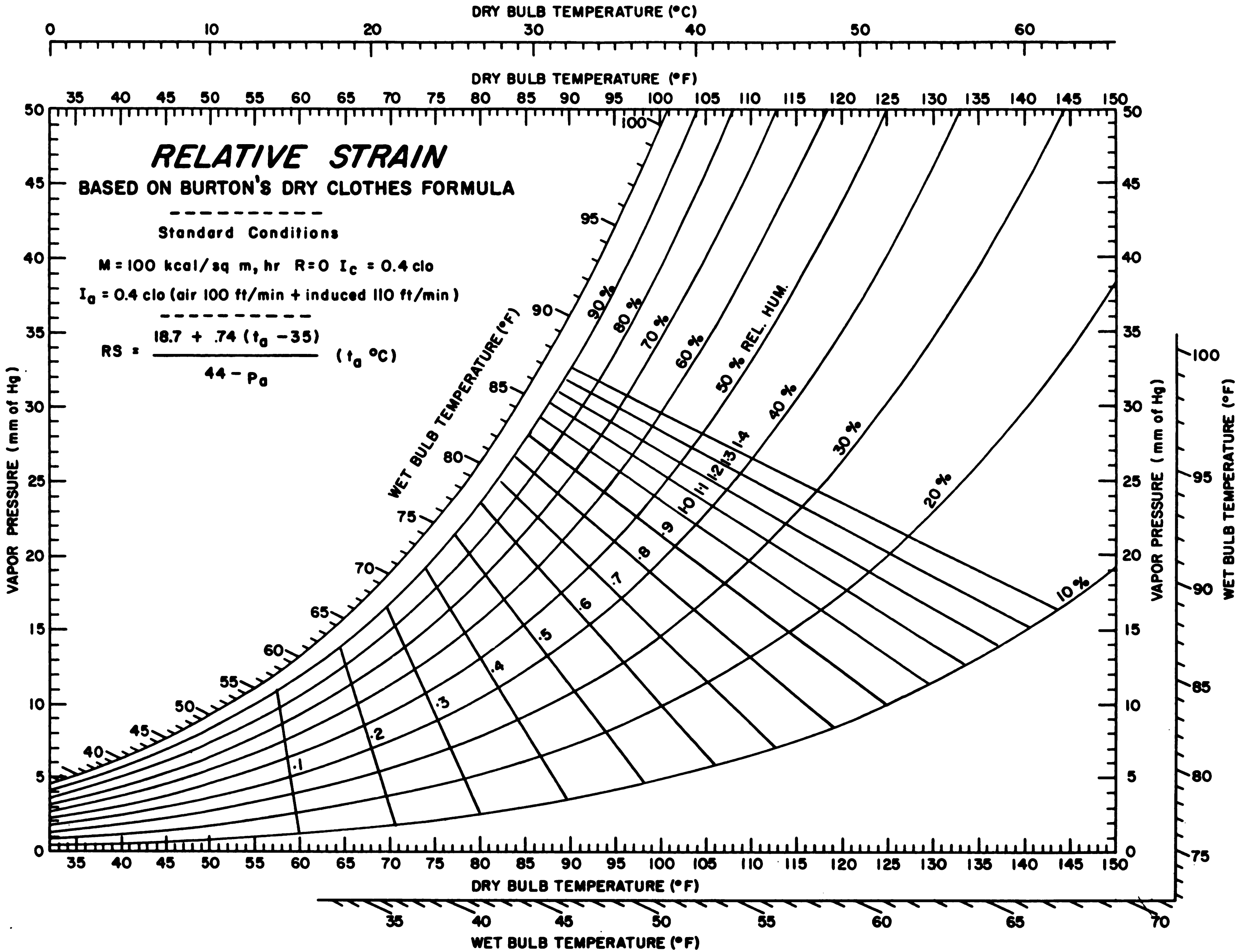
$$RS_{BDC} = \frac{18.7 + .74(t_a - 35)}{44 - p_a} \qquad (t_a \text{ in } ^{o}C)$$

The corresponding expression from Belding and Hatch's formula would be:

$$RS_{BH} = \frac{8.2 + .58(t_a - 95)}{44 - p_a} \qquad (t_a \text{ in } ^{o}F)$$

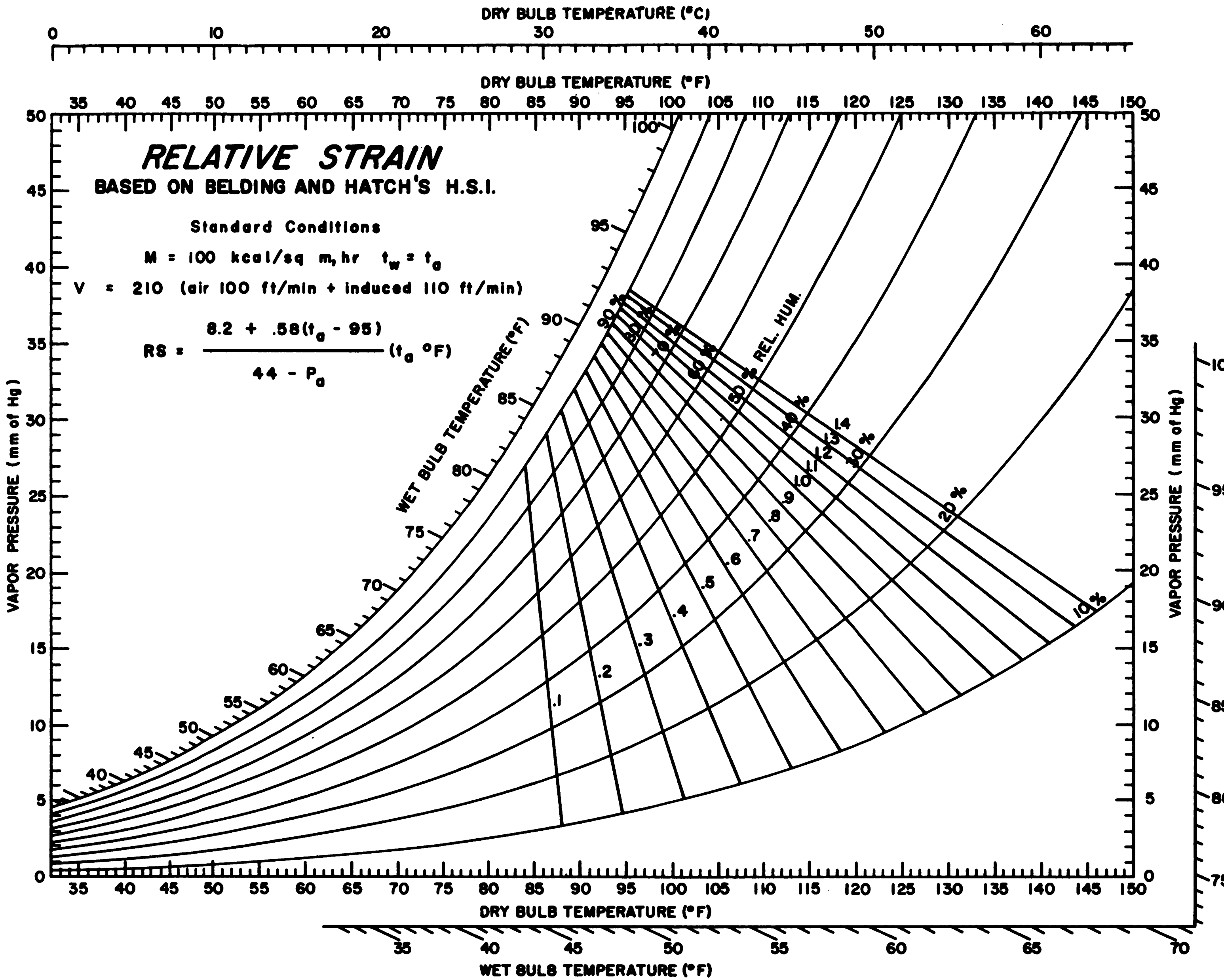
The corresponding sets of relative strain lines are illustrated in Figs. 9 and 10.

Figure 9. **RELATIVE STRAIN LINES FOR STANDARD CONDITIONS BASED ON BURTON'S DRY CLOTHES FORMULA.**



RELATIVE STRAIN
BASED ON BURTON'S DRY CLOTHES FORMULA
Standard Conditions
M = 100 kcal/sq m, hr R = 0 I_c = 0.4 clo
I_a = 0.4 clo (air 100 ft/min + induced 110 ft/min)
$RS = \frac{18.7 + .74\,(t_a - 35)}{44 - P_a}$ (t_a °C)
DRY BULB TEMPERATURE (°C)
DRY BULB TEMPERATURE (°F)
VAPOR PRESSURE (mm of Hg)
WET BULB TEMPERATURE (°F)
90 %
80 %
70 %
60 %
50 % REL. HUM.
40 %
30 %
20 %
10 %

Figure 10. RELATIVE STRAIN LINES FOR SAME STANDARD CONDITIONS BASED ON BELDING AND HATCH H.S.I.


RELATIVE STRAIN
BASED ON BELDING AND HATCH'S H.S.I.
Standard Conditions
M = 100 kcal/sq m, hr $t_w = t_a$
V = 210 (air 100 ft/min + induced 110 ft/min)
$RS = \frac{8.2 + .58(t_a - 95)}{44 - P_a} (t_a\ ^\circ F)$
DRY BULB TEMPERATURE (°C)
DRY BULB TEMPERATURE (°F)
VAPOR PRESSURE (mm of Hg)
WET BULB TEMPERATURE (°F)
REL. HUM.
100
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4

Neither of these sets corresponds very well with one's experience. The Burton dry clothes formulation lies much too low and gives a value of zero strain which is clearly in the cool region. The Belding and Hatch formulation, on the other hand, places the zero strain position under conditions that are too warm. It also seems to under-emphasize the effects of high humidity at high temperatures, as might be expected of a formula based on the reaction of nude men.

Further consideration showed that the values assigned to the insulation of clothing in the dry clothes formula were too great in two respects: (a) movement reduces the effectiveness of the insulation by promoting exchange of air between deeper spaces and the ambient air; and (b) the maximum opportunity for evaporation is not attained when the skin is completely wet unless the clothing above it is also wet.

The mathematical considerations for these two factors are far from fully worked out, and they would greatly complicate the expression used for relative strain. At this juncture one must rest content to make an estimate of the extent to which the value for dry clothing insulation at rest needs to be reduced when the clothing is wet and movement is taking place. We found that, when a value of 0.4 for I_{cw} was substituted in the formula instead of the value of 1.0 for I_c, much greater compatibility with experience was obtained.

Doubtless in the future much more precise estimations will be possible, but for the present we believe that the estimate used here is permissible.

The proposed formula for the previously postulated "standard" conditions then reduces to:

$$RS_{BWC} = \frac{80 + 5.55(t_a - 35)}{7.55(44 - p_a)}$$

$$= \frac{1.07 + .74(t_a - 35)}{44 - p_a}$$

If the air temperature (t_a) is to be expressed in ^oF, the coefficient in front of the bracket becomes .41. The applicability of this formulation will be examined after a short recapitulation.

SHELTER ENVIRONMENTS

DEFINITIVE FORMULA

FOR STANDARD CONDITIONS

To recapitulate, we have:

as general formula:

$$RS = \frac{M + \dfrac{5.55(t_a - 35) + RI_a}{I_a + I_{cw}}}{\dfrac{5(44 - p_a)}{r_a} \cdot \dfrac{I_a}{I_a + I_{cw}}}$$

which reduces to:

$$RS = \frac{M(I_{cw} + I_a) + 5.55(t_a - 35) + RI_a}{7.5(44 - p_a)}$$

and, when we substitute reasonable values for a person with activity equivalent to walking at 2 mi/hr, in a light business suit, with ambient air movement at 100 ft/min, and wall temperature equal to air temperature, reduces to:

$$RS_s = \frac{1.07 + .74(t_a - 35)}{44 - p_a} \quad \text{with } t_a \text{ in } ^\circ C$$

$$\text{or} \quad \frac{1.07 + .41(t_a - 95)}{44 - p_a} \quad \text{with } t_a \text{ in } ^\circ F$$

For each value of relative strain from 0 (no strain), through 1 (maximum theoretically tolerable strain), to higher values (body must heat up), a straight line can be drawn on a psychrometric chart.

SHELTER ENVIRONMENTS

There remains the question of limiting values. If we accept Belding and Hatch's estimation that for continued tolerance the maximum allowable sweat rate is 1 liter/hour, and if we further assume that, after equilibrium is established, the rate of evaporation will be maintained at the same rate, then the denominator in the general equation cannot exceed the rate of cooling produced by the evaporation of this sweat. Under our postulated standard conditions, this would mean:

$$\frac{5(44 - p_a)}{r_a} \cdot \frac{I_a}{I_a + I_{cw}} \ngtr \frac{1000 \times .54}{1.75}$$

where the latent heat of evaporation is taken as .54 kcal/gm, and the surface area of the body as 1.75 sq m.

This reduces to:

$$p_a \nless 11 \text{ mm hg.}$$

or, to put it more clearly, at vapor pressures below 11 mm hg, the maximum attainable rate of evaporation cannot further increase, and relative strain lines would become vertical.

This constraint upon maximum rate of evaporation appears reasonable, and one would certainly expect the unit strain line to show an inflection at the critical vapor pressure line. The definition adopted for relative strain would certainly make it logical that relative strain lines of both lower and higher values should become vertical at the same vapor pressure, but one cannot escape the feeling that it is unrealistic to require a change in the slope of a lower valued line at a point where the full potentiality of skin wetness is not yet reached, or, for that matter, to delay the change of slope in a higher valued line beyond the vapor pressure at which the skin actually becomes completely wet. At the time of making this report the problem is unresolved. For the time being the authors have decided arbitrarily to continue the relative strain lines without change of slope down to the 10 per cent relative humidity curve or the 10 mm hg line, whichever is lower and leave lower humidities in a zone of uncertainty. Since very high relative humidities are apt to introduce special factors of undetermined effect, they have also terminated the relative strain lines at the 90 per cent relative humidity curve.

Fig. 11 presents relative strain lines for values .1 to 1.5 drawn on a psychrometric chart for the postulated standard conditions.

SHELTER ENVIRONMENTS

The position of the zero line with this formulation is considered to be in an acceptable position, and the position of the unit strain line corresponds well to the authors' experience in such varied conditions as saturated atmospheres in military tanks, hot wet jungle conditions, summer operations in Death Valley, and conditions in machinery enclosures exposed to full desert sun. Under the various sets of conditions represented by this line, the maintenance of any kind of thermal balance is precarious, and tolerance beyond a few hours virtually impossible. This line corresponds very closely to that established by Robinson as marking the limit beyond which heat equilibrium could not be reliably maintained for more than two hours. Other comparisons between the lines of our proposed chart and values established by others will be given in the succeeding section of this report.

ADJUSTMENTS FOR NON-STANDARD CONDITIONS

While the chart drawn for the postulated standard conditions will suffice for a large proportion of situations encountered, there will be instances where conditions will depart significantly from those postulated. It is not necessary, however, to draw a family of charts to meet all of these cases. Reference to the reduced version of the general formula (p. 18) will show that a change from the postulated value for the metabolic rate (M), ambient air movement (represented by I_a), or insulation of clothing (I_{cw}) can be imitated by a change in t_a (temperature of the air). In other words if one wishes to use the standard chart for other than the postulated values, one simply has to know what change in the air temperature would give the same effect, and add or subtract this value from the actual air temperature. The same thing could be done where the mean radiant temperature of the surroundings is different from air temperature.

The following table gives estimated changes in the metabolic rate (M), insulation of wet clothing (I_{cw}) and insulation of the air (I_a) due to body movement occasioned by activities other than the standard "walking at 2 mi/hr".

SHELTER ENVIRONMENTS

Activity	M	I_{cw}	Work Air Movement*
Sleeping	40	.6	0
Lying awake	50	.5	20
Sitting still	55	.5	20
Desk work	60	.4	50
Stand still	65	.5	30
Occasional stroll	100	.4	100
Walk 2 mph	100	.4	200
Walk 3 mph	140	.35	300
Walk 4 mph	190	.3	400
Moving loads	100-350	.3	250

* to be added to ambient air movement in determining I_a (ft/min)

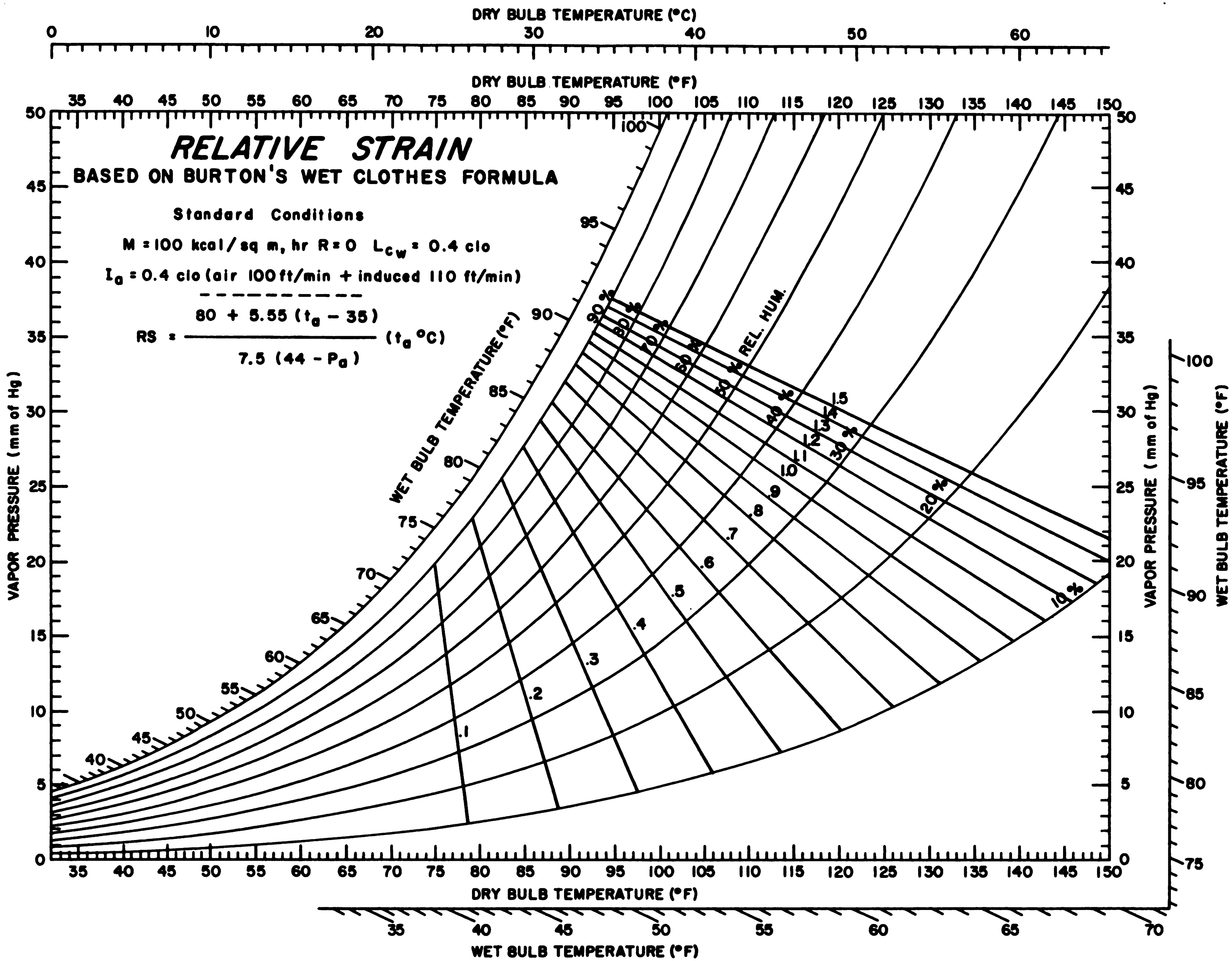
If the air movement is different from 100 ft/min, then a change must be made in I_a irrespective of the above. Table 2 presents the amounts to be added to or subtracted from actual air temperature to compensate for activity and air movement different from those used in compiling the standard chart.

Table 2

Correction to t_a for Non-Standard Activity and Air Movement °F

Activity		Ambient Air Movement (ft/min)							
Type	M kcal/ sq m,hr	25	50	75	100	200	300	400	500
Sleeping	40	-5	-6	-8	-0	-10	-11	-12	-13
Lying awake	50	-3	-5	-6	-8	-10	-11	-12	-13
Desk work	60	-6	-7	-8	-9	-10	-11	-12	-12
Standing still	65	-2	-3	-4	-5	-6	-7	-8	-9
Walking 2 mph	100	X	X	-1	-2	-3	-4	-5	-5
Walking 3 mph	140	+6	+5	+4	+4	+3	+2	+1	-1
Walking 4 mph	190	+11	+11	+10	+10	+9	+8	+7	+5
Lifting	100-350	-3 to +50	-5 to +50	-5 to +48	-5 to +48	-6 to +42	-8 to +37	-8 to +37	-8 to +37

Figure 11. RELATIVE STRAIN LINES FOR SAME STANDARD CONDITIONS BASED ON BURTON'S WET CLOTHES FORMULA -- ADOPTED FOR USE IN REMAINDER OF REPORT.


RELATIVE STRAIN
BASED ON BURTON'S WET CLOTHES FORMULA
Standard Conditions
M = 100 kcal/sq m, hr R = 0 L_{cw} = 0.4 clo
I_a = 0.4 clo (air 100 ft/min + induced 110 ft/min)
RS = $\frac{80 + 5.55 (t_a - 35)}{7.5 (44 - P_a)}$ (t_a °C)
DRY BULB TEMPERATURE (°C)
DRY BULB TEMPERATURE (°F)
VAPOR PRESSURE (mm of Hg)
WET BULB TEMPERATURE (°F)
% REL. HUM.

SIGNIFICANCE OF THE ZONES FOR A STANDARD PERSON

THE STANDARD PERSON

In the previous section a formula was derived and a chart prepared showing lines of equal relative strain for various combinations of air temperature and humidity, other physical variables, such as rate of work, clothing, air movement, and radiant heat being held constant at certain stated values believed to be fairly characteristic of shelter conditions. A table was provided for adjusting the chart for certain departures from these physical conditions.

It is now necessary to indicate the significance of each of the values of relative strain shown on the chart, or, more realistically, the significance of the psychrometric zones lying between the lines. But again we must take a standard situation first, leaving the modifications brought about by departures from the standard situation for later treatment. This time it is the individual exposed to the conditions that needs to be standardized.

The characteristics chosen for the standard individual are those of a healthy male about 25 years of age, not acclimatized to heat. Most of the subjects reported in the literature of heat physiology are of this type, and this type seems to present a logical point of departure for the consideration of responses to shelter conditions.

CRITERIA OF SIGNIFICANCE

The application of the charts of equal strain zones to practical situations of shelter, industrial or other environments requires a knowledge of the significance of each of the zones in terms of physiological and psychological responses and strain. The types and magnitude of the responses may be multiple and will, of course, vary with the individual and the combination of environmental factors to which he is exposed. To keep the number of combinations of interacting variables to manageable proportions, broad groupings of significant responses and modifying individual characteristics had to be made.

The selection of generalizable categories of physiological and psychological responses that would be meaningful for shelter management presented conceptual, scientific and semantic problems that required rather arbitrary decisions. To make the system manageable the number of categories had to be kept to a minimum commensurate with clearly distinguishable characteristics with a minimum of "gray areas" of overlap. Four categories pertaining to health and well-being and two categories related to capabilities were chosen. The significance of each of the 15 zones of equal environmental stress was determined on the bases of published data for each of the categories. The synthesized and interpreted information is presented in chart form for ready reference. The literature that was consulted in formulating the concepts and conclusions is included as the second part of the bibliography. In utilizing the published data much of it had to be converted to the standard conditions that were used in calculations and construction of the chart on zones of equal environmental stress. Data from several typical studies were corrected to the Standard Conditions of this report and plotted on the zones of environmental stress chart to illustrate the application of the data obtained from the literature (Fig. 12).

A precise and absolute definition of each of the categories again presents problems in semantics in part because the categories are concepts and are not entirely circumscribed entities that can be described or defined in the usual sense. The definitions of the categories are, therefore, for guidance and should not be construed as rigid, non-deviating axioms. The following definitions of categories were used in constructing the standard effects charts.

Comfort

Condition of thermal neutrality; the environment feels neither too warm or too cool; a state of contented enjoyment in physical and mental well-being with freedom from anxiety; a state of satisfaction with conditions present.

Discomfort

Thermal sensation of heat or cold; physical and mental uneasiness; uncomfortable; lack of comfort and well-being.

Distress

Physical and mental strain or oppression; faintness, nausea, headache, apprehension, dizziness, irritability, lack of attention, weakness, unsteady gait, excessive thirst or hunger; pain or suffering; anguish of body or mind.

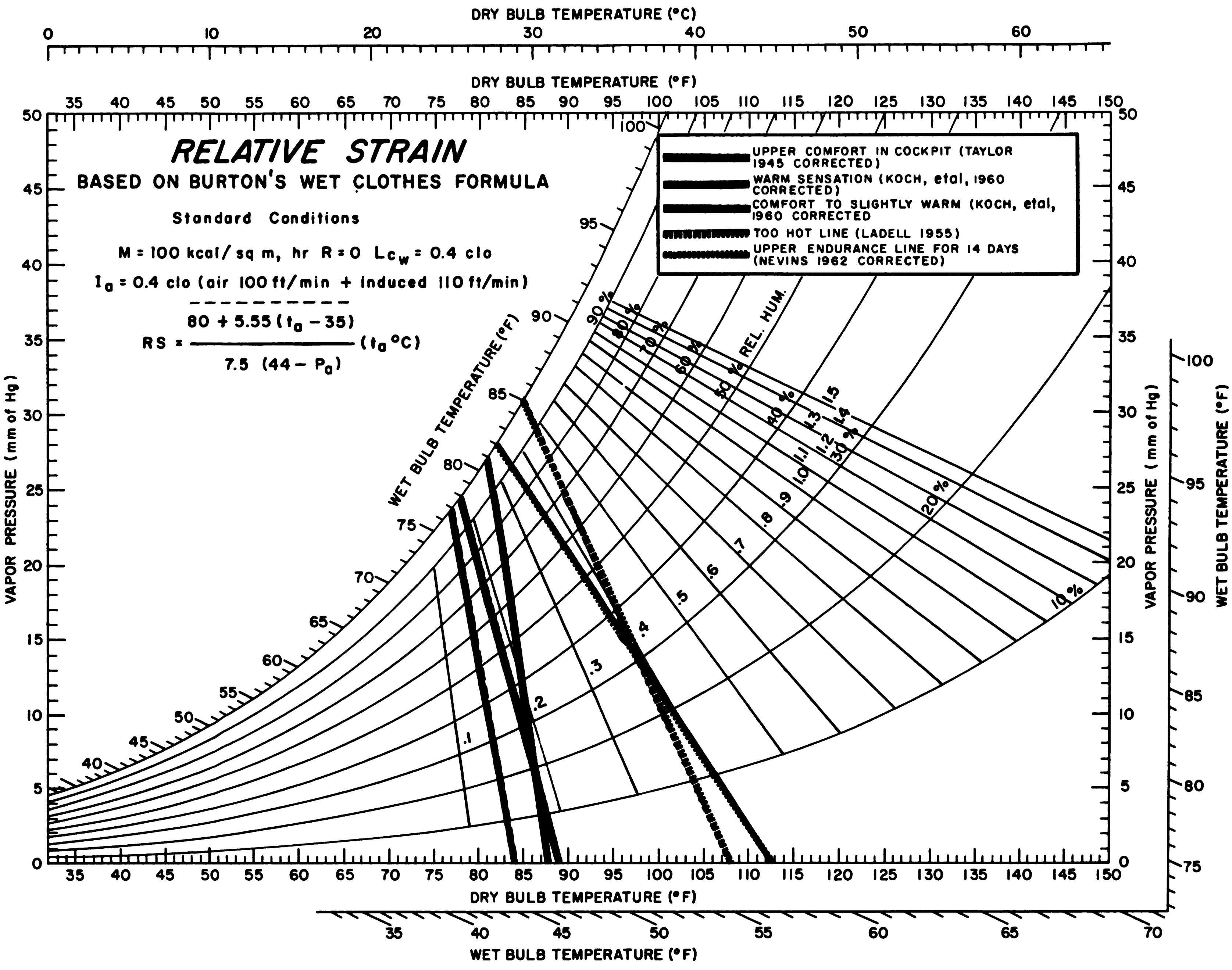
Failure

Physiological and psychological equilibrium not possible within acceptable limits of reserve capacity; rise in pulse rate and body temperature, disturbances in circulatory and temperature regulation; may progress to collapse and coma; meaning similar to military concept of casualty.

Performance

The quantity and quality of physical or mental work accomplished; capability to accomplish useful work.

Figure 12. CORRECTED DATA FROM TYPICAL LITERATURE STUDIES PLOTTED ON STANDARD ZONE CHART.


RELATIVE STRAIN
BASED ON BURTON'S WET CLOTHES FORMULA
Standard Conditions
M = 100 kcal/sq m, hr R = 0 Lcw = 0.4 clo
Ia = 0.4 clo (air 100 ft/min + induced 110 ft/min)
RS = [80 + 5.55 (ta − 35)] / [7.5 (44 − Pa)] (ta °C)
UPPER COMFORT IN COCKPIT (TAYLOR 1945 CORRECTED)
WARM SENSATION (KOCH, etal, 1960 CORRECTED)
COMFORT TO SLIGHTLY WARM (KOCH, etal, 1960 CORRECTED)
TOO HOT LINE (LADELL 1955)
UPPER ENDURANCE LINE FOR 14 DAYS (NEVINS 1962 CORRECTED)
DRY BULB TEMPERATURE (°C)
DRY BULB TEMPERATURE (°F)
VAPOR PRESSURE (mm of Hg)
WET BULB TEMPERATURE (°F)
REL. HUM.

SHELTER ENVIRONMENTS

Tolerance

Time of exposure before physiological or psychological responses reach unacceptable levels.

INTERPRETATION

On the basis of the foregoing definitions, assumptions and interpretations of pertinent data in the literature corrected to our standard conditions, a chart expressing the physiological and psychological significance of the zones was constructed for the Standard Person. These relationships for each of the categories of responses at each of the zones of equal environmental stress are expressed in the charts (Figs. 13-24). The concept of use of the charts is straightforward and is based on a few rather general rules. The basic rules for the utilization of the charts are:

1. A completely filled square at any response category -- stress zone intersect means that most individuals will respond to the environment of the zone with the responses characteristic of the category.

2. A blank square at any response category -- stress zone intersect occurring to the right of the shaded area means that the stress zone is beyond the range of normal, expected responses. If it occurs to the left of the shaded area, it means that the zone falls below the conditions at which abnormal reactions can be expected.

3. A three-fourths, one-half or one-fourth filled square at any response category -- stress zone intersect means that that proportion of individuals will exhibit the characteristic responses.

4. A blunt point on the filled category line means that there is narrow range of inter-individual variability in response to the stress.

5. A long point on the filled category line means there is a wide range of inter-individual variability in response to the stress.

6. Where there are no criteria for estimating the response in any category, the entire line is blank.

The interpretation of the significant effects charts will be illustrated by a detailed discussion of chart for the Standard Person (Fig. 13). The procedure for utilization of the chart is similar for all of the charts.

SHELTER ENVIRONMENTS

Comfort Category

The block of intersect zone .1 is filled in completely except for a small area in the top and bottom corners at the junction of zones .1 and .2. This means that all individuals will be comfortable for most of zone .1. A few individuals, less than 25 per cent, will feel that the set of environmental conditions represented in the right hand portion of zone .1 will be too warm. As the environmental conditions become progressively more severe through zone .2, a progressively larger per cent of individuals will say the conditions are too warm until at the junction between zone .2 and .3 and beyond everyone will feel that the conditions are too warm. The blank area in the comfort category line indicates those environmental conditions where people will not be comfortable. In general most individuals will be comfortable in zone .1, on the average only 50 per cent of individuals will be comfortable in zone .2 and no one will be comfortable beyond zone .2.

Discomfort Category

In the combinations of environmental conditions represented in zone .1 very few individuals will experience discomfort. The percentage of individuals who will find the environment uncomfortable will progressively increase through zone .2 and from zone .3 through zone 1.5 everyone will express discomfort or will have more serious symptoms and complaints. Zone .2 then is the boundary between comfortable conditions and conditions that are too hot for comfort.

Distress Category

Complaints and symptoms should not reach serious proportions in combinations of environment conditions less stressful than those represented in zone .3; zones .1 and .2 would not be expected to elicit distress complaints. In zone .3 the percentage of individuals with complaints and the severity of the symptoms will progressively increase. When the conditions represented by the mid-point of zone .4 are reached, all individuals will experience some degree of distress. From zone .5 onward the severity and number of symptoms will progressively increase and will shortly be overshadowed by the more serious failure of physiological and psychological systems.

Failure Category

The inter-individual variability in ability to meet the challenges of a stressful thermal environment is large. As indicated in this category some individuals will show signs of failure at the beginning of zone .4, about 50 per cent will exhibit signs of failure under conditions represented by the zone .4 to .5 boundary, and all will have some degree of

Figure 13. SIGNIFICANT EFFECTS FOR STANDARD MAN.

COMFORT - 100 per cent of individuals will be comfortable in zone .1 until environmental conditions reach the zone .1-.2 boundary at which time at least 85 per cent will consider the conditions acceptable. 50 per cent will be comfortable at mid-zone .2, but none will be comfortable at the zone .2-.3 boundary.

DISCOMFORT - A few individuals, 10-15 per cent, will report conditions to be too warm at the zone .1-.2 boundary, and 100 per cent will be too warm at the zone .2-.3 boundary. In zone .3 50 per cent will report conditions to be hot, and 100 per cent will find it hot in zone .4. Above zone .4 conditions will be considered too hot to be endurable.

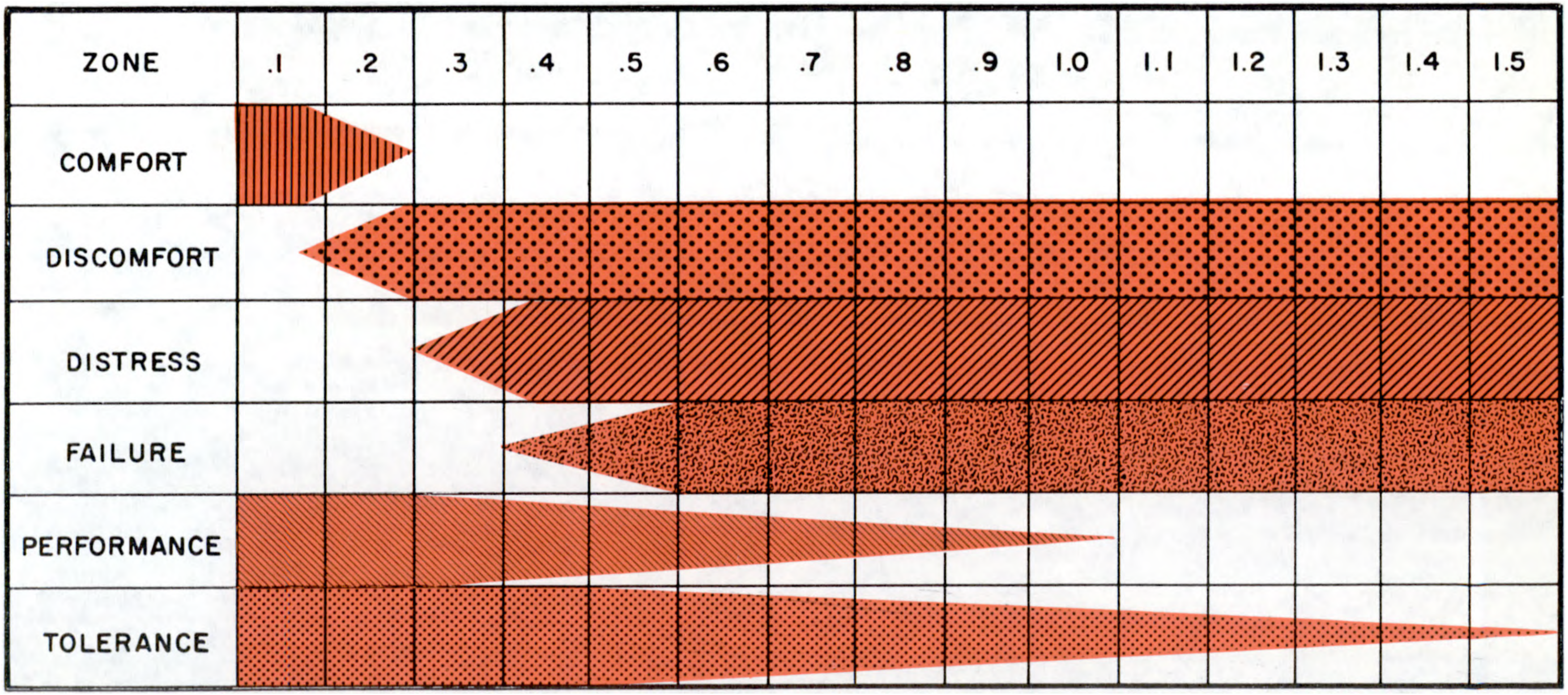
DISTRESS - Complaints and signs of distress will first appear at those conditions represented by the zone .2-.3 boundary. About 75 per cent will show distress at the zone .3 .4 boundary, and 100 per cent will have distress in zone .4. Beyond zone .4 distress will become progressively more severe and will require action to alleviate the distress.

FAILURE - Signs of failure will first occur under conditions of the zone .3-.4 boundary; 50 per cent will show signs of failure at the zone .4-.5 boundary; and 100 per cent will show signs of failure at the zone .5-.6 boundary. In zone .6 and beyond the responses will progressively become more severe and approach or exceed the range of physiological responses which can normally be tolerated without breakdown of the system.

PERFORMANCE - Performance will be maintained at acceptably high levels until the zone .4-.5 boundary is reached at which time 10-15 per cent will show a drop in performance. In zone .5 about 25 per cent, in zone .6 about 50 per cent and in zone .7 about 75 per cent of the group will have a drop in performance capacity of 25 to 50 per cent. A few individuals will be capable of useful work up to zone 1.0 but only for short periods of time not to exceed 1-2 hours.

TOLERANCE - A reduction in tolerance time will not be a major factor in shelter management for the Standard Person. Discomfort and distress will reach proportions that will require action before irreversible alterations in the physiological and psychological functions will occur.

SIGNIFICANT EFFECTS FOR STANDARD MAN



failure under the conditions of the zone .5 to .6 boundary. Failures will be progressively more severe as environmental conditions become more stressful in zone .6 and above. At zone 1.0 and above the onset of failures will be rapid and severe.

Performance Category

Deterioration in physical and mental work capacity is not likely to occur under environmental conditions in zones .1 and .2. With the occurrence of distress, performance will fall off with some individuals. However, a wide inter-individual range of resistance to deterioration of performance can be expected. This is indicated by the long-tapering shaded area extending into zone 1.0. Level of skill, motivation, state of physical training, experience in hot situations and many other factors will alter the rate and extent of deterioration that is likely to occur in any of the environmental stress zones above 0.3. A general rule is, however, that the greater the environmental stress the more extensive and rapid will be the deterioration of performance.

Tolerance Category

Besides the severity of the environmental stress, the length of time the individual is exposed is important in determining tolerance. Physiologically and psychologically most people can tolerate environmental conditions up to those represented in zone .4. Beyond zone .4 the conditions can still be tolerated provided the length of exposure is decreased. The Standard Person can tolerate conditions more severe than those represented in zone 1.5 for periods of 15 to 30 minutes. The long tapered shaded area from zone .5 through 1.5 indicates that tolerance time becomes progressively shorter as the environmental conditions become progressively more severe.

CHANGED SIGNIFICANCE OF THE ZONES FOR NON-STANDARD PERSON

Many of the people who may make up a shelter population will have characteristics quite different from the Standard Person. There will be infants, children, middle age adults, aged, people of all ages with a variety of diseases, disorders and limitations--conditions all of which will change the physiological and psychological significance of the zones of equal environmental stress. Appreciating the magnitude of the changes in the significance of the zones for individuals who may differ from the Standard Person, separate charts of significance were prepared for major groups of non-standard individuals. The choice of groupings was based on literature reports of factors which had been observed to alter the normal responses to thermal stress.

SHELTER ENVIRONMENTS

Eleven non-standard situations were selected which cover most of the factors known to alter responses to heat. A separate "significance of zones chart" with interpretation was prepared for each of the eleven non-standard situations. Each of these charts will also be briefly analyzed to illustrate its use and to point out the major differences between it and the Standard Person chart.

AGE 45-65 YEARS (Fig. 14)

The major change, as a function of increasing age, will be a decrease in the range of adaptability. This is indicated by a blunting of the points in the comfort and discomfort categories of responses. How much of the decreased adaptability is due to changes in capacity to adapt and how much is due to increasing self-indulgence and reluctance to put-up with unpleasant situations is not apparent from the available data. In the end, however, the practical importance to shelter management may not be greatly different.

The onset of distress and of failure will occur on the average at combinations of environmental stress about one stress zone less severe than for the Standard Person. Many middle aged adults will be remarkedly resistant to the environmental stresses but a much greater proportion than in the standard group will show signs and symptoms of deterioration, reduced performance and decreased tolerance to heat stress.

AGE 65 AND OVER (Fig. 15)

Older adults will have lost a major part of their ability to adapt to stressful environments. This is indicated by the extreme blunting of the points in the comfort and discomfort categories, a shifting to the left, blunting of the distress and failure categories and a large reduction in the ability to perform work and to tolerate severe conditions. Distress and failures will occur about one and one-half environmental stress zones sooner than they occur in the Standard Person. The same relative relationships are to be expected for performance and tolerance.

INFANTS (Fig. 16)

In many aspects the responses and adaptability of infants will resemble those intermediate between the middle aged adults and the elderly. The comfort and discomfort overlap will be rather sharply limited to zone .2 but the cooler conditions at the beginning of zone .1 maybe too cool for the newborn. Prickly heat and increased irritability may be prominent in category .2 particularly if the skin cannot be kept dry. Some breakdown of body temperature regulation can be expected in zone .3 in the younger infants and in those in whom the temperature regulating mechanism has not been fully developed. Because of the slow maturing of temperature

Figure 14. SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - AGE 45-65

COMFORT - Nearly 100 per cent will be comfortable to the zone .1 -.2 boundary, and 100 per cent will reach the upper limits of comfort mid-point in zone .2.

DISCOMFORT - A few individuals will be too warm at the zone .1 -.2 boundary, and 100 per cent will find conditions too warm at the mid-point of zone .2. Beyond zone .2 100 per cent will find conditions to be too hot until in zones .4 and above it will be too hot to be endured.

DISTRESS - First symptoms of distress will appear in a few at the zone .1 -.2 boundary; 100 per cent will have some symptoms of distress in the zone .2-.3 boundary. In zone .3 and .4 the symptoms of distress will become more numerous and more severe leading on into more serious responses.

FAILURE - A few signs of failure will appear in some individuals in mid-zone .2. By mid-zone .3 most will have some indications of impending failures. In zone .4 and .5, 100 per cent will exhibit signs of serious breakdowns of equilibrium. Beyond zone .5 failures will appear with progressively shorter exposure times.

PERFORMANCE - The quality and quantity of performance will start to deteriorate under conditions of zone .2-.3 boundary; 50 per cent deterioration will occur in zone .4 and beyond zone .5 effective performance cannot be expected except for limited periods of time. Individuals in good physical condition who have had repeated experiences in working in the heat will respond much the same as will the Standard Person.

TOLERANCE - A decrease of 25 per cent in zone .4-.5; 50 per cent in zone .6-.7 and 75 per cent in zone .8 in tolerance should be expected. The upper limits of tolerance except for short periods of less than 30 minutes will occur at zone 1.0.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Age 45-65

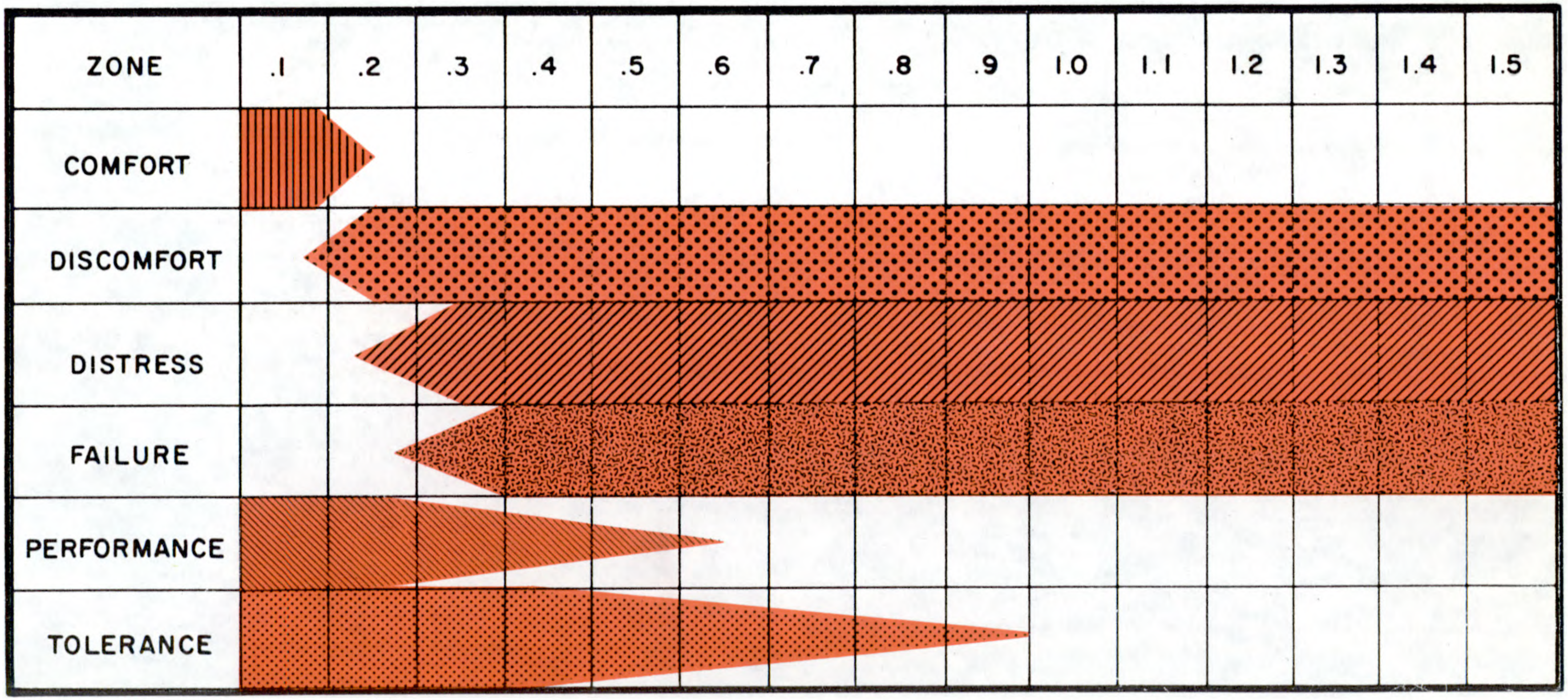


Figure 15. **SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - AGE 65 AND OVER**

COMFORT - Most elderly individuals will find zone .1 comfortable; few will consider conditions beyond the mid-point of zone .2 comfortable.

DISCOMFORT - The incidence of complaints of too warm will rapidly increase as conditions become hotter in zone .2. By the mid-point of zone .2 most will find it too warm.

DISTRESS - Some symptoms of distress will appear at the boundary of zone .1-.2, and 100 per cent of the group will have some symptoms by the zone .2-.3 boundary. Beyond zone .3 the number and severity of the symptoms will progressively become more serious.

FAILURE - Signs of failure will occur in a few mid-points in zone .2; about 50 per cent will have signs of failure at the zone .2-.3 boundary and 100 per cent will have signs of failure at the mid-point of zone .3. In zone .4 and beyond failure will be exaggerated and the onset will occur after only hours or a day or two of exposure.

PERFORMANCE - The limited performance capacity of the individuals over 65 years of age will be further drastically curtailed by hot conditions. Effective performance beyond zone .3-.4 boundary cannot be expected.

TOLERANCE - This group will not be able to tolerate severe environmental conditions for long. In zone .3 a 25 per cent reduction in tolerance can be expected, a 50 per cent reduction in zone .4, and a 75 per cent reduction in zone .5. In zone .6 and beyond exposures for more than minutes may precipitate crisis that would jeopardize the individual's life.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Age 65 and Over

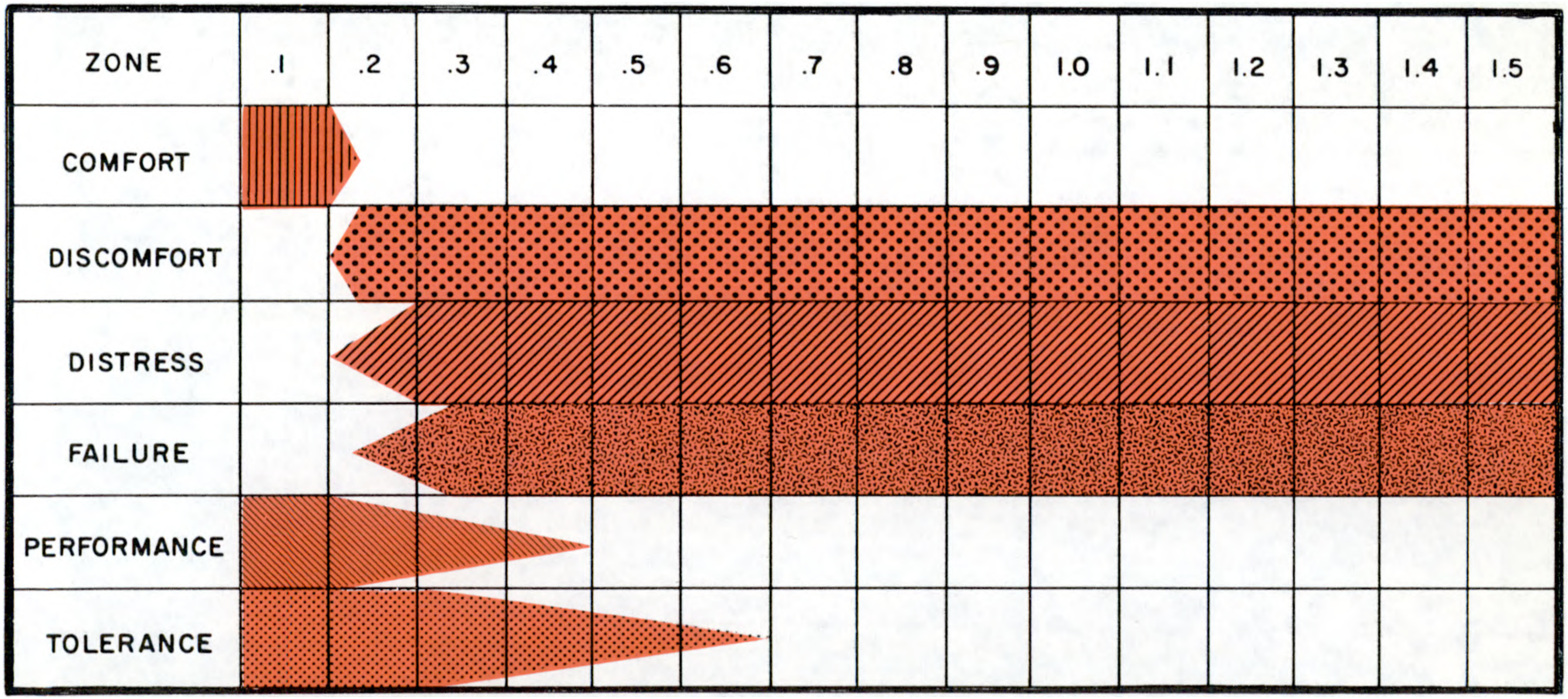


Figure 16. SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - INFANTS

COMFORT - 100 per cent will accept conditions at the zone .1-.2 boundary, but 100 per cent will not be comfortable beyond the mid-point of zone .2. Conditions at the lower boundary of zone .1 may be too cool for some infants unless additional insulation is furnished.

DISCOMFORT - Expressions of discomfort will start to occur at the zone .1-.2 boundary, and beyond the mid-point of zone .2 will be too warm for most.

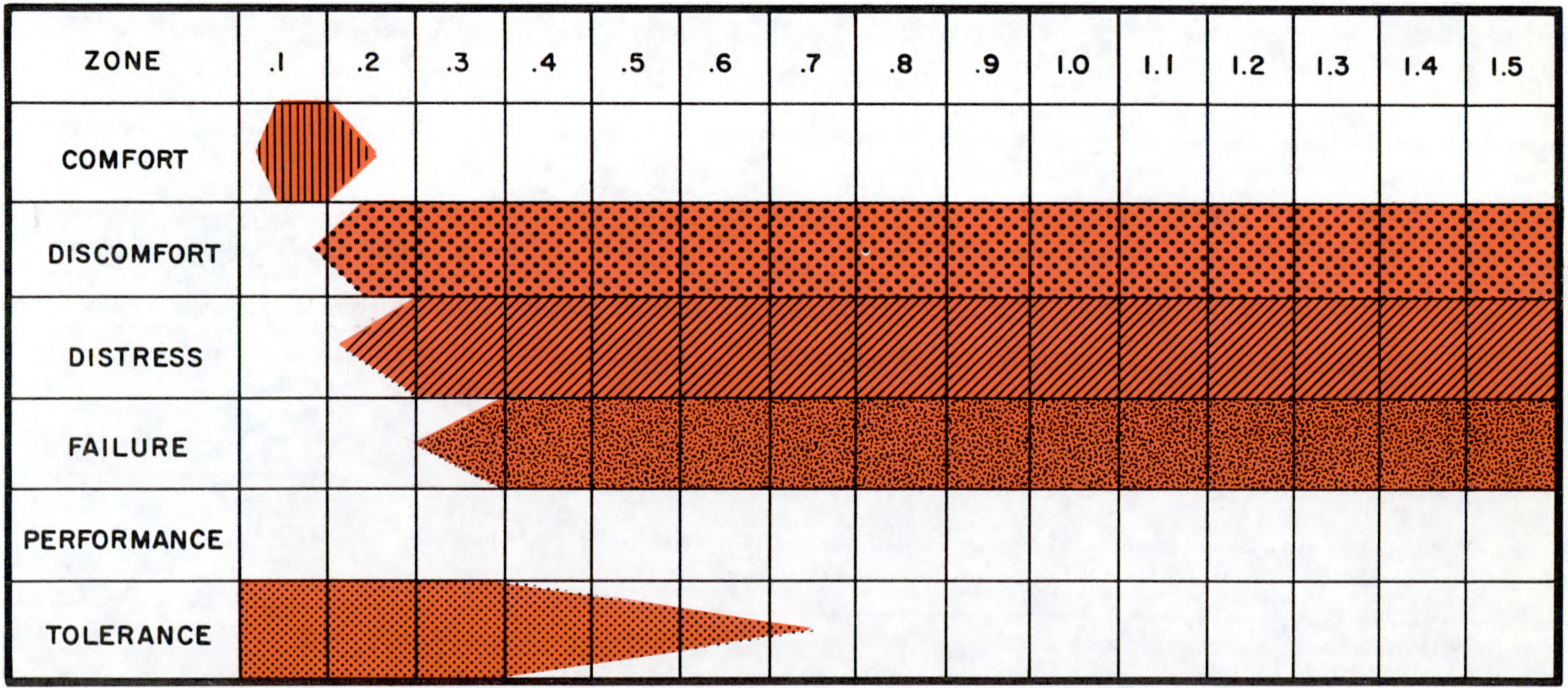
DISTRESS - Expressions of distress will appear by the mid-point in zone .2 and in zone .3 and beyond all will have some symptoms of distress.

FAILURE - Because of the limited ability of infants to effectively regulate body temperature, failures are likely to occur in zone .3. As conditions become more severe in zone .4 and beyond, the failures will present sinous medical and management problems in most infants.

PERFORMANCE - What constitutes normal performance in infants could not be decided; therefore, the performance category was left blank.

TOLERANCE - Tolerance may be better than would be expected from the symptoms of distress and signs of failure. At the zone .4-.5 boundary a 25 per cent decrease can be expected, a 50 per cent decrease in zone .5 and a 75 per cent decrease in zone .6. Continued exposure to conditions beyond zone .6 could not be tolerated.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---Infant



regulation in infants, tolerance time may be sharply limited at the more extreme environmental conditions of zone .5 and beyond. None of the usual criterion of performance is applicable to infants; consequently, the entire category is left blank and is not considered to be pertinent.

OBESE (Fig. 17)

Obesity will, even in young adults, decrease the capacity to adjust to environmental stress. The energy cost of carrying the added weight as fat will, of course, increase the total heat production at any level of work. Its effect will be similar to increasing work rate. The thick subcutaneous fat layer may also serve as a barrier to heat exchange between the underlying tissue and the skin surface. The obese young adult can be expected to react to a heat stress much as the middle aged adult does. Tolerance time, however, in extreme conditions of short exposure may actually be rather better than expected because the subcutaneous fat will act as a thermal insulator to the gain of heat from the external environment. Such severe conditions when the fat would help to prevent heat gain is not likely to occur in shelter conditions. Obesity can be expected to exaggerate the deterioration that will occur in increasing age and in the disease or disorder conditions.

ACCLIMATIZED PERSON (Fig. 18)

The benefits to be obtained from being acclimatized to heat are dramatic for all individuals. The upper limit of conditions that will be considered comfortable is extended by at least half an environmental stress zone and discomfort will, of course, appear later. The great advantages will occur in the distress, failure, performance and tolerance categories. In the Standard Person, being acclimatized to a hot environment will in effect eliminate most of the impact of the environment. The Standard Person can be acclimatized to environment stresses as severe as those encountered in zone .9 to 1.0. Beyond this point, acclimatization as usually defined probably cannot be fully achieved.

LIMITED WATER (Fig. 19)

Lack of sufficient fluid intake to replace the water lost in the urine, through the skin and lungs and by vomiting, diarrhea or bleeding will eventually lead to a decreased ability to adapt to a hot environment. Under most situations, sweating will be the major avenue of excessive water loss. In some metabolic and dermatological disorders the rate of sweating may be augmented or severely reduced--each of which may lead to serious consequences. Gastrointestinal disorders with vomiting or diarrhea can result in rather large water losses. If a limited water intake results in a body water deficit of more than 2.5-3.0 liters, rapid deterioration will ensue in a hot environment. This is depicted in the chart by the onset of distress and failure in the environmental stress zone .2, and rapid decay of performance and tolerance under conditions of zones .2-.5 and the complete inability for useful work at zone .5 and beyond.

METABOLIC DISORDERS (Fig. 20)

Only those metabolic disorders are included here that will influence the normal responses to a hot environment mainly by increasing body heat production, by altering the body temperature regulating mechanism and by altering peripheral vascular control; hypometabolic disorders were disregarded. The net effect will be to decrease the maximum environmental stress at which thermal equilibrium can be achieved. There is little evidence to suggest that the comfort and discomfort responses will be significantly altered. However, the distress and failure categories will appear at lower environmental stresses and performance and tolerance will also be decreased. Individuals with mild metabolic disorders will have less deterioration in adaptation than those shown in the chart while severe metabolic disorders will result in exaggerated changes.

DERMATOLOGICAL DISORDERS (Fig. 21)

Dermatological disorders will exert three effects on heat adaptability mainly through alterations in peripheral blood flow, through reduction in sweat production and by being a primary source of pain and distress. Comfort will be experienced in zone .1 and in part of zone .2 with discomfort appearing as the inverse of the rate of disappearance of comfort. Distress will occur at environmental conditions which are not particularly severe but failure may not occur unusually early except in individuals with extensive sweating defects or alterations in peripheral blood flow or peripheral vascular control. Again except for the individuals with rather extensive involvements, deterioration of performance and tolerance will not present a seriously limiting problem through zone .3 and .4.

CARDIOPULMONARY DISORDERS (Fig. 22)

Disorders of the cardiopulmonary system would not be expected to alter, to any marked extent, the environmental limits which would be considered comfortable and the onset of discomfort. Besides the general diminution in reserve capacity associated with cardiopulmonary disorders, alterations in peripheral blood flow will have a special significance related to the thermal exchange with the environment. Under conditions of a hot environment similar to that represented by zones .4 to .5, in the Standard Person peripheral blood flow and cardiac output will be increased several times over that required in cool environments. If this increased demand for blood flow cannot be met, then distress and failure to maintain thermal balance with all its consequences will ensue. Performance and tolerance will rapidly deteriorate with increasing thermal loads and the individuals will become quite ineffective as early as zone .3 or .4.

Figure 17. **SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - OBESE**

COMFORT - 100 per cent of obese will be comfortable through the lower two-thirds of zone .1. All will find conditions no longer comfortable by the middle of zone .2.

DISCOMFORT - Conditions will be considered too warm by a few in the upper third of zone .1, and all will feel too warm in the first one-third of zone .2.

DISTRESS - The first symptoms of distress will appear early in zone .2, and 100 per cent will show some symptoms of distress at the zone .2-.3 boundary. In zone .3 and beyond symptoms will increase in number and severity.

FAILURE - The first signs of failure will occur at the mid-point of zone .2, 50 per cent will exhibit some signs at the zone .2-.3 boundary and 100 per cent will have signs by the mid-point of zone .3. In zone .4 and above signs will increase rapidly in severity and number.

PERFORMANCE - Significant decreases in performance will occur in 25 per cent of the individuals in zone .3, 50 per cent at the zone .4-.5 boundary and 75 per cent in zone .6. Useful performance will be greatly reduced by zone .7 and beyond.

TOLERANCE - Tolerance will slowly decrease beyond zone .3-.4, but some individuals may tolerate conditions up to zone 1.0. Beyond zone 1.0 conditions will be tolerated for only minutes.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---Obese

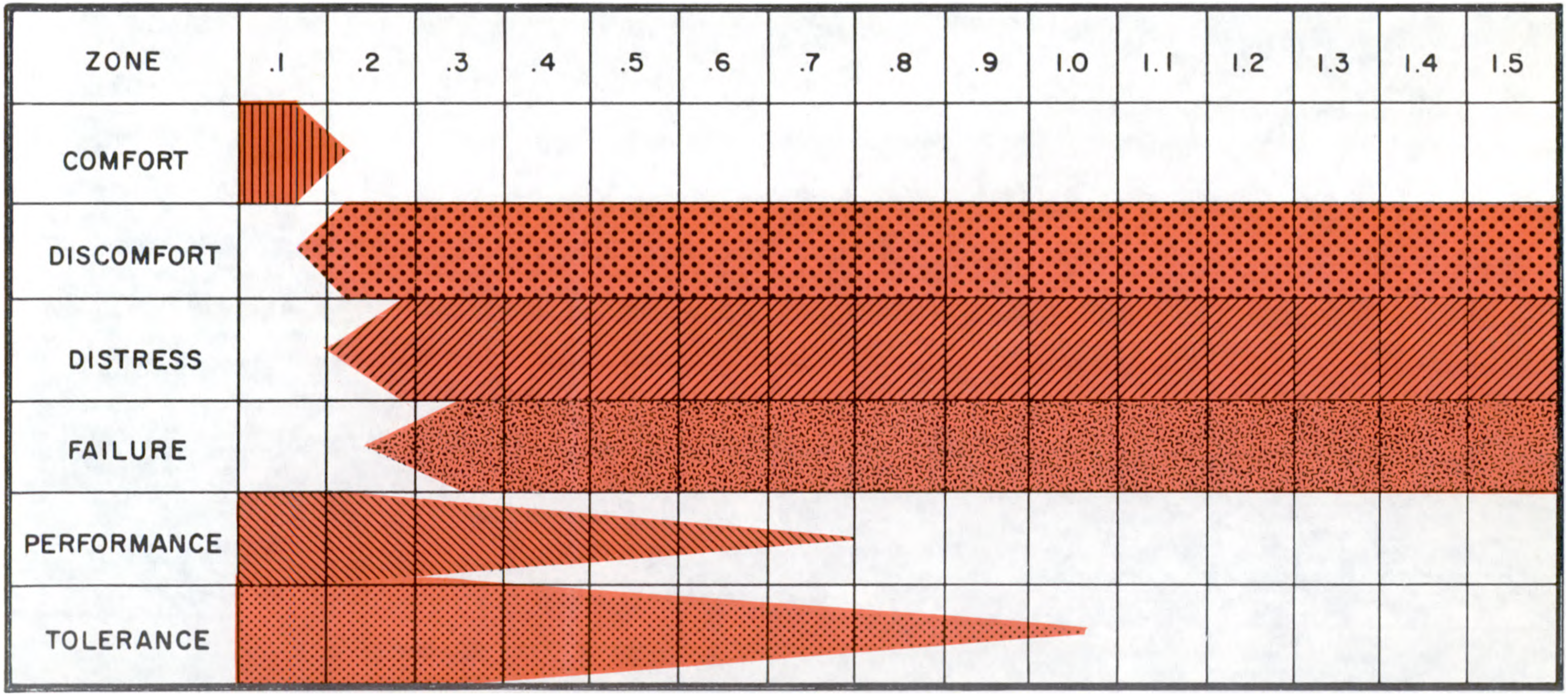


Figure 18. **SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - ACCLIMATIZED**

COMFORT - 100 per cent comfortable into zone .2, 50 per cent comfortable at the mid-point of zone .2, 25 per cent will be comfortable at the upper boundary of zone .2, and a few may find the conditions in the lower part of zone .2 acceptable.

DISCOMFORT - A few will find conditions too warm mid-point in zone .2, 50 per cent at the zone .2-.3 boundary and 100 per cent at the mid-point of zone .2.

DISTRESS - Symptoms of distress will first appear at the mid-point of zone .4, 50 per cent will have symptoms at zone .5 mid-point and 100 per cent at the zone .5-.6 boundary.

FAILURE - Signs of failure will not occur until the zone .7-.8 boundary provided acclimatization has been accomplished to severe conditions, 25 per cent will have signs at the zone .8-.9 boundary and 100 per cent will have signs in zone 1.0.

PERFORMANCE - Decrease in performance will be delayed until zone .7, 50 per cent will show deterioration in zone .9-1.0 but a few may be capable of useful activities up to zone 1.5 provided exposure is limited to only a few hours a day.

TOLERANCE - Tolerance should provide no problem in usual shelter environments. Little deterioration will occur before zone .9-1.0.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---Acclimatized

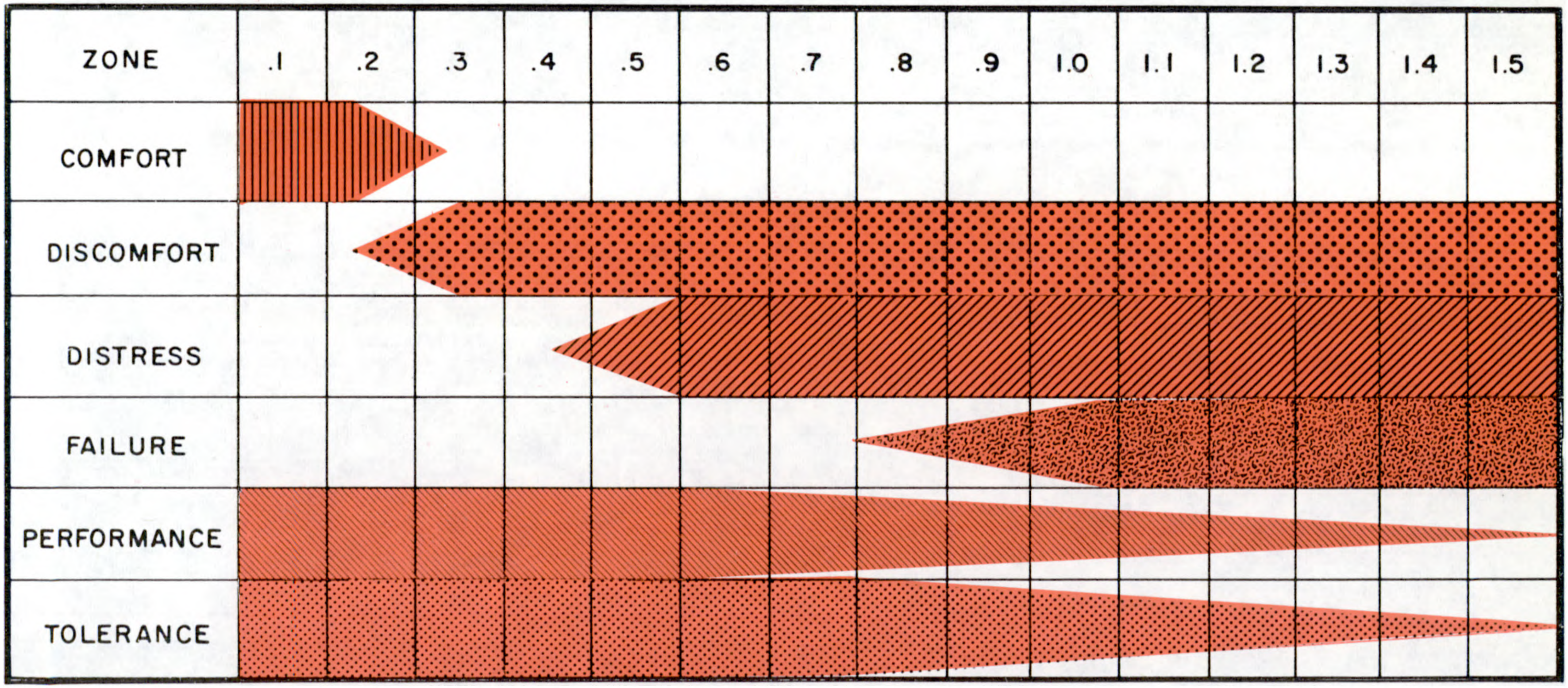


Figure 19. SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - LIMITED WATER

COMFORT - 100 per cent will be comfortable until the upper part of zone .1 is reached, 50 per cent will be comfortable at the zone .1 -.2 boundary and none will be comfortable in conditions more severe than the mid-point of zone .2.

DISCOMFORT - 50 per cent will find the boundary of zone .1-.2 too warm; and after the first one-third of zone .2, 100 per cent will be too warm.

DISTRESS - First symptoms will appear at the zone .1 -.2 boundary; and 100 per cent will show one or more symptoms at the zone .2-.3 boundary. Beyond zone .3 severity of symptoms will rapidly intensify.

FAILURE - At mid-point of zone .2 signs of failure will first appear, 75 per cent will have signs at the zone .2-.3 boundary and 100 per cent early in zone .3. Beyond zone .3 rapid loss of capacity to maintain acceptable physiological equilibrium will occur.

PERFORMANCE - Decrease in performance will progress rapidly in zone .2 and beyond, 50 per cent decrease in performance will occur in zone .3 and little useful activity can be expected in zone .4 and beyond.

TOLERANCE - At the zone .2-.3 boundary deterioration in tolerance will occur. In zone .4 and beyond tolerance will be limited to short periods and not more than 50 per cent of the group will be able to tolerate the conditions.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Limited Water

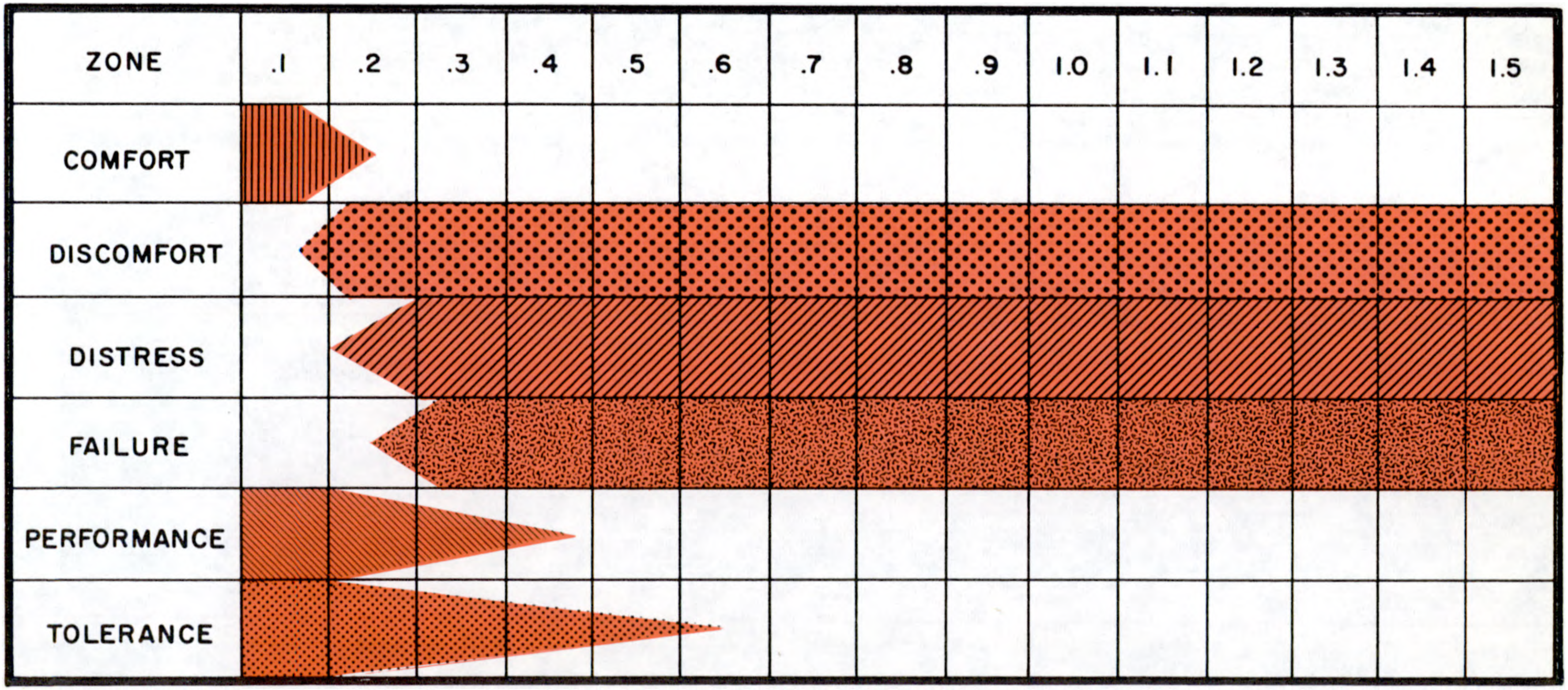


Figure 20. **SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - METABOLIC DISORDERS**

COMFORT - 100 per cent will be comfortable at the zone .1-.2 boundary, and none will be comfortable beyond the mid-point of zone .2.

DISCOMFORT - A few will find the zone .1-.2 boundary too warm, and 100 per cent will consider the mid-point of zone .2 too warm.

DISTRESS - First symptoms of distress will occur at the mid-point of zone .2, 100 per cent will have symptoms at the zone .2-.3 boundary. In zone .3 and beyond symptoms will become more numerous and severe.

FAILURE - Signs of failure will first occur at the zone .2-.3 boundary and will increase in number until 100 per cent will have signs of failure at the zone .3-.4 boundary. In zone .4 and beyond signs will become more prevalent and severe.

PERFORMANCE - A 25 per cent decrease will be present by zone .4, a 50 per cent in zone .6 and 100 per cent in zone .8.

TOLERANCE - A 25 per cent decrease in tolerance at zone .5, 50 per cent in zone .7 and tolerance will be minimal in zone 1.0.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Metabolic Disorders

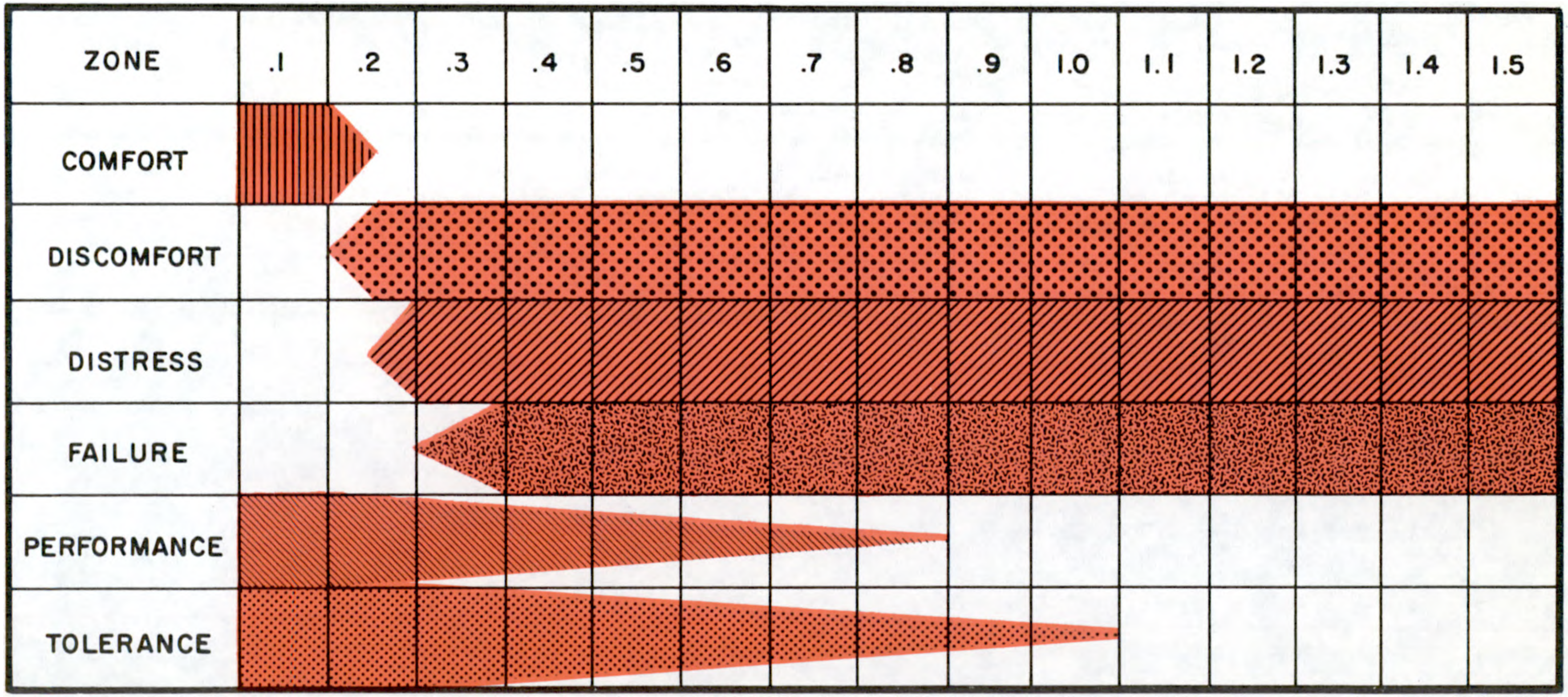


Figure 21. **SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - DERMATOLOGICAL DISORDERS**

COMFORT - 100 per cent will be comfortable through zone .1; none will be comfortable at the mid-point of zone .2.

DISCOMFORT - A few will find it too warm at the zone .1-.2 boundary; 100 per cent will be too warm at the mid-point of zone .2.

DISTRESS - Symptoms of distress will first appear at the mid-point of zone .2; 100 per cent will have symptoms of distress by the zone .2-.3 boundary. In zone .3 and beyond symptoms will become progressively more intense and frequent.

FAILURE - First failures can be expected at the zone .2-.3 boundary, and 100 per cent will show some signs of failure at the zone .3-.4 boundary. In zone .4 and beyond the failures will be more serious and numerous.

PERFORMANCE - Decrease of 25 per cent in performance likely to occur in zone .3, 50 per cent in zone .4, 75 per cent in zone .5, and no effective performance beyond zone .6-.7.

TOLERANCE - Tolerance will be restricted in zones .3 and beyond. The reduction in tolerance will reflect the severity of the skin involvement, skin blood flow and sweating.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Dermatological Disorders

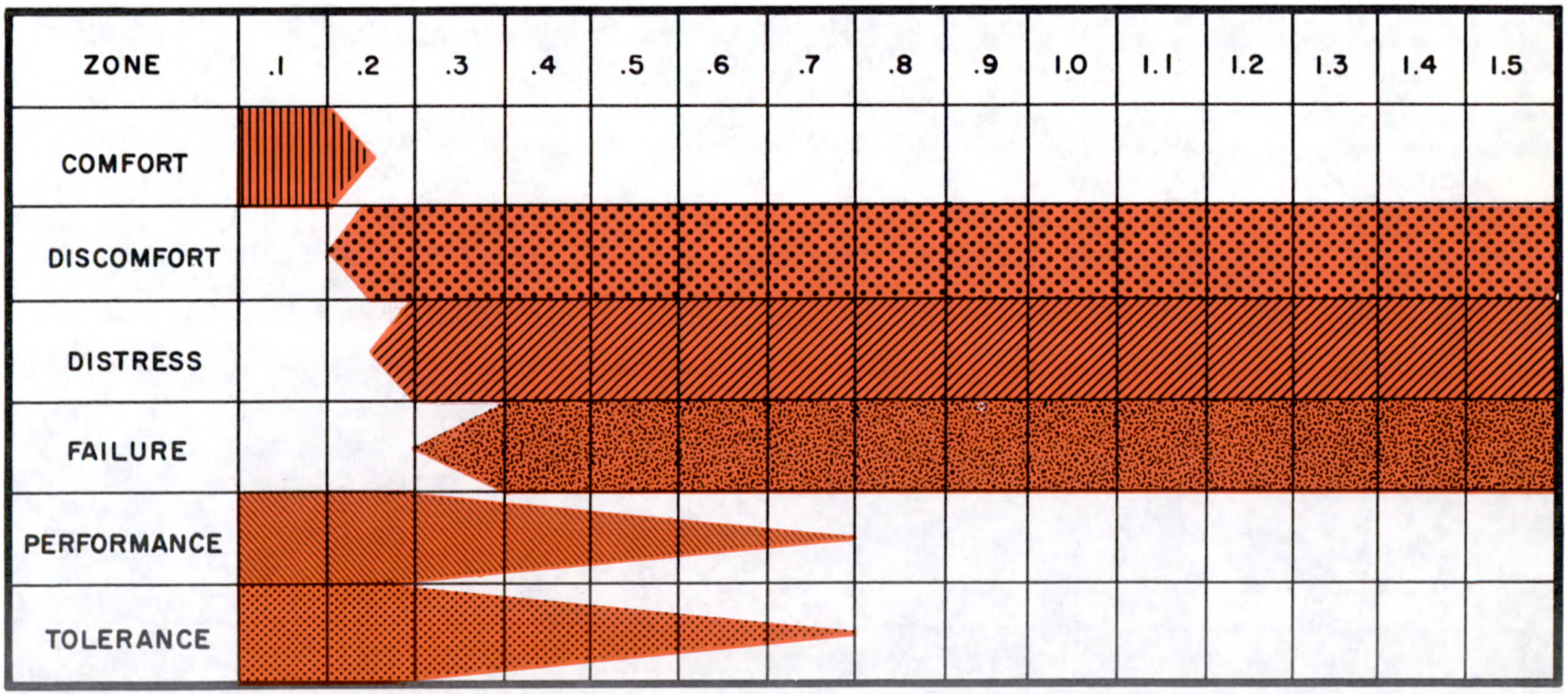


Figure 22. **SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - CARDIOPULMONARY DISORDERS**

COMFORT - 100 per cent comfortable until near the zone .1-.2 boundary, beyond 75 per cent will be comfortable. None will be comfortable at conditions more severe than the mid-point of zone .2.

DISCOMFORT - 25 per cent will find conditions too warm at the zone .1-.2 boundary. For 100 per cent it will be too warm at the mid-point of zone .2.

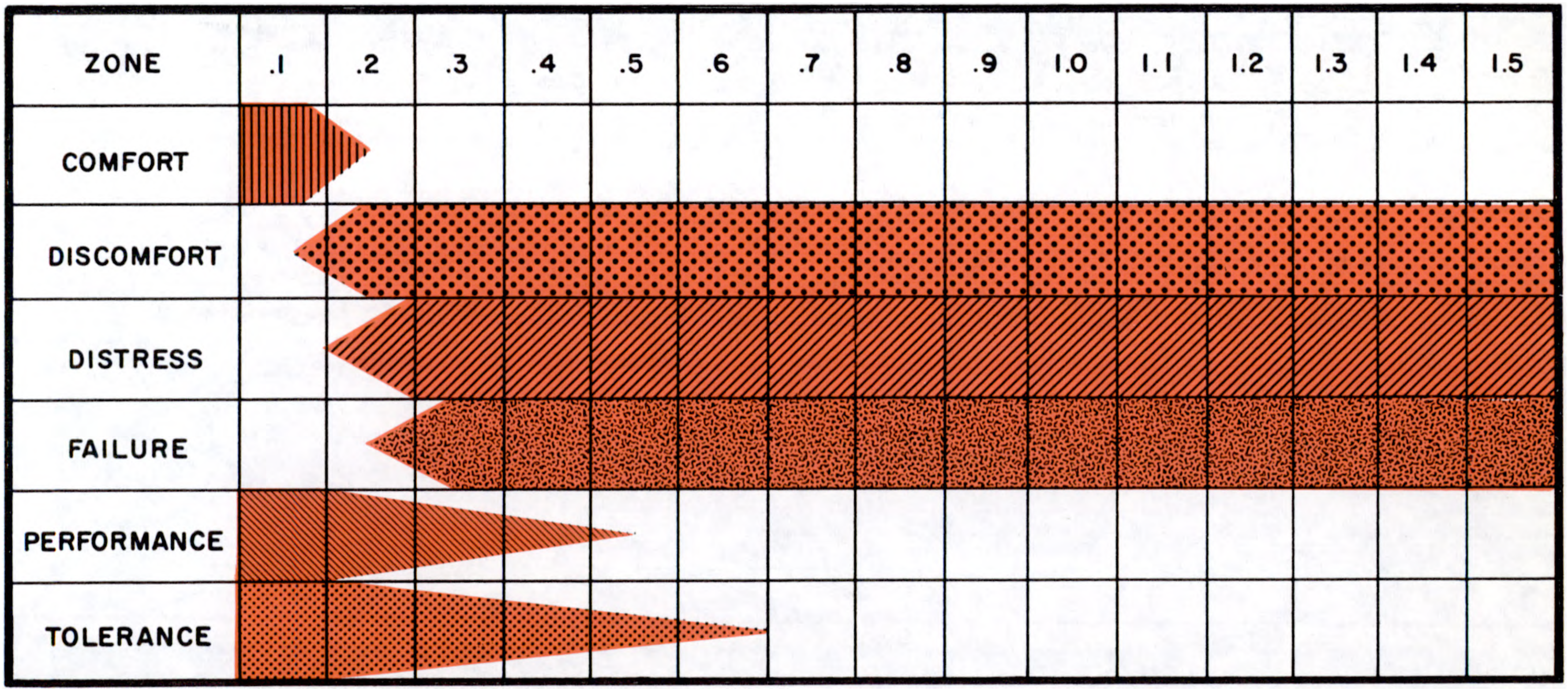
DISTRESS - First symptoms will appear at the zone .1-.2 boundary; 100 per cent will have distress at the zone .2-.3 boundary. In zone .3 and beyond symptoms will increase in number and severity.

FAILURE - First signs of failure at the mid-point of zone .2, 50 per cent at the zone .2-.3 boundary, and 100 per cent at the mid-point of zone .3. Beyond zone .3 the signs will become progressively more numerous and severe.

PERFORMANCE - Range of performance will be sharply limited. Deterioration will start in zone .2, reduced 50 per cent in zone .3, and in zone .4 little can be accomplished.

TOLERANCE - Reduction in tolerance will be about 25 per cent in zone .3, 50 per cent in zone .4 and 75 per cent in zone .5.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Cardiopulmonary Disorders



SHELTER ENVIRONMENTS

GASTROINTESTINAL DISORDERS (Fig. 23)

Besides the overall distress associated with gastrointestinal disorders, when combined with a thermal load the consequences can be quite devastating. The comfort zone and the onset of discomfort need not necessarily be seriously altered. However, the dehydration likely to occur as a result of vomiting and diarrhea can result in serious interference with heat exchange and the inevitable increase in body temperature, with distress and failure at environmental heat loads which the Standard Person will find relatively unstressful. Acceptable levels of performance and tolerance can be expected only at the lower zones of equal environmental stress (zones .1 and .2). In addition to the dehydration that may be part of the disorders, circulatory effects may also be a complicating factor particularly in the presence of a thermal load. Under such circumstances the ability to meet the insult of the thermal load will be drastically reduced.

PSYCHOLOGICAL ABNORMALITIES (Fig. 24)

The alterations in responses that are likely to be exhibited by this group of individuals may seem inordinately dramatic in view of minor changes in functions that may be present. The range of conditions to which they can adapt will be narrow so that small changes in the level of stress will provoke abnormally large reactions. Comfort will be mostly limited to zone .1 and conditions in zone .2 will evoke both discomfort and distress reactions. On the other hand, failures may not occur as readily as would be expected from the expressions of discomfort and distress. Performance and tolerance will be grossly limited to a large extent because of the characteristics of the group to put up with a situation that is not to their liking. For shelter management this may be one of the groups that will cause the greatest problems. The reactions to any level environmental stress outside the comfort zone will be exaggerated.

Figure 23. **SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - GASTROINTESTINAL DISORDERS**

COMFORT - These disorders will have little effect on the range of conditions considered comfortable, 100 per cent comfortable at the zone .1-.2 boundary and none comfortable at the zone .2-.3 boundary.

DISCOMFORT - A few will find conditions at the zone .1 -.2 too warm, and for 100 per cent it will be too warm at the zone .2-.3 boundary.

DISTRESS - First symptoms at the mid-point of zone .2, 50 per cent with symptoms at the zone .2-.3 boundary and 100 per cent at the mid-point of zone .3. Beyond zone .3 symptoms will progressively become more prevalent and serious.

FAILURE - No failures before the zone .2-.3 boundary; 50 per cent with signs at the zone .3 mid-point; 100 per cent with signs at the zone .3-.4 boundary. In zone .4 and beyond failures increase in number and severity in 100 per cent of the group.

PERFORMANCE - Limitation of performance will be prominent. A 25 per cent reduction can be expected in zone .3, a 50 per cent in zone .4, and a 75 per cent in zone .5. Beyond zone .5 little useful work will be accomplished.

TOLERANCE - There will be a 25 per cent reduction in tolerance in zone .4, a 50 per cent in zones .5-.6 and a 75 per cent in zone .7.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Gastrointestinal Disorders

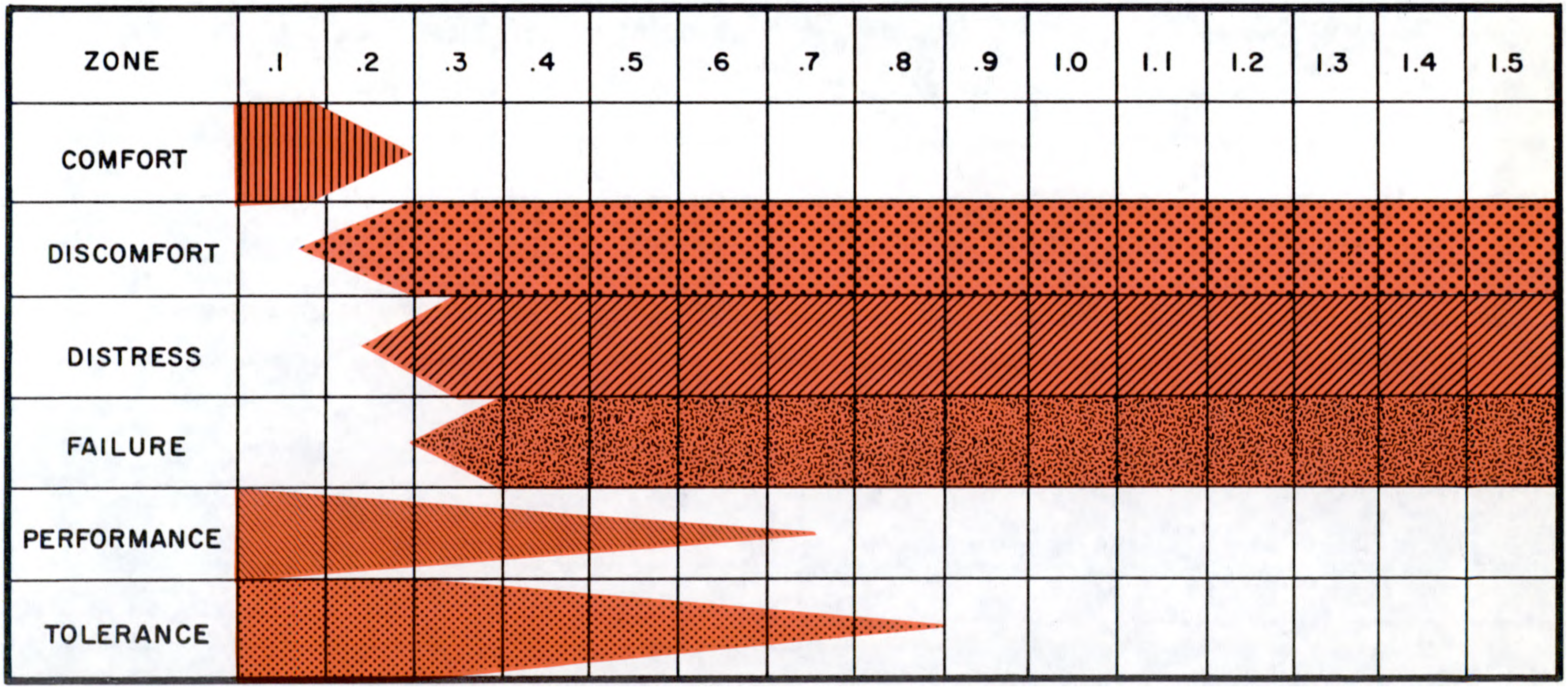


Figure 24. SIGNIFICANT EFFECTS FOR NON-STANDARD MAN - PSYCHOLOGICAL ABNORMALITIES

COMFORT - 100 per cent will be comfortable throughout most of zone .1, 50 per cent will be comfortable at the mid-point of zone .1-.2; none will be comfortable beyond the first one-third of zone .2.

DISCOMFORT - A few will find the upper range of zone .1 too warm, for 50 per cent the conditions at the zone .1-.2 boundary will be too warm, 100 per cent will be too warm at the first third of zone .2. Beyond zone .2 conditions will be too hot for comfort.

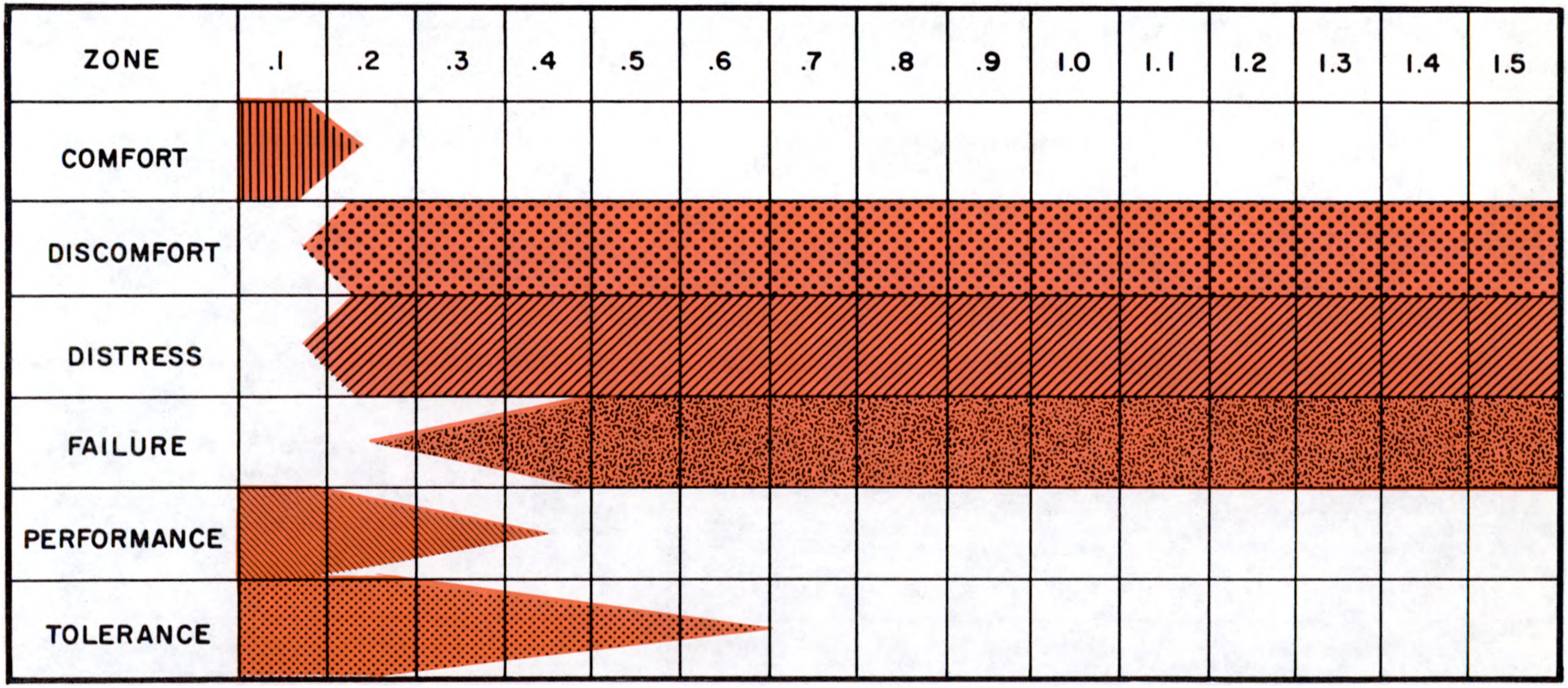
DISTRESS - Symptoms of distress will appear in the upper part of zone .1, 50 per cent will have symptoms at the zone .1-.2 boundary and 100 per cent at the first third of zone .2. In zone .2 and beyond symptoms and complaints will be prevalent and severe.

FAILURE - Signs of failure will first appear at the mid-point of zone .2, 50 per cent will show signs at the zone .3-.4 boundary, and 100 per cent at the zone .4-.5 boundary. Signs of failure will appear later than would be expected from the complaints and symptoms of distress.

PERFORMANCE - Performance will be dramatically curtailed mainly because of the motivational aspect and circulatory lability. A 50 per cent reduction can be expected in zone .2 and 75 per cent reduction in zone .3. In zone .4 and beyond little sustained performance can be expected.

TOLERANCE - Tolerance will be decreased 25 per cent in zone .3, 50 per cent in zone .4 and 75 per cent in zone .5. Tolerance will be limited more by psychological than physiological reactions.

SIGNIFICANT EFFECTS FOR NON-STANDARD MAN---
Psychological Abnormalities



CONCLUSION

This report arose out of a need for a systematic method of predicting the probable effect of given shelter environments upon the various types of people who might have occasion to use them. By agreement, it was restricted to the thermal aspects. Even within this limited scope a considerable body of information is available, but such attempts as have previously been made to derive from it a systematic prediction scheme have largely failed to include the action of certain important variables, or to indicate the significance of conditions for populations other than the ideally healthy.

The predictive scheme offered here is in four parts: (a) a chart for determining the probable relative strain posed by any temperature-humidity combination upon a (specified) standard individual under (specified) standard conditions; (b) a table for adjusting the chart to other than the standard values of activity and air movement; (c) an evaluation of the significance of each zone of relative strain for a (specified) standard individual; and (d) evaluations of each zone of relative strain for certain non-standard individuals.

This scheme is by no means the ultimate in predictive measures; it represents the best judgment of the authors based on the limited available evidence. As data accumulate, knowledge is extended, and understanding of physiological mechanisms improve, greater precision will undoubtedly be possible, and better schemes will be devised. They believe, however, that the present scheme will enable those responsible for shelter management to anticipate reasonably well the consequences of any given set of thermal conditions.

Certain items contained in the original list of factors to be considered (contiguity, nutrition, individual variability, and exacerbation of pre-existing conditions) have not been reported upon, by reason of the difficulty in acquiring adequate information in the available time. Of the six major criteria of an adequate predictive scheme listed early in the report, the first three are fairly well met. The fourth, adjustment of prediction to non-standard individuals, has been covered in summary fashion. It would be very desirable to expand this aspect of the scheme, to provide separate predictions, for example, for congestive cardiac failure, anginal affections, hypertensive states, and dysrhythmias; but for only one of these cardiac disorders are anything approaching adequate data readily available. Under the term "metabolic disorders", also, a variety of quite different disturbances are lumped together, many of which deserve separate treatment. For the sixth criterion - time effect - we have assumed an occupancy of more than 24 hours as characteristic of shelter use. For the fifth - limits of confidence - we simply do not have sufficient data.

SHELTER ENVIRONMENTS

The extensive bibliography should be of assistance to those who wish either to check the evidence on which the authors based their judgments, or to seek further for the information that is in many instances so sadly lacking.

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