Comfort Climates at Grand Rapids, Michigan: A Dynamic Approach

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Robert L. Janiskee
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CHAPTER I

INTRODUCTION

Background and Purpose

Comfort is a basic element of human response to weather and climate, and geographers have long appreciated the fact that the distribution of comfort conditions at least partially explains the distribution of many climate-related cultural phenomena. Accordingly, the geographic distribution of comfort conditions has been a frequent subject for research, often incident to geographic analyses of clothing requirements, housing types, and similar "dependent" variables. Those


2 Douglas H. K. Lee and Hoyt Lemons co-authored what has become the classic study of clothing requirements in relation to comfort ("Clothing for Global Man," Geographical Review, XXXIX [April, 1949], pp. 181-213). For an example of a study considering comfort parameters in efficient housing design, see Lee's "Thoughts on Housing for the Humid Tropics" Geographical Review, XXXI.
studies which place man himself at the center of attention in this fashion come under the broad heading of physiological climatology, and the technique may be logically termed the "physioclimatic approach."

Traditionally, geographic researches employing the physioclimatic approach have been small-scale map studies dealing with the gross distribution of mean monthly comfort conditions. The level of detail adopted for these studies is consistent with the generally-accepted definition of climate as "the average condition of the weather," and the focus on areal distribution is, of course, central to geographic analysis. It is therefore not surprising that the physioclimatic approach currently enjoys status as a legitimate and generally reliable tool for

(January, 1951), pp. 124-47. Comfort conditions are also an important consideration in many studies of health and disease, economic activity, social habits, human behavior, work efficiency, ethnology, military tactics, etc. (Werner H. Terjung, "Physiological Climates of Africa," [Unpublished Ph.D. dissertation, University of California at Los Angeles, 1966], p. ix).

3 Physiological climatology is a subdivision of bioclimatology. As seen from the geographic viewpoint, the field may be defined as "... a study of the spatial aspects of the direct and indirect relationships between the micro, macro, and cosmic geophysical, topoclimatological, and geochemical environments of the atmosphere and man, as affecting his well-being, habits, energy, history and evolution, and works." (Werner H. Terjung, "Physiological Climates of Africa," op. cit., p. 4).
geographic research and teaching.

Although the "traditional approach" has yielded much useful information and continues to do so, there are deficiencies of concept and methodology which seriously hamper its usefulness. Among the more serious of these deficiencies is excessive reliance on mean monthly comfort conditions to portray comfort climates, and the resulting entrenched concept of the comfort climate as an essentially static phenomena. A number of geographers have evidenced concern over the excessive use of averages in climatic studies. Although he was not referring to comfort climates directly, Lee⁴ aptly summarized the problem when he stated that

Climate has often been referred to as the average condition of the weather. In many aspects, this is a useful definition, since it emphasizes the habitual as against the day-to-day variations in conditions. But it also tends to obscure the fact of variation, which may bear importantly upon certain climatic effects. To understand climate moreover, something more than the mere collection of statistics that might be implied in the word 'average' is required. (italics mine)

Comfort is one of a number of climatic effects which are quite responsive to diurnal and interdiurnal variations of the weather elements. It is therefore essential

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that such variability be taken into account when describing a given comfort climate. Recognizing this, Terjung has recently called for a more "dynamic" approach to the study of comfort climates and has suggested that such an approach would result in the depiction of more realistic comfort conditions. Implied, if not stated, is the fact that the "traditional approach" may be due for a major revision. What seems to be called for is a concept of the comfort climate as a complex association of dissimilar comfort conditions created by diurnal and interdiurnal variability of the weather elements rather than a vague "average" comfort condition. Such a revised concept demands, of course, that much more emphasis be placed upon the identification and description of short-term (diurnal and interdiurnal) variability characteristics of the various comfort climates. Carried to its logical conclusion, the concept envisions the comfort climate to be best described in terms of its variability characteristics.

Before it will be possible to apply a "dynamic" physioclimatic approach at national, regional, and global scales, it will first be necessary to conduct studies at

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*Terjung, "Physiological Climates of Africa," op. cit., p. 3.*
the local level to determine in what manner diurnal and interdiurnal variability characteristics of the comfort condition might best be identified and described. The present research is seen as a first attempt to provide a model for studies of this type.

The objective of the present investigation is to identify and describe diurnal and interdiurnal variability characteristics of the comfort condition at a specific location--Grand Rapids, Michigan--and to integrate these variability features into a meaningful description of the local comfort climate during representative cool season and warm season months. Consistent with this goal, the frequency, duration, sequential distribution, and range of comfort conditions are investigated.

This research is considered innovative in at least two important respects. First, the use of mean data of any type was avoided wherever possible in classifying comfort conditions. Thus, the local comfort climate was derived from actual occurrences of specific comfort conditions rather than from implied occurrences based on statistical averages. Secondly, the adopted classification scheme is herein employed for the first time to analyze diurnal and interdiurnal variability of the comfort condition at a specific location.
Site selection

Grand Rapids, Michigan was selected as the location for this study primarily because a first-order weather station (ESSA Weather Bureau Installation) is located adjacent to the city and accurate data of the type required were thus readily available. Other factors considered included the proximity of the city to Western Michigan University (for ease of access to weather installation records and personnel) and the personal familiarity of the investigator with the city and its weather. The selection of this particular city was therefore largely based on convenience, and a number of other cities might have been selected on the same basis.

Data observations reflect comfort conditions at the Kent County Airport, which is located several miles from the downtown Grand Rapids area. Extrapolation of the results of this research to include all of the urbanized area is limited somewhat by the displacement of the airport site and by local topographic and heat-island effects, but results should be reasonably representative of conditions existing throughout the area. It would probably not be advisable to apply the results to any
specific site, however, unless some allowances were made for the above-mentioned variability factors.

Time period

January and July, the traditional cool season and warm season months, were selected for this investigation. A four year study period was considered sufficiently long to include a representative range of comfort conditions, and the period 1965-1968 inclusive was selected to obtain recent data.

Comfort conditions were classified at tri-hourly intervals (1 AM through 10 PM) during each January and July day of the study period. The resulting 1,984 "instantaneous" observations of the comfort condition formed the data base for this study.

Data source

Data for the tri-hourly observations were gathered from the Local Climatological Data monthly series for Grand Rapids (Kent County Airport), published by the ESSA Weather Bureau, Department of Commerce. These monthly data sheets are ideal for research of this type because they contain the information needed to classify comfort conditions at frequent diurnal intervals, and they also arrange the data in convenient daily and monthly summary
format. No other single data source provides the needed information.

Classification scheme used

The Terjung empirical physioclimatic classification scheme was employed, with certain modifications, to classify comfort conditions throughout the study period. Terjung's scheme attempts the integration of the four major physioclimatic elements: air temperature, relative humidity, air movement, and sunshine. The effects of temperature and relative humidity, which are always present and therefore considered the primary elements, are expressed in a Comfort Index. The combined effects of air movement and sunshine, which are at times absent or nearly so, are expressed in a Wind Effect Index, which is seen to modify and create subdivisions of the Comfort Index. A specific comfort condition is expressed in an assembly consisting of a Comfort Index and an accompanying Wind Effect Index.


7 Other physioclimatic elements of less direct or highly variable significance include barometric pressure, aerosol and ozone content of the air, rainfall, noise levels, etc.
The design and construction of the Comfort and Wind Effect Index nomograms will not be exhaustively detailed in this section, since this would be both tedious and unnecessary. The discussion of the indices which follows is limited to briefly explaining their concept and derivation.

The Comfort Index nomogram (Figure 1) indicates the comfort sensations of the average individual in response to varying conditions of dry-bulb temperature and relative humidity. The nomogram consists of various subjective categories of comfort superimposed upon a psychrometric chart containing lines of relative humidity, wet- and dry-bulb temperature, and effective temperature (ET).

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9 An effective temperature is an index of warmth experienced by humans, and lines of effective temperature (ET) are lines which connect combinations of conditions which produce like sensations of warmth. The ET lines are not reliable at relative humidities above 70 per cent or below 30 per cent (American Society of Heating and Air Conditioning Engineers, Heating Ventilating Air Conditioning Guide [Baltimore: Waverly Press, 1959], p. 67). On the Comfort Index nomogram, ET lines alone separate the Sultry and Extremely Hot categories (Terjung symbols +2b and +3) and the Keen and Cold categories (Terjung symbols -2 and -3). For all other comfort category boundaries on the nomogram, the ET lines are replaced by wet-bulb temperature lines at relative humidities above 70 per cent. For a complete explanation of the reasoning behind this, see Terjung, "Physiological Climates of the Conterminous United States," op. cit., pp. 145 and 152-53.
Figure 1.--Comfort Index

Symbols:  
-6 Ultra Cold (UC)  
-5 Extremely Cold (EC)  
-4 Very Cold (VC)  
-3 Cold (CD)  
-2 Keen (K)  
-1 Cool (C)  
0 Mild (M)  
+1 Warm (W)  
+2a Hot (H)  
+2b Sultry (S)  
+3 Extremely Hot (EH)

(Reproduced by permission from the Annals of the Association of American Geographers, Volume 56, 1966.)
Below the 35°ET line, and extending to the cold extreme of the comfort continuum, comfort categories based on clothing requirements at low temperatures replace the psychrometric chart. Broadly speaking, psychological response factors delimit comfort categories in the central portion of the nomogram (the mild zone and those immediately adjacent to it), while physiological response factors delimit categories in the hot and cold portions of the chart.

Application of the Comfort Index is quite simple. At temperatures exceeding 35°ET, the appropriate Comfort Index symbol\(^{10}\) for a given temperature-humidity combination is determined by the comfort category into which the intersection of the respective temperature and humidity lines falls. For example, a dry-bulb temperature of 80°F in combination with a relative humidity of 60 percent produces warm sensations, and the appropriate Comfort Index would be "W." At temperatures below 35°ET, the Comfort Index is determined solely by the category

\(^{10}\) The Terjung Comfort Index symbolization procedure has been modified somewhat incident to the present investigation. Letter symbolization (e.g., "W" for Warm) rather than digital symbolization (e.g., +1 for Warm) is used consistently throughout the text. The original symbolization, which was thought to be too abstract, is retained on the nomogram only to provide a cross-reference to the basic scheme from which the modified form was derived.
into which the dry-bulb temperature falls.

The Wind Effect Index nomogram (Figure 2) is a slightly modified version of the windchill nomogram developed by the U. S. Army Quartermaster.\textsuperscript{11} It directly indicates the cooling power of the atmosphere in Kcal/m\textsuperscript{2}-hr. heat loss from exposed skin surfaces at various combinations of dry-bulb temperature and wind velocity. Bright sunshine is considered to counteract the cooling power of the atmosphere at the rate of 200 Kcal/m\textsuperscript{2}hr.\textsuperscript{12}

The appropriate Wind Effect Index symbol for a given combination of air temperature, wind velocity and sunshine is derived in three steps. First, windchill in Kcal/m\textsuperscript{2}hr. is read from the nomogram at the intersection


\textsuperscript{12}The specified reduction value of 200 Kcal/m\textsuperscript{2}hr. is an average adopted to simplify what would otherwise be an extremely complicated classification procedure. The heat imposed per unit area of skin surface by direct sunshine varies with time of day, solar zenith angle, water vapor and dust content of the air, and several other factors (W.-L. Roller and R. F. Goldman, "Estimation of Solar Radiation Environment," International Journal of Biometeorology, XI [1967], pp. 329-36).
Figure 2.—Wind Effect Index

Heat loss is experienced in Kcal/m²·hr. for the various temperatures and wind velocities. Assume a skin temperature of 91.4°F, with the individual in a state of inactivity. Under conditions of bright sunshine, reduce cooling rate by 200 Kcal/m²·hr. See Appendix A for key to symbolization. (Reproduced by permission from the Annals of the Association of American Geographers, Volume 56, 1966.)
of the appropriate dry-bulb temperature and wind velocity lines. Next, allowance is made for the counteracting effects of sunshine by reducing this figure at the rate of 200 Kcal/m²/hr. for bright sunshine, and proportionately less for varying amounts of cloud cover. No reduction is required, of course, for nighttime observations and overcast sky conditions. The final step is to convert the resulting positive or negative value in Kcal/m²/hr. to the corresponding Wind Effect Index symbol by reference to the Wind Effect Index symbolization key (Appendix A).

13 A wind velocity of at least 1 mph must be assumed to apply the Wind Effect Index nomogram (Terjung, personal letter, January 15, 1969). Because of marked cluttering of the nomogram at wind velocities approaching calm, all such observations were calculated from the windchill factor tables published by the Quartermaster (Windchill in the Northern Hemisphere, op. cit., pp. 4-5).

14 The original Terjung scheme for weighting the sunshine factor is not applicable for "instantaneous" observations such as the tri-hourly observations used in the present investigation. Incident to the present investigation, the bright sunshine reduction rate (200 Kcal/m²/hr.) was lowered by 20 Kcal/m²/hr. for each one-tenth cloud cover present at the time of the observation before the counteracting effects of sunshine were applied against the windchill rate derived from the Wind Effect Index nomogram. For example, the counteracting effects of sunshine with five-tenths cloud cover were assigned a value of 100 Kcal/m²/hr. While this is an admittedly crude estimate, Terjung has suggested that this approach is a reasonable one under the circumstances (Terjung, letter to the investigator, dated December 19, 1968).
The Wind Effect Index nomogram cannot be applied at air temperatures exceeding 90°F, and probably should not be applied at temperatures exceeding about 86°F (the approximate threshold value for human skin temperature). When air temperature actually exceeds skin temperature, heat is added to the skin by conduction and there is consequently no cooling rate to be measured. Under such circumstances, sunshine effects are assigned a positive value and the Wind Effect Index symbol is derived directly from the symbolization key (Appendix A). If, as is frequently the case in summertime, the effects of sunshine and air movement counteract each other, the resulting wind effect is described as "neutral."

A specific comfort condition (e.g., a tri-hourly observation) is indicated by combining the derived

Skin temperatures vary among individuals and for the same individual through time. It is therefore quite difficult to determine at what point heat additions to the skin actually begin. Terjung has approached this problem by specifying a range of 86°F to 96°F for skin temperature (with the average at about 91°F) and designing the heat additions portion of the Wind Effect Index to incorporate these values (Terjung, "Physiological Climates of the Conterminous United States," op. cit., p. 156). Thus, 86°, 91°, and 96° are used as threshold values for various heat additions categories (see Appendix A). Recently, Terjung stated that the empirical approach to this problem is very deficient and should be eventually discarded in favor of a physical-theoretical scheme which would consider the amount and disposition of net radiation on the skin-clothing surface (Terjung, letter to the investigator, dated January 15, 1969).
Comfort Index with the corresponding Wind Effect Index. For example, if the derived Comfort Index is "M" and the corresponding Wind Effect Index is "-b," the comfort condition is expressed in the assembly M -b, which is interpreted "mild with pleasant wind effects." To express the range of comfort condition during a day (i.e., the diurnal range), digital subscripts are added to the Comfort and Wind Effect Indices in the assembly to indicate the degree of departure of the nighttime comfort condition from the daytime comfort condition (Appendix B). For example, if the warmest daytime condition is M -b and the coolest nighttime condition is M -c, the assembly is M_{1-b_2}, which is interpreted "mild day with pleasant wind effects, followed by a mild night with cool windchill."

Interpretation of results

The objective of this section is to provide the reader with additional information which will aid him in interpreting the results presented in the text. Readers who may wish to further apply the results of this research should also consult the publications cited in this and subsequent chapters for additional criteria which may bear importantly on specific research problems.

The following factors limit interpretation of the
results presented:

(1) The classification scheme employed is empirical and cannot be interpreted in terms of sound physical theory.

(2) The Comfort Index nomogram is not reliable at the upper end of the chart, at or near the $35^\circ$ET line, and when applied at wind velocities of less than 25 feet per minute.\(^\text{16}\)

(3) The Wind Effect Index applies only to heat losses from (or heat additions to) exposed skin surfaces; it is not applicable to clothed surfaces.\(^\text{17}\) Moreover, it ignores heat losses from the lungs at low temperatures and is not reliable at very low wind velocities.\(^\text{18}\)


\(^{17}\)Burton and Edholm observed that the windchill nomogram has proven to be quite reliable in the field despite improper consideration of clothing factors. Pointing out that windchill has no real scientific basis in spite of the usefulness of the concept, they argue that "... it is theoretically impossible to express the effect of wind on heat loss without references to the amount of clothing that is being worn." (Alan C. Burton and Otto G. Edholm, Man in a Cold Environment [London: Edward Arnold Publishers Ltd., 1955], p. 111).

\(^{18}\)As can be seen in the design of the windchill nomogram, small increases or decreases in wind velocity have marked effects on the cooling rate in near-calm
(4) The delimitation of categories in the Comfort and Wind Effect Index nomograms is arbitrary to a certain degree in that delimitations are made in comfort continuums in which no sharp boundary lines are apparent.\(^{19}\)

(5) The assumption of individual differences in the perception of comfort is virtually axiomatic in studies of this type. Although the classification scheme makes certain allowances for such differences, the allowances are nevertheless (predicted) error rates.

The results are thought to most accurately describe the comfort sensations that the "average" healthy urban dweller of about 35 years of age\(^{20}\) would feel while standing motionless in the open, dressed as for a comfortable indoor environment. For practical purposes, the conditions—especially at low and very low temperatures. To the extent that small fluctuations in wind velocity are difficult to measure, reliability of the windchill nomogram falls off rapidly in that zone below about 5 mph wind velocity.

\(^{19}\)Terjung, "Physiological Climates of the Conterminous United States," op. cit., p. 151.

reader may assume that the responses of this hypothetical "Everyman" are typical of the responses of the majority of individuals who are exposed to similar conditions under similar circumstances.
CHAPTER II

REVIEW OF THE LITERATURE

It will be the objective of this chapter to briefly summarize the evolution of geographical discourse on the subject of human comfort and its distribution, and to more clearly establish the relevancy of the present investigation within the context of previous researches and present research requirements.

The Pre World War II Era

Well over 75 classifications or partial classifications of climate have been attempted since 1880, but ". . . little thought has been given to analyzing or classifying the climate with which we have to live." Terjung underscored the fact that geographers have


generally neglected the comfort factor in climate when he recently observed that

A survey of existing literature reveals a certain lack of interest in actual classifications and maps centered upon the feelings of man in regard to climate, incorporating the major elements affecting him . . .

Many of the reasons for the "lack of interest" to which Terjung refers can be traced to circumstances and events of several decades past. Throughout the pre World War II era, geographical thought concerning the impact of weather and climate on man was dominated by the simplistic cause-and-effect theories of the environmentalists, especially Huntington. The researches of this era, which were based on very incomplete knowledge of human physiology and psychology, were often poorly conceived and executed, and were invariably inconclusive. They were, in short, capable of extremely limited practical

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4 Ellsworth Huntington, Civilization and Climate (New Haven: Yale University Press, 1924). Huntington's theories persist in one form or another to the present. Sewell, after reviewing the present state of geographical knowledge concerning the human factor in climate, was recently moved to remark: "It seems ironic that today, when tools and instruments of considerable sophistication are available to define with some precision human response to weather and climate, the level of geographical discourse still rests primarily either on Huntingtonian assertion or on introductory textbook generalization." (W. R. D. Sewell and others, "Human Response to Weather and Climate," Geographical Review, LVIII [April, 1968], p. 280).
application—contemporary claims to the contrary notwithstanding. Some valuable knowledge of the comfort factor in climate was gained, to be sure, but no reliable scheme for systematically classifying and mapping comfort climates was devised. Significantly, when geographers began to retreat from the grand theory of environmentalism, they were disinclined to deal with the human factor in climate at all. Thus,

Accompanying the changes in geographical thought about the relationship between weather and climate and human activity has been a general decline in geographical interest in the matter.

Research During and Following World War II

With the advent of the World War II era, research interest in the area of comfort climates and their distribution was revived, and geographers were called upon to contribute importantly. Wartime investigations of

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6 Sewell and others, "Human Response to Weather and Climate," op. cit., p. 266.
human physiological and psychological response to factors of weather and climate, prompted by concern for the comfort, health, and effectiveness of troops committed to the field on a global scale, eventually led to the first practical geographical analysis of the distribution of comfort conditions--namely, Lee and Lemons' innovative study. It is difficult to determine the extent to which this pioneer work served as the impetus for post-war geographical research into the occurrence and distribution of comfort conditions, but it has certainly been influential.

The post World War II era has witnessed the concurrent but inconsistent expansion of three themes central to the physioclimatic approach: (1) the accumulation of a sizeable fund of knowledge concerning physiological and psychological responses to factors of weather and

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8 Lee and Lemons, op. cit.
climate, (2) the limited and sporadic development of physioclimate classification schemes based on this knowledge, and (3) the occasional preparation and partial analysis of maps based on physioclimate classification.

The most notable advances have been made in the areas of physiology and psychology. In addition to conducting and evaluating their own experiments, geographers have freely drawn on physiological and psychological response data accumulated by other disciplines. Thus, there is a wealth of reliable information concerning the impact of the major physioclimate elements affecting man's comfort; temperature, humidity, air movement, and sunshine.\(^9\) This collective research effort is, of course, a continuing one.

Currently, the most active research in the general field of human climatic comfort (or discomfort) is done by the American Society of Heating and Ventilating Engineers (ASHVE) and the U. S. Army Quartermaster's climatic and environmental research sections. The former specializes in indoor microclimates, taking air temperature and water vapor pressure in considerations of relative conditions of comfort. The latter is concerned mainly with

the effects of chill on the human body, including radiation as a counterforce against windchill.10

Classifying and Mapping Comfort Conditions

A number of physioclimatic classifications,** some of them quite specialized, have been developed from accumulated response data and suggested for use by geographers. Although no scheme developed to date represents a single best classification for all circumstances and environments, the effective temperature (ET) schemes have been widely (albeit conditionally) accepted for general use. Among


11 See, for example: the effective temperature schemes used by the American Society of Heating and Ventilating Engineers (American Society of Heating and Ventilating Engineers, op. cit., p. 67); C. P. A. Yaglou, "A Method of Improving the Effective Temperature Index," Transactions of the American Society of Heating and Ventilating Engineers, LIII (1947), pp. 307-26; the temperature-humidity index used by the U. S. Weather Bureau (Earl C. Thom, "The Discomfort Index," Weatherwise, XII [1959], pp. 57-60); the Thermal Wind Decrement (Burton and Edholm, op. cit., pp. 112-16); the windchill index used by the U. S. Army Quartermaster (U. S. Army Quartermaster, op. cit.); Lee's Index of Thermal Strain (D. H. K. Lee, "Proprioclimates of Man and Domestic Animals," in Climatology: Reviews of Research [Paris: UNESCO Arid Zone Research X, 1958], pp. 108-10); and the Comfort and Wind Effect Indices (Terjung, "Physiological Climates of the Conterminous United States," op. cit.).
these, the Terjung classification\(^\text{12}\) appears to lend itself most readily to geographical research, regardless of scale or time dimensions. Terjung has incorporated the better features of many other classifications in his scheme and has quite rationally weighted the extremely important psychological response factor.

Since the publication of Lee and Lemons' study,\(^\text{13}\) a number of additional map-studies of the comfort condition have been attempted. For example: Terjung has mapped the physiological climates of California, the United States, and Africa, and the world distribution of the monthly Comfort Index; Gregorczuk has mapped the global distribution of comfort sensations in relation to air enthalpy (total heat content of the air); Gregorczuk and Cena have described the world distribution of effective temperature; and Juaregui and Soto have shown the areal distribution of the Discomfort Index in Mexico.\(^\text{14}\) With

\(^{12}\) Terjung, "Physiological Climates of the Conterminous United States," op. cit.

\(^{13}\) Lee and Lemons, op. cit.

few exceptions, the existing map-studies are at a macro-
scale, and all employ mean monthly weather data as the
basic measure of the comfort condition. Because they

   depict only one aspect of the comfort climate (the
"average" comfort condition during a given period) and
do not apply at specific locations, the maps lend them-
selves to only the most general sort of interpretation.

Need for the Present Study

To date, no thorough investigation of a local com-
fort climate, depicting realistic comfort conditions,
and considering the complex variability of those condi-
tions through time, has been conducted. In point of

Climates of Africa," op. cit.; Werner Terjung, "The Geo-
ographical Application of Some Selected Physioclimatic
Indices to Africa," International Journal of Biometeoro-
ology, XI (March, 1967), pp. 5-19; Terjung, "World
Patterns of the Distribution of the Monthly Comfort
Index," op. cit.; M. Gregorczuk, "Bioclimates of the
World Related to Air Enthalpy," International Journal of
Biometeorology, XII (January, 1968), pp. 35-39; M.
Gregorczuk and K. Cena, "Distribution of Effective Tem-
perature Over the Face of the Earth," International
Journal of Biometeorology, XI (1967), pp. 145-49; and E.
Jauregui and C. Soto, "Wet-Bulb Temperature and Discom-
fort Index Areal Distribution in Mexico," International

   Terjung's physioclimatic maps of California are a
noteworthy exception. See especially, Terjung, "Physio-
logical Climates of the Conterminous United States," op.
cit., p. 171.
fact, however, a number of local-level studies have been published from time to time. For example: Hounam used an effective temperature index to investigate the variability of daily afternoon comfort conditions at Alice Springs, Australia; Miller recently investigated the frequency of crimes in relation to the occurrence of the very discomforting Santa Ana Wind (a foehn-like local weather type) at Los Angeles; and Liopo offered a computational method for determining clothing requirements on the basis of probable day-to-day fluctuations of the weather elements in parts of Siberia. These and other local-level studies have a common characteristic; each views a local comfort climate as something much more dynamic than an "average" comfort condition, and each stresses the local significance of deviations of the comfort condition extending through brief periods of time. Still, the existing local-level studies leave much unsaid about local comfort climates. Hounam, for example, did

not describe variability features as such, preferring to
deal with frequency distributions of the comfort condi-
tion on a monthly basis. Miller dealt with an anomalously
local comfort condition and gave normal conditions cur-
sory mention. Liopo referred to only one aspect of the
local comfort climate—physiological response in relation
to clothing requirements. Other local-level studies have
been similarly narrow in scope; none has attempted to in-
tegrate diurnal and interdiurnal variability characteristics of the comfort condition into a reasonably complete
picture of the local comfort climate. In short, for most
locations on the earth surface, the only body of informa-
tion in a physioclimatic format is that which can be im-
plied from small-scale physioclimatic maps, with some
supplemental information provided for a relatively few
locations.

Terjung has suggested that "future field investiga-
tions could be applied at local levels to refine the
maps (he) presented." In one sense, the present study
is just such a study. In a broader sense, however, it
may be seen that any well-organized local-level study of
comfort conditions does much more than simply verify or

17Terjung, "Physiological Climates of the Contermin-
ous United States," op. cit., p. 177.
correct existing small-scale physioclimatic maps. It supplements these maps with a dynamic description of realistic comfort conditions, providing an altogether different perspective.
CHAPTER III

JANUARY COMFORT CONDITIONS

In this chapter, the comfort conditions of the cool season at Grand Rapids, as represented by January, are identified and described. A complete realistic description of the January comfort climate from a dynamic viewpoint necessarily involves the identification and description of both diurnal and interdiurnal variability features of the comfort condition, but several fundamental characteristics of the comfort climate must first be investigated before attention may be turned to these variability features. The first order of business is to establish the frequency and range of comfort conditions for the month as a whole, and for the daytime and nighttime periods respectively.

Frequency and Range of January Comfort Conditions

A total of 18 comfort conditions were discerned among the 992 tri-hourly observations for January (Table 1). The absolute range was quite large, varying all the way from cool with cool windchill (C -c) to extremely cold with bitterly cold windchill (EC -g), and including
### TABLE 1
FREQUENCY OF JANUARY COMFORT CONDITIONS

<table>
<thead>
<tr>
<th>Comfort Condition</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comfort Index</strong></td>
<td><strong>Wind Effect Index</strong></td>
</tr>
<tr>
<td>C</td>
<td>-c</td>
</tr>
<tr>
<td></td>
<td>-d</td>
</tr>
<tr>
<td></td>
<td>-c</td>
</tr>
<tr>
<td></td>
<td>-d</td>
</tr>
<tr>
<td></td>
<td>-e</td>
</tr>
<tr>
<td></td>
<td>-c</td>
</tr>
<tr>
<td></td>
<td>-d</td>
</tr>
<tr>
<td>CD</td>
<td>-e</td>
</tr>
<tr>
<td></td>
<td>-f</td>
</tr>
<tr>
<td></td>
<td>-g</td>
</tr>
<tr>
<td></td>
<td>-d</td>
</tr>
<tr>
<td></td>
<td>-e</td>
</tr>
<tr>
<td>VC</td>
<td>-f</td>
</tr>
<tr>
<td></td>
<td>-g</td>
</tr>
<tr>
<td></td>
<td>-h</td>
</tr>
<tr>
<td></td>
<td>-e</td>
</tr>
<tr>
<td></td>
<td>-f</td>
</tr>
<tr>
<td></td>
<td>-g</td>
</tr>
<tr>
<td>Totals:</td>
<td></td>
</tr>
</tbody>
</table>

*aBased on tri-hourly observations of the comfort condition during the Januarys of the period 1965-1968.

*bRanked from least uncomfortable to most uncomfortable.

*cRanked by cooling rate, lowest to highest, within each comfort group.

*dTo nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.
potentially dangerous frostbite conditions (Wind Effect Index -h). At no time during the study period, however, did comfortable conditions occur.

For the month as a whole, two comfort conditions were co-dominant; cold with cold windchill (CD -e) and cold with very cold windchill (CD -f). These conditions alone accounted for more than half of the tri-hourly observations, and none other occurred more frequently than about 9 per cent of the time.

Daytime Comfort Conditions

The distribution of daytime comfort conditions (Table 2) is not markedly different from that of the month as a whole. Not surprisingly, the CD -e and CD -f conditions (cold, with cold or very cold windchill) are co-dominant and together account for the majority of observations.

Daytime comfort groups

Each Comfort Index delimits a comfort group, within which various wind effects delimit subdivisions. The frequencies of the 5 major daytime comfort groups are shown in the right-hand column of Table 2 and in Figure 3.

The cold (CD) group is clearly dominant during the daylight hours, accounting for about 2 out of every 3
TABLE 2
FREQUENCY OF JANUARY DAYTIME COMFORT CONDITIONS\textsuperscript{a}

<table>
<thead>
<tr>
<th>Comfort Condition</th>
<th>Wind Effect Index\textsuperscript{b}</th>
<th>Frequency</th>
<th>Percentage of All Observations\textsuperscript{d}</th>
<th>Comfort Group Frequency (%)\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tri-hourly Observations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>-c</td>
<td>1</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>-d</td>
<td>1</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>9</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-d</td>
<td>35</td>
<td>9.4</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>25</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>-e</td>
<td>2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-d</td>
<td>18</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>101</td>
<td>27.2</td>
<td>66.9</td>
</tr>
<tr>
<td>CD</td>
<td>-f</td>
<td>103</td>
<td>27.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-g</td>
<td>25</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>6</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>VC</td>
<td>-f</td>
<td>20</td>
<td>5.4</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>-g</td>
<td>22</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-h</td>
<td>3</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>-f</td>
<td>1</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Totals:</td>
<td></td>
<td>372</td>
<td>100.0</td>
<td>99.9</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Based on daytime tri-hourly (10 AM, 1 PM, and 4 PM) observations of the comfort condition during the Januarys of the period 1965-1968.

\textsuperscript{b}Ranked from least uncomfortable to most uncomfortable.

\textsuperscript{c}Ranked by cooling rate, lowest to highest, within comfort groups.

\textsuperscript{d}To nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.
observations. The keen (K) and very cold (VC) groups account for virtually all of the remainder, with the keen group occurring more frequently than the very cold group. Since the cool (C) and extremely cold (EC) groups are represented by only 1 or 2 isolated observations, it is reasonable to conclude that January daytime conditions are almost invariably confined to the keen through very cold portion of the comfort continuum.

**Daytime wind effects**

Terjung subordinated the Wind Effect Index to the Comfort Index in his classification scheme because temperature-humidity effects are, in the overview, more important than wind effects. At low temperatures, however, windchill is an extremely important avenue of heat loss—and therefore an important cause of cold discomfort.

Six categories of wind effects, ranging from relatively innocuous cool windchill to potentially dangerous frostbite conditions, occur during the daylight hours (Table 3). With few exceptions, daytime wind effects produce sensations described as very cool or worse, and the large majority of occurrences (about two-thirds) involve either cold or very cold windchill. Despite the predominance of cooling by wind, bitterly cold windchill and frostbite conditions are very much in the minority.
### Table 3
FREQUENCY OF JANUARY DAYTIME WIND EFFECTS

<table>
<thead>
<tr>
<th>Wind Effects</th>
<th>Sensation felt by the Majority</th>
<th>Frequency Tri-hourly Observations</th>
<th>Percentage of Total</th>
<th>Percentage of Observations Colder than Observed Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>-c Cool</td>
<td>windchill</td>
<td>12</td>
<td>3.2</td>
<td>96.7</td>
</tr>
<tr>
<td>-d Very cool</td>
<td>windchill</td>
<td>54</td>
<td>14.5</td>
<td>82.2</td>
</tr>
<tr>
<td>-e Cold</td>
<td>windchill</td>
<td>132</td>
<td>35.5</td>
<td>46.7</td>
</tr>
<tr>
<td>-f Very cold</td>
<td>windchill</td>
<td>124</td>
<td>33.3</td>
<td>13.4</td>
</tr>
<tr>
<td>-g Bitterly</td>
<td>cold windchill</td>
<td>47</td>
<td>12.6</td>
<td>0.8</td>
</tr>
<tr>
<td>-h Exposed</td>
<td>flesh freezes</td>
<td>3</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Totals:</td>
<td></td>
<td>372</td>
<td>99.9</td>
<td>--</td>
</tr>
</tbody>
</table>

- Based on daytime tri-hourly (10 AM, 1 PM, and 4 PM) observations of the Wind Effect Index during the Januaries of the period 1965-1968.

- Ranked by cooling rate, lowest to highest.

- To nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.
Thus, with few exceptions, daytime windchill ranges from very cool to bitterly cold, and normally produces cold or very cold sensations.

Nighttime Comfort Conditions

The distribution of nighttime comfort conditions (Table 4) does not depart significantly from that of the daytime period, although there is a discernible shift toward the cold extreme of the comfort continuum. As in the daytime, the CD -e and CD -f conditions (cold, with cold or very cold windchill) are co-dominant, together accounting for the majority of occurrences. No other condition occurs more frequently than 10 per cent of the time.

Nighttime comfort groups

Although five nighttime comfort groups occur during January, virtually all nighttime comfort conditions are confined within the keen to very cold portion of the comfort continuum (Table 4 and Figure 3). The cold group dominates the nighttime just as it does the daytime; comfort conditions are of the cold group almost two-thirds of the time. The shift toward the cold extreme of the comfort continuum after sundown is seen in the fact that very cold conditions occur more frequently than keen
### TABLE 4

**FREQUENCY OF JANUARY NIGHTTIME COMFORT CONDITIONS**

<table>
<thead>
<tr>
<th>Comfort Condition</th>
<th>Wind Effect Index</th>
<th>Tri-hourly Observations</th>
<th>Percentage of Total</th>
<th>Comfort Group Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>-c</td>
<td>1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>6</td>
<td>1.0</td>
<td>13.4</td>
</tr>
<tr>
<td>K</td>
<td>-d</td>
<td>30</td>
<td>4.8</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>47</td>
<td>7.6</td>
<td>15.4</td>
</tr>
<tr>
<td></td>
<td>-d</td>
<td>31</td>
<td>5.0</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>159</td>
<td>25.6</td>
<td>31.0</td>
</tr>
<tr>
<td>CD</td>
<td>-f</td>
<td>166</td>
<td>26.8</td>
<td>63.7</td>
</tr>
<tr>
<td></td>
<td>-g</td>
<td>39</td>
<td>6.3</td>
<td>12.6</td>
</tr>
<tr>
<td></td>
<td>-d</td>
<td>1</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>13</td>
<td>2.1</td>
<td>4.5</td>
</tr>
<tr>
<td>VC</td>
<td>-f</td>
<td>50</td>
<td>8.1</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td>-g</td>
<td>61</td>
<td>9.8</td>
<td>15.3</td>
</tr>
<tr>
<td></td>
<td>-h</td>
<td>5</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>2</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>-f</td>
<td>1</td>
<td>0.2</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>-g</td>
<td>8</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td></td>
<td>620</td>
<td>100.1</td>
<td>100.1</td>
</tr>
</tbody>
</table>

*a Based on nighttime tri-hourly (7 PM through 7 AM) observations of the comfort condition during the Januarys of the period 1965-1968.

*b Ranked from least uncomfortable to most uncomfortable.

*c Ranked by cooling rate, lowest to highest, within comfort groups.

*d To nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.
conditions, which is just the reverse of the daytime situation (refer to Figure 3).

**Nighttime wind effects**

Nighttime windchill, except on rare occasions, produces sensations ranging from very cool to bitterly cold (Table 5). More than two-thirds of the time, these sensations are of the cold or very cold variety. As in the daytime, bitterly cold windchill and frostbite conditions occur infrequently.

**Summary**

It has been shown that the range of January comfort conditions is quite large; and that at least 18 comfort conditions occur. Despite the large variety of comfort conditions known to occur, it has been determined that nearly all daytime and nighttime conditions are of the keen, cold, and very cold comfort groups. Further, the conditions of the cold comfort group dominate the month as a whole, including both the daytime and nighttime periods. Among the many comfort conditions which occur during the January month, cold conditions with cold and very cold windchill are by far the most frequently occurring.
<table>
<thead>
<tr>
<th>Wind Effect Index</th>
<th>Sensation felt by the Majority</th>
<th>Tri-hourly Observations</th>
<th>Percentage of Observations Colder than Observed Total</th>
<th>Percentage of Observations Colder than Observed Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>-c</td>
<td>Cool windchill</td>
<td>7</td>
<td>1.1</td>
<td>98.8</td>
</tr>
<tr>
<td>-d</td>
<td>Very cool windchill</td>
<td>62</td>
<td>10.0</td>
<td>88.8</td>
</tr>
<tr>
<td>-e</td>
<td>Cold windchill</td>
<td>221</td>
<td>35.6</td>
<td>53.2</td>
</tr>
<tr>
<td>-f</td>
<td>Very cold windchill</td>
<td>217</td>
<td>35.0</td>
<td>18.2</td>
</tr>
<tr>
<td>-g</td>
<td>Bitterly cold windchill</td>
<td>108</td>
<td>17.4</td>
<td>0.8</td>
</tr>
<tr>
<td>-h</td>
<td>Exposed flesh freezes</td>
<td>5</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Totals:</td>
<td></td>
<td>620</td>
<td>99.9</td>
<td>--</td>
</tr>
</tbody>
</table>

*Based on tri-hourly (7 PM through 7 AM) observations of the Wind Effect Index during the January nights of the period 1965-1968.*

*Ranked by cooling rate, lowest to highest.*

*To nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.*
Cooling by windchill was found to be an important source of discomfort during January. In the large majority of instances, including both the daytime and nighttime periods, cold or very cold sensations are produced.
CHAPTER IV

DIURNAL AND INTERDIURNAL VARIABILITY
OF JANUARY COMFORT CONDITIONS

Now that the frequency and range of January comfort conditions has been established, it is the objective of this chapter to investigate diurnal and interdiurnal variability characteristics of the January comfort climate. From a dynamic viewpoint, three aspects of this variability merit special attention: (1) the daily comfort extremes; (2) the diurnal range of comfort conditions; and (3) the interdiurnal sequences and duration of comfort conditions.

Diurnal Variability

Daytime comfort extremes

There is no term in the Terjung nomenclature which specifically refers to the warmest comfort condition which occurs during an individual day. Accordingly, the term daytime physioclimatic extreme is adopted for use here. The daytime physioclimatic extreme is derived for any day by selecting the warmest Comfort Index from among the tri-hourly observations for the daylight hours, and the Wind Effect Index in that comfort group.
indicating the least cooling.

The range of January daytime physioclimatic extremes encompassed 12 comfort conditions (Table 6). The daytime physioclimatic extreme of the most uncomfortable day was very cold, with frostbite wind effects (VD -h), while that of the least uncomfortable day was cool, with cool windchill (C -c). A potential for significant variability of the daytime comfort extreme was therefore clearly demonstrated.

Cold with cold windchill (CD -e) accounted for about 1 out of every 3 daytime extremes, but this comfort condition did not actually dominate the daytime extreme. Other commonly-occurring extremes were: cold with very cold windchill (CD -f); keen with very cool windchill (K -d), and keen with cold windchill (K -e). These comfort conditions together accounted for nearly 3 out of 4 daytime physioclimatic extremes. Thus, the large majority of January daytime physioclimatic extremes were either cold with cold or very cold windchill, or keen with very cool or cold windchill.

**Nighttime comfort extremes**

The term **nighttime physioclimatic extreme** is adopted here to infer the opposite of the daytime comfort extreme; the most uncomfortable condition to occur during the
### TABLE 6

**FREQUENCY OF JANUARY DAYTIME PHYSIOCLIMATIC EXTREMES**

<table>
<thead>
<tr>
<th>Physioclimatic Extreme</th>
<th>Wind Effect Index(^b)</th>
<th>Number of Days Occurring</th>
<th>Percentage of Total</th>
<th>Comfort Group Frequency(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C</strong></td>
<td>-c</td>
<td>1</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>7</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>-d</td>
<td>13</td>
<td>10.5</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td>-e</td>
<td>12</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>1</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-d</td>
<td>9</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td><strong>CD</strong></td>
<td>-g</td>
<td>41</td>
<td>33.1</td>
<td>67.0</td>
</tr>
<tr>
<td></td>
<td>-f</td>
<td>26</td>
<td>21.0</td>
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<td></td>
<td>-g</td>
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</tr>
<tr>
<td></td>
<td>-h</td>
<td>4</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td><strong>VC</strong></td>
<td>-g</td>
<td>3</td>
<td>2.4</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>-h</td>
<td>1</td>
<td>0.8</td>
<td></td>
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</tbody>
</table>

Totals: 124 100.0 100.0

\(^{a}\) Based on the January days of the period 1965-1968.

\(^{b}\) Ranked from least uncomfortable to most uncomfortable.

\(^{c}\) Ranked by cooling rate, lowest to highest, within each comfort group.

\(^{d}\) To nearest 0.1 per cent.
course of a night. The nighttime physioclimatic extreme is derived for any night by selecting the coldest Comfort Index from among the tri-hourly observations for the nighttime hours, and the Wind Effect Index indicating the greatest cooling.

A total of 12 nighttime physioclimatic extremes were identified during January (Table 7). The physioclimatic extremes of the most uncomfortable nights were extremely cold with bitterly cold windchill (EC -g) or very cold with frostbite wind effects (VC -h), whereas those of the least uncomfortable nights were keen with very cool windchill (K -d). Thus, a significant potential for variability of the nighttime comfort extreme was also demonstrated.

No single comfort condition clearly dominated the nighttime comfort extreme. The most frequently-occurring extreme, cold with very cold windchill (CD -f), actually occurred during only about 1 out of 3 nights. Other commonly-occurring extremes were: cold with cold windchill (CD -e); very cold with bitterly cold windchill (VC -g); and very cold with very cold windchill (VC -f). These conditions together accounted for nearly 81 per cent of the nighttime physioclimatic extremes. To put this in a slightly different way, the very large majority of January nights were either cold with cold or very cold
## TABLE 7
FREQUENCY OF JANUARY NIGHTTIME PHYSIOCLIMATIC EXTREMES

<table>
<thead>
<tr>
<th>Physioclimatic Extreme</th>
<th>Frequency</th>
<th>Wind Effect Index</th>
<th>Number of Days Occurring</th>
<th>Percentage of Total</th>
<th>Comfort Group Frequency</th>
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<tr>
<td>K</td>
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<td></td>
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<td>1.6</td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td></td>
<td>-d</td>
<td>1</td>
<td>0.8</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>-e</td>
<td>24</td>
<td>19.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-f</td>
<td>40</td>
<td>32.3</td>
<td>58.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-g</td>
<td>7</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>VC</td>
<td></td>
<td>-e</td>
<td>2</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-f</td>
<td>13</td>
<td>10.5</td>
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<td></td>
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<td>23</td>
<td>18.5</td>
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</table>

*aBased on the January nights of the period 1965-1968.

*bRanked from least uncomfortable to most uncomfortable.

*cRanked by cooling rate, lowest to highest, within each comfort group.

*dTo nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.
windchill, or very cold with very cold or bitterly cold windchill. All other conditions occurred infrequently at the nighttime extreme.

A general comparison of the daytime and nighttime physioclimate extremes (Tables 6 and 7) reveals several factors which provide meaningful insight into the nature of January day-night comfort contrasts. First, the absolute range of comfort groups at the daytime extreme is cool through very cold, whereas the range at the nighttime extreme is keen through extremely cold. Thus, there is a shift in the range of comfort conditions toward the colder end of the comfort continuum at the nighttime extreme. Secondly, conditions of the cold comfort group are in the majority at both extremes. Finally, there are important differences between the two extremes regarding the probability of occurrence of the keen and very cold comfort groups. Keen conditions occur at the daytime extreme nearly 26 per cent of the time, whereas they occur at the nighttime extreme only 4 per cent of the time. Conversely, very cold conditions occur at the daytime extreme about 6 per cent of the time, while they occur at the nighttime extreme fully 33 per cent of the time. Thus, while both the daytime and nighttime comfort extremes are dominated by conditions of the cold comfort group, departures from this category
are very likely to produce keen conditions (more comfortable than usual) at the daytime extreme, and very cold conditions (less comfortable than usual) at the nighttime extreme.

**Diurnal ranges**

The range of comfort conditions during a day is depicted here by combining the daytime and nighttime physioclimatic extremes in a single assembly, with the nighttime physioclimatic extreme shown by digital subscripts indicating the degree of departure from the daytime physioclimatic extreme. Possible combinations are shown in Appendix B. Diurnal ranges are broadly classified into **diurnal variability groups**, based on the diurnal range of the Comfort Indices.

A total of 36 diurnal ranges occurred during January (Table 8). This profusion of ranges, which reflects variable combinations of 15 comfort conditions, comprises 8 diurnal variability groups (refer to the marginal columns, Table 8). No diurnal range has a frequency exceeding 15 per cent, and even the most frequently-occurring diurnal variability group (CD₁, the cold day/cold night group) has a frequency of only 35.5 per cent. There is, in short, an extremely wide variety of diurnal ranges and diurnal variability groups, among which none

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<table>
<thead>
<tr>
<th>Comfort Index</th>
<th>Wind Effects</th>
<th>Frequency of Diurnal Ranges</th>
<th>Frequency of Diurnal Variability Groups</th>
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<tr>
<td></td>
<td>-d2</td>
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<td>1.6</td>
</tr>
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<td>0.8</td>
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<td>-d2</td>
<td>7</td>
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**TABLE 8: FREQUENCY OF JANUARY DIURNAL RANGES** (Continued)

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<td>No. of Days Occurring</td>
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<td>-g2</td>
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</table>

*Note: CD1 and CD2 represent different categories or groups.*
<table>
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<tr>
<th>Comfort Index</th>
<th>Wind Effects</th>
<th>Frequency of Diurnal Ranges</th>
<th>Frequency of Variability Groups</th>
</tr>
</thead>
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<td>Percentage of Total</td>
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<tr>
<td>$-f_2$</td>
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<td>0.8</td>
</tr>
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<td>0.8</td>
</tr>
<tr>
<td>$-f_2$</td>
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</tr>
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<td>$v_C_1$</td>
<td>$-g_2$</td>
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<td>$-h_1$</td>
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<td>$v_C_2$</td>
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<td>$-f_2$</td>
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</tr>
<tr>
<td></td>
<td>$-g_1$</td>
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<td>0.8</td>
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<tr>
<td><strong>Totals:</strong></td>
<td></td>
<td>124</td>
<td>99.5</td>
</tr>
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</table>
**TABLE 8: FREQUENCY OF JANUARY DIURNAL RANGES**

*a* Based on the January days of the period 1965-1968.

*b* Ranked by comfort group, warmest to coldest, and by degree of diurnal variability, lowest to highest, within groups.

*c* Ranked by cooling rate, lowest to highest, within each comfort group, and by degree of diurnal variability, lowest to highest, within each wind effects category.

*d* To nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.

*e* Wind Effect Index disregarded (see text).
is dominant and many are unique.

Despite the complexity of the distribution shown in Table 8, certain broad patterns can be discerned, and a number of generalizations based on these patterns can be made.

First, there is about a 95 per cent probability that the range of comfort conditions during a day will be confined entirely within the keen to very cold portion of the comfort continuum—only the C₃, CD₃, and VC₂ diurnal variability groups reflect the occurrence of conditions outside this zone.

Secondly, marked contrasts between the daytime and nighttime physioclimatic extremes (indicated by subscripts of 3 or larger in the diurnal ranges listed in Table 8) occur relatively infrequently during January. Taking into account the Comfort and Wind Effect Index subscripts of the 36 diurnal ranges listed in Table 8, it appears that less than 20 per cent of January days witness such contrasts in either index. Thus, there is an apparent probability of about 80 per cent that the range of comfort conditions during a January day will span no more than two comfort groups and will include no more than two adjacent windchill categories—meaning that no more than four comfort conditions will be involved at the maximum. Moreover, there is a probability of about
43 per cent (the sum of the $K_1$, $CD_1$, and $VC_1$ diurnal variability group frequencies) that the diurnal range will be confined within a single comfort group.

Thirdly, although 8 diurnal variability groups occur during January, only 3 occur relatively frequently, together accounting for 86 per cent of the days and 23 diurnal ranges. In order of frequency, these are:

1. the cold day/cold night ($CD_1$) group, 35.5 per cent;
2. the cold day/very cold night ($CD_2$) group, 29 per cent; and
3. the keen day/cold night ($K_2$) group, 22 per cent. It appears that these 3 groups together form the basic framework for the diurnal range of January comfort conditions; no other diurnal variability group occurs more frequently than 4 per cent of the time.

Finally, it may be seen from the foregoing that variable wind effects serve to add a great deal of variety (or complexity) to the January comfort climate, as reflected in the number of diurnal ranges with occur. Moreover, since the range of comfort conditions is confined to a single comfort group during 43 per cent of January days, the diurnal range of comfort conditions is primarily determined by windchill variability during nearly half of the days.
Interdiurnal Variability

The results of this investigation thus far suggest that the January comfort climate at Grand Rapids is characterized by a good deal of monotony. Such a conclusion seems to be supported by the facts. For example, it has been shown that conditions of the cold comfort group generally dominate both the daytime and nighttime periods, and little variety in comfort conditions is normally experienced in the course of a day. There is, however, yet another important variability feature of the January comfort climate which must be investigated before a reasonably complete picture of realistic conditions is obtained. This concerns the interdiurnal sequences and duration of comfort conditions which occur during the month.

In this section, a simple classification of interdiurnal comfort condition sequence and duration is devised and then utilized in the description of the January comfort climate. An exhaustive description of interdiurnal variability is considered to be beyond the scope of the present investigation. Accordingly, it is the limited objective of this section to identify important interdiurnal comfort patterns and to describe the January comfort climate in terms of these patterns.
Classification procedure and nomenclature

The interdiurnal sequence and duration of comfort conditions can be classified according to various criteria, depending upon the level of detail desired. For the purposes of satisfying the objectives outlined above, the variability of the warmest daytime Comfort Index appears to offer the single best criterion for a simple classification. The reasoning behind this is as follows. First, maximum human outdoor exposure occurs during the daylight hours. The variability of daytime comfort conditions is therefore of primary concern in the comfort climate, while the variability of nighttime comfort conditions is of secondary concern and need not be considered at the specified level of detail. Secondly, the nature of the daytime comfort extremes provides a convenient, logical means of comparing among daytime periods. Finally, the Comfort Index is the most important portion of the daytime physioclimatic extreme; the Terjung scheme consistently subordinates the Wind Effect Index to the Comfort Index.

It must be emphasized that the Comfort Index, viewed in isolation, presents a less realistic picture of comfort conditions than that which is conveyed by the physioclimatic extreme assembly, which contains a corresponding
Wind Effect Index. Accordingly, results derived through the use of this classification procedure must be accompanied by a statement of probable accompanying wind effects. This supplementary information is derived from Table 6 and provided, as required, below.

It was noted that the interdiurnal distribution of the Comfort Indices strongly tends toward consecutive occurrences, or "runs." These runs, hereafter termed comfort spells, are periods of two or more consecutive days having identical Comfort Indices. Isolated occurrences of the Comfort Indices, hereafter termed short cycle intervals, appear to represent either brief interruptions of comfort spells or transitional periods between comfort spells.

January comfort profiles

January comfort spells are of 3 basic types; keen spells, cold spells, and very cold spells. Each January of the study period has a comfort profile consisting of either 5 or 6 comfort spells and from 2 to 4 short cycle intervals (Figure 4). Despite these broad similarities, each comfort profile is unique. Thus, the January comfort climate cannot be described in terms of a simple comfort profile. There are many different types of January comfort profiles, and the results suggest that
JANUARY MONTHLY COMFORT PROFILES

Figure 4

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perhaps no two are alike.

**Keen spells**

Keen spells are periods spanning two or more consecutive days during which temperatures in excess of 35°ET occur at the daytime comfort extreme (refer to Figure 1). When these temperatures occur, clothing requirements fall from a normal of about 4 clo units (heavy clothing) to less than 5, and perhaps as little as 2 clo units. The implication is that the average individual perceives January keen spells as periods of relatively mild daytime comfort conditions. Accompanying wind effects, in any event, are likely to produce very cool or cold sensations (refer to Table 6).

There are 1 or 2 keen spells in each comfort profile in Figure 4. Thus, no comfort profile is devoid of this relatively desirable comfort feature. Spells range up to 6 days in length, but their median length is 4 days.

---

1The thermal insulation value of clothing is commonly expressed in terms of clo units. The reader should visualize one clo unit as the amount of clothing normally worn for sedentary activities in a comfortable indoor environment (Burton and Edholm, *op. cit.*, p. 35). As employed in the text, relative values are more important than absolute values. The normal value of 4 clo units referred to applies to conditions of the cold comfort group.
Cold spells

During cold spells, temperatures at the daytime comfort extremes range from 14°F to 35°FET and clothing requirements remain at the 4 to 4.5 clo unit level (heavy clothing). Since it has already been shown that conditions of the cold comfort category are quite normal for January, the implication is that the average individual perceives cold spells as periods of normal daytime comfort conditions during this time of year. Although windchill can range all the way from cool (-c) to bitterly cold (-g) at the daytime comfort extremes, cold or very cold sensations (-e or -f) are likely to be experienced (refer to Table 6).

There are 3 cold spells of varying lengths in each profile in Figure 4. Although the longest such spell is of 17 days duration, median length is 5 days. In terms of both frequency and length, cold spells figure most importantly in each comfort profile; in each case, cold spells occur more frequently than any other type and the spell of longest duration is a cold spell.

Very cold spells

A very cold spell is a span of two or more consecutive days during which dry-bulb temperatures at the
daytime comfort extremes do not exceed 13°F and may drop as low as -4°F. Clothing requirements under such conditions are at least 4.5 clo units, and may be 5.5 clo units or more (very heavy clothing). Since conditions of the very cold comfort category are uncommon at the daytime comfort extreme, occurring less than 7 per cent of the time (refer to Table 6), the implication is that the average individual perceives very cold spells as periods of unusually cold January daytime comfort conditions. Moreover, windchill at the daytime comfort extremes produces discomforting sensations ranging from very cold to frostbite effects. Since the conditions described above are the most comfortable to occur during very cold spells, it may be seen that these spells are truly undesirable comfort features.

Only 2 very cold spells appear in the January comfort profiles (Figure 4). Half the profiles have no spells of this type, and no profile has more than one. Those that occurred were of 2 or 3 days duration--quite brief in comparison with the majority of cold spells and keen spells in the profiles.
Summary

Investigation of the January daily comfort extremes has revealed that both the daytime and nighttime extremes are dominated by conditions of the cold comfort group, although there is a significant potential for variability, primarily within the keen to very cold portion of the comfort continuum, at each extreme. It was determined that there is a definite shift toward the colder end of the comfort continuum at the nighttime extreme.

The diurnal range of comfort conditions is characteristically small, normally spanning no more than 2 comfort groups and 2 adjacent windchill categories (or a maximum of 4 comfort conditions) within the keen to very cold portion of the comfort continuum. During nearly half the days, the diurnal range is entirely confined within a single comfort group. The cold day/cold night \((CD_1)\), cold day/very cold night \((CD_2)\), and keen day/cold night \((K_2)\) diurnal variability groups are the only ones which occur frequently, and there is little probability (about 14 per cent) that a January day will witness a diurnal range of comfort conditions which does not fall within one of these groups. Thus, the conclusion is that the 3 groups together constitute the basic diurnal variability framework of the January comfort climate.
Wind effects are an important consideration within this framework, and it is variable windchill which essentially determines the diurnal range of comfort conditions during nearly half the days.

A simple classification of interdiurnal comfort condition sequence and duration was devised and utilized to gain additional insight into the nature of the January comfort climate. Each January has a comfort profile consisting of a variable combination of keen spells, cold spells, very cold spells, and short cycle intervals, and it is unlikely that any 2 are alike. A characteristic profile, one which would suggest the central tendency of January comfort profiles, would be comprised of 1 or 2 keen spells of about 4 days duration, 5 cold spells of about 5 days duration, and perhaps a single very cold spell of 2 or 3 days duration in addition to several short cycle intervals.
CHAPTER V

JULY COMFORT CONDITIONS

The dynamic approach to the investigation of the warm season comfort climate at Grand Rapids, as represented by July, is essentially identical to that employed in the preceding chapters which dealt with the cool season comfort climate. Accordingly, it is the objective of this chapter to lay the foundation for the investigation of diurnal and interdiurnal variability features of the July comfort climate by describing the frequency and range of July comfort conditions, both for the month as a whole and for the daytime and nighttime periods respectively.

Frequency and Range of July Comfort Conditions

A total of 25 comfort conditions were identified among the 992 tri-hourly observations for July (Table 9). The absolute range of these conditions was very large—all the way from sultry ( oppressively hot) with discomforting heat additions to the skin (S_b), to keen with very cool windchill (K_c). To put this in a slightly different way, the July conditions ranged from much too
TABLE 9
FREQUENCY OF JULY COMFORT CONDITIONS

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</tr>
<tr>
<td></td>
<td>-d</td>
</tr>
<tr>
<td>Totals:</td>
<td>992</td>
</tr>
</tbody>
</table>

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TABLE 9: FREQUENCY OF JULY COMFORT CONDITIONS (Continued)

\(^a\)Based on tri-hourly observations of the comfort condition during the Julys of the period 1965-1968.

\(^b\)Ranked from hottest to coolest.

\(^c\)Ranked from largest heat additions (or slightest cooling effects) to greatest cooling effects within each comfort group.

\(^d\)To nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.
hot for comfort to much too cool for comfort and included conditions which were, for the average individual, comfortable.

Daytime Comfort Conditions

All but one of the July comfort conditions (K -d, the coldest) occurred during the daylight hours (Table 10). Thus, the comfort range for the daylight hours includes 24 comfort conditions and is almost identical to that of the month as a whole. No comfort condition dominates the daytime period, but 4 conditions figure very importantly in the distribution, together accounting for 54 per cent of the observations. In order of relative frequency these are: mild with warm wind effects (M -a), 16.1 per cent; warm with neutral wind effect (W n), 13.7 per cent; warm with warm wind effects (W -a), 13.1 per cent; and mild with pleasant wind effects (M -b), 11.1 per cent. No other comfort condition has a frequency exceeding 10 per cent.

Daytime comfort groups

Although daytime conditions involved 6 comfort groups, the mild (M) and warm (W) groups were clearly co-dominant (Table 10 and Figure 5). In fact, the mild group alone accounted for a healthy 42 per cent of all
<table>
<thead>
<tr>
<th>Comfort Condition</th>
<th>Frequency</th>
<th>Comfort Group Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tri-hourly Observations</td>
<td>Percentage of Total</td>
</tr>
<tr>
<td><strong>Comfort Index</strong></td>
<td><strong>Wind Effect Index</strong></td>
<td><strong>b</strong></td>
</tr>
<tr>
<td><strong>S</strong></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>H</strong></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td>620</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
TABLE 10: FREQUENCY OF JULY DAYTIME COMFORT CONDITIONS
(Continued)

a Based on daytime tri-hourly (7 AM through 7 PM) observations of the comfort condition during the Julys of the period 1965-1968.

b Ranked from hottest to coolest.

c Ranked from largest heat additions (or slightest cooling effects) to greatest cooling effects within each comfort group.

d To nearest 0.1 per cent. Due to rounding, column may not total 100 per cent.
Fig. 5—FREQUENCY OF JULY COMFORT GROUPS
July daytime observations, and the warm group accounted for nearly 1 out of every 3 such observations. No other comfort group occurred more frequently than about 8 per cent of the time.

Fully 81 per cent of all observations fell within the central portion of the comfort continuum; i.e., either into or immediately adjacent to the mild zone.

**Daytime wind effects**

Daytime wind effects involved 6 categories, ranging from discomforting heat additions (b) to cool windchill (-c)(Table 11). Warm wind effects occurred more frequently than any other type, but they occurred only about 34 per cent of the time, therefore were not dominant.

Daytime wind effects are of 3 broad types: heat additions (a,b); neutral effects (n); and windchill (-a, -b, -c). From Table 11, it may be seen that heat additions occur slightly more than 5 per cent of the time, neutral effects occur about 25 per cent of the time, and windchill accounts for the remaining 70 per cent. Significantly, discomforting heat additions occur less than 3 per cent of the time and discomforting windchill (cool or worse) occurs less than 16 per cent of the time. Thus, there is a probability of slightly better than 81 per cent that daytime wind effects will involve either neutral
<table>
<thead>
<tr>
<th>Wind Effect Index</th>
<th>Wind Effects</th>
<th>Sensation felt by the Majority</th>
<th>Frequency</th>
<th>Percentage of Observations</th>
<th>Percentage of Observations Colder than Observed Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>Discomforting heat addition to skin</td>
<td>16</td>
<td>2.6</td>
<td>97.4</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>Warming sensation to skin</td>
<td>18</td>
<td>2.9</td>
<td>94.5</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>Neutral wind effect</td>
<td>157</td>
<td>25.3</td>
<td>69.2</td>
<td></td>
</tr>
<tr>
<td>-a</td>
<td>Warm wind effects</td>
<td>210</td>
<td>33.9</td>
<td>35.3</td>
<td></td>
</tr>
<tr>
<td>-b</td>
<td>Pleasant wind effects</td>
<td>122</td>
<td>19.7</td>
<td>15.6</td>
<td></td>
</tr>
<tr>
<td>-c</td>
<td>Cool windchill</td>
<td>97</td>
<td>15.6</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Totals:</td>
<td></td>
<td>620</td>
<td>100.0</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

a Based on daytime tri-hourly (7 AM through 7 PM) observations of the Wind Effect Index during the Julys of the period 1965-1968.

b Ranked from greatest heat additions to greatest cooling effects.

c To nearest 0.1 per cent.
conditions or relatively minor departures from the neutral condition.

**Nighttime comfort conditions**

Nighttime observations yielded 11 comfort conditions (Table 12). The contrast with the distribution of daytime conditions is striking, with decidedly cooler conditions prevailing. Further, the nighttime period is much more nearly uniform as to comfort than the daytime period--the variety of nighttime comfort conditions being less than half that of the daytime period.

Although 11 comfort conditions were identified, 4 were especially important in the distribution. In order of relative frequency these were: keen with cool windchill (K -c), 30.4 per cent; mild with cool windchill (M -c), 21.5 per cent; cool with cool windchill (C -c), 18.8 per cent; and mild with pleasant wind effects (M -b), 15.3 per cent. No other comfort condition occurred more frequently than 6 per cent of the time.

**Nighttime comfort groups**

Nighttime comfort conditions involved 5 comfort groups, but slightly more than 90 per cent were confined within the mild to keen portion of the comfort continuum (refer to Table 12 and Figure 5). Less than
TABLE 12

FREQUENCY OF JULY NIGHTTIME COMFORT CONDITIONS\textsuperscript{a}

<table>
<thead>
<tr>
<th>Comfort Condition</th>
<th>Wind Effect Index\textsuperscript{b}</th>
<th>Frequency</th>
<th>Tri-hourly Observations</th>
<th>Percentage of Total\textsuperscript{d}</th>
<th>Comfort Group Frequency (%)\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>-a</td>
<td>2</td>
<td>0.5</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>-a</td>
<td>11</td>
<td>3.0</td>
<td></td>
<td>8.9\textsuperscript{a}</td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>22</td>
<td>5.9</td>
<td></td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>-a</td>
<td>5</td>
<td>1.3</td>
<td></td>
<td>8.9\textsuperscript{a}</td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>57</td>
<td>15.3</td>
<td></td>
<td>38.2</td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>80</td>
<td>21.5</td>
<td></td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>10</td>
<td>2.7</td>
<td></td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>70</td>
<td>18.8</td>
<td></td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>1</td>
<td>0.3</td>
<td></td>
<td>8.9\textsuperscript{a}</td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>113</td>
<td>30.4</td>
<td></td>
<td>38.2</td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>1</td>
<td>0.3</td>
<td></td>
<td>38.2</td>
</tr>
<tr>
<td>Totals:</td>
<td></td>
<td>372</td>
<td>100.0</td>
<td></td>
<td>100.0</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Based on nighttime tri-hourly (10 PM through 4 AM) observations of the comfort condition during the Julys of the period 1965-1968.

\textsuperscript{b} Ranked from hottest to coolest.

\textsuperscript{c} Ranked from largest heat additions (or slightest cooling effects) to greatest cooling effects within each comfort group.

\textsuperscript{d} To nearest 0.1 per cent.
10 per cent of the observations, therefore, were of the uncomfortably warm or sultry variety.

The shift toward cooler conditions during the night is clearly seen in the fact that there is a very pronounced drop in the incidence of warm and hot conditions and a corresponding marked increase in the incidence of cool and keen conditions (refer to Figure 5). The frequency of mild conditions, however, differs but little from that of the daytime.

**Nighttime wind effects**

Four categories of windchill occur during July nights (Table 13). Cool windchill clearly dominates the nighttime hours, accounting for about 7 out of every 10 observations. Very cool windchill, however, seldom occurs. In the overview, July nighttime windchill almost invariably produces either cool or pleasant sensations.
### TABLE 13
**FREQUENCY OF JULY NIGHTTIME WIND EFFECTS**

<table>
<thead>
<tr>
<th>Wind Effects</th>
<th>Frequency</th>
<th>Percentage of Observations Cooler than Observed Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tri-hourly Observations</td>
<td>Total</td>
</tr>
<tr>
<td>-a Warm wind effects</td>
<td>18</td>
<td>4.8</td>
</tr>
<tr>
<td>-b Pleasant wind effects</td>
<td>90</td>
<td>24.2</td>
</tr>
<tr>
<td>-c Cool windchill</td>
<td>263</td>
<td>70.7</td>
</tr>
<tr>
<td>-d Very cool windchill</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Totals:</td>
<td>372</td>
<td>100.0</td>
</tr>
</tbody>
</table>

---

*a Based on tri-hourly (10 PM through 4 AM) observations of the Wind Effect Index during the July nights of the period 1965-1968.

*Ranked by cooling rate, lowest to highest.

*To nearest 0.1 per cent.
Summary

It has been shown that at least 25 comfort conditions occur during July and that the range of comfort conditions extends from sultry with discomforting heat additions through keen with very cool windchill. During the daytime, comfort conditions fall within the central portion of the comfort continuum in the very large majority of instances (about 81 per cent), with conditions of the mild and warm comfort groups co-dominant. In the overview, daytime wind effects do not characteristically involve large departures from the neutral condition—meaning that wind effects are not an important source of discomfort during July days. The nighttime period witnesses a marked shift of conditions toward the cooler end of the comfort continuum, with warm or hot conditions occurring much less frequently and cool or keen conditions occurring much more frequently than in the daytime. Mild conditions, however, occur with approximately the same frequency as in the daytime. Nighttime wind effects normally produce minor cold discomfort or pleasant sensations.
CHAPTER VI

DIURNAL AND INTERDIURNAL VARIABILITY OF JULY COMFORT CONDITIONS

In the preceding chapter it was established that the July comfort climate is characterized by a good deal of complexity, as reflected in a remarkably large range of comfort conditions and a significant potential for variability during both the daytime and nighttime periods. It is the objective of this chapter to delve into additional dynamic aspects of the July comfort climate and describe the daytime and nighttime comfort extremes, the diurnal ranges, and the broad interdiurnal variability patterns which occur during the month.

Diurnal Variability

Daytime comfort extremes

One of the noteworthy features of the July comfort climate is the large variety of daytime physioclimatic extremes (Table 14). These extremes, of which no less than 16 were identified during the study period, range all the way from sultry with discomforthing heat additions to the skin (Sb), to cool with cool windchill (Cc).
# TABLE 14

FREQUENCY OF JULY DAYTIME PHYSIOCLIMATIC EXTREMES\textsuperscript{a}

<table>
<thead>
<tr>
<th>Physioclimatic Extreme</th>
<th>Wind Comfort Effect Index\textsuperscript{b}</th>
<th>Number of Days Occurring</th>
<th>Percentage of Total</th>
<th>Comfort Group Frequency\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b</td>
<td>3</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a</td>
<td>2</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>6</td>
<td>4.8</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>-a</td>
<td>4</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>5</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a</td>
<td>3</td>
<td>2.4</td>
<td>7.3</td>
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<td></td>
<td>n</td>
<td>1</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>38</td>
<td>30.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-a</td>
<td>16</td>
<td>12.9</td>
<td>48.4</td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>6</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>12</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-a</td>
<td>18</td>
<td>14.5</td>
<td>27.4</td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>4</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-a</td>
<td>1</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-b</td>
<td>1</td>
<td>0.8</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>-c</td>
<td>4</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>Totals:</td>
<td>124</td>
<td>99.7</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a}Based on the July days of the period 1965-1968.

\textsuperscript{b}Ranked from hottest to coolest.

\textsuperscript{c}Ranked from largest heat additions (or slightest cooling effects) to greatest cooling effects within each comfort group.

\textsuperscript{d}To nearest 0.1 per cent. Due to rounding, column may not total 100 per cent.
Despite the potential for cooler conditions, one fact is abundantly clear; a July day is not likely to be comfortable at its daytime comfort extreme. The probability of comfort conditions of the mild group at the daytime extreme appears to be only about 27 per cent, whereas the probability of warm, hot, or sultry conditions appears to be about 68 per cent. Significantly (or perhaps unfortunately), about 1 July day in 5 is hot or sultry at its daytime extreme. An interesting aspect of the July comfort climate is the fact that about 5 per cent of the days remain too cool for comfort throughout.

Nearly half the days of the month have daytime physioclimatic extremes of the warm group, and the most frequently-occurring daytime physioclimatic extreme for the month as a whole (frequency about 31 per cent) is warm with a neutral wind effect (W n). Other daytime physioclimatic extremes with an incidence greater than 5 per cent are: mild with warm wind effects (M -a), 14.5 per cent; warm with warm wind effects (W -a), 12.9 per cent; and mild with a neutral wind effect (M n), 9.7 per cent.

Nighttime comfort extremes

The distribution of comfort conditions at the nighttime extreme (Table 15) is much different from that at
TABLE 15
FREQUENCY OF JULY NIGHTTIME PHYSIOCLIMATIC EXTREMES

<table>
<thead>
<tr>
<th>Physioclimatic Extreme</th>
<th>Frequency</th>
<th>Comfort Group Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comfort Group Frequency</td>
<td>Wind Effect Indexc</td>
</tr>
<tr>
<td>W -b</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>-a</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>M -b</td>
<td>13</td>
<td>10.5</td>
</tr>
<tr>
<td>-c</td>
<td>25</td>
<td>20.2</td>
</tr>
<tr>
<td>C -b</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>-c</td>
<td>25</td>
<td>20.2</td>
</tr>
<tr>
<td>K -c</td>
<td>56</td>
<td>45.2</td>
</tr>
<tr>
<td>-d</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>Totals: 124</td>
<td>100.1</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Based on the July nights of the period 1965-1968.

bRanked from warmest to coolest.

cRanked by cooling rate, lowest to highest, within each comfort group.

dTo nearest 0.1 per cent. Due to rounding, column may not total 100 per cent.
the daytime extreme, reflecting a much narrower range, less variety, and a pronounced shift toward the cooler end of the comfort continuum. Virtually all nighttime physioclimatic extremes (more than 98 per cent) are confined within the mild to keen portion of the comfort continuum, with the median falling within the cool zone. The number of nighttime physioclimatic extremes, moreover, is just 8—or only half the variety of daytime physioclimatic extremes.

For practical purposes, only 4 nighttime physioclimatic extremes occur frequently—the combined frequency of all others being just 4 per cent. Keen conditions with cool windchill (K -c) occur at the nighttime extreme nearly half the time, which is far more frequently than any other type. This comfort condition therefore dominates the nighttime comfort extreme. The other frequently-occurring extremes are: cool with cool windchill (C -c) and mild with cool windchill (M -c), each with a frequency of about 20 per cent; and mild with pleasant wind effects (M -b), with a frequency of about 10 per cent.

With reference to Table 15, it appears that the probability of a July night remaining uncomfortably warm throughout is something less than 2 per cent, a very important consideration from the standpoint of sleeping comfort.
Diurnal ranges

Considering the wide variety of daytime physio-climatic extremes and the markedly different distribution of conditions at the daytime and nighttime comfort extremes, it is not surprising that at least 38 diurnal ranges occur during July (Table 16). This great diversity of diurnal ranges is certainly a noteworthy feature of the July comfort climate in the overview.

Only 6 of the diurnal ranges listed in Table 16 have a frequency exceeding 5 per cent and 18 (nearly half) have a frequency of less than 1 per cent. Moreover, even the most frequently-occurring diurnal range--mild conditions with warm wind effects at the daytime extreme, followed by keen conditions with cool windchill at the nighttime extreme ($M^3 - a_3$)--occurs less than 14 per cent of the time, or less than once a week on the average. Thus, no diurnal range is dominant and about half of those which are known to occur do not occur during every July.

The interpretation of Table 16 is facilitated by reference to the frequencies of the 11 diurnal variability groups (refer to the marginal columns). The mild day/keen night ($M_3$) group occurs more often than any other, accounting for about 22 per cent of the diurnal
<table>
<thead>
<tr>
<th>Diurnal Range</th>
<th>Frequency of Diurnal Ranges</th>
<th>Frequency of Diurnal Variability Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comfort Index</td>
<td>Wind Effects</td>
</tr>
<tr>
<td>S3</td>
<td>a2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>-a2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>b2</td>
<td>2</td>
</tr>
<tr>
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<td></td>
<td>a3</td>
<td>1</td>
</tr>
<tr>
<td>S4</td>
<td>n2</td>
<td>2</td>
</tr>
<tr>
<td></td>
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</tr>
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<td></td>
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<tr>
<td></td>
<td>n2</td>
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<td>Diurnal Range</td>
<td>Comfort Index</td>
<td>Wind Effects</td>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₄</td>
<td>a₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a₃</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n₂</td>
<td></td>
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<tr>
<td></td>
<td>n₃</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-a₂</td>
<td></td>
</tr>
<tr>
<td>W₂</td>
<td>-a₃</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-b₁</td>
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<tr>
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<td>-b₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n₃</td>
<td></td>
</tr>
<tr>
<td>W₃</td>
<td>-a₃</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-b₂</td>
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</tr>
<tr>
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<td>n₃</td>
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</tr>
<tr>
<td>W₄</td>
<td>-a₃</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-b₂</td>
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</tr>
<tr>
<td>Diurnal Range</td>
<td>Frequency of Diurnal Ranges</td>
<td>Frequency of Diurnal Variability Groups</td>
</tr>
<tr>
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<td>---------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td></td>
<td>No. of Days Occurring</td>
<td>Percentage of Total</td>
</tr>
<tr>
<td>$M_1$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n_3$</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>$-b_2$</td>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>$M_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n_3$</td>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>$-a_3$</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>$-b_2$</td>
<td>1</td>
<td>0.8</td>
</tr>
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<td>$M_3$</td>
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<td></td>
</tr>
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<td>$n_3$</td>
<td>9</td>
<td>7.3</td>
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<td>$-a_3$</td>
<td>17</td>
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</tr>
<tr>
<td>$-b_2$</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$-a_3$</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>$C_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$-b_2$</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>$-c_1$</td>
<td>4</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td>$124$</td>
<td><strong>99.7</strong></td>
</tr>
</tbody>
</table>
TABLE 16: FREQUENCY OF JULY DIURNAL RANGES

Based on the July days of the period 1965-1968.

Ranked by comfort group, hottest to coolest, and by degree of diurnal variability, lowest to highest, within comfort groups.

Ranked from greatest heat additions (or least cooling effects) to greatest cooling effects within each group, and by degree of diurnal variability, lowest to highest, within each wind effects category.

To nearest 0.1 per cent. Due to rounding, column does not total 100 per cent.

Wind Effect Index disregarded. See text for explanation.
ranges. The warm day/keen night \((W_4^1)\) group, however, occurs almost as often, about 19 per cent of the time. There are only 3 other groups which occur more than 10 per cent of the time. In order of their frequencies, they are: the warm day/cool night \((W_3^1)\) group; the warm day/mild night \((W_2^1)\) group; and the sultry day/mild night \((S_4^1)\) group. Each of the remaining diurnal variability groups has a frequency of less than 5 per cent.

About 3 out of 4 July diurnal ranges reflect marked day-night comfort contrasts, as denoted by Comfort Index subscripts of 3 or 4. Virtually all of the remainder reflect significant contrasts (Comfort Index subscript 2); less than 3 per cent reflect relatively insignificant contrast (Comfort Index subscript 1).

Interdiurnal Variability

For reasons explained earlier, this investigation of the interdiurnal variability of July comfort conditions is oriented toward the identification and description of broad interdiurnal variability patterns of the daytime comfort extremes, as represented by variability of the warmest daytime Comfort Index. Since wind effects do not frequently constitute an important source of discomfort at July daytime extremes, the Comfort Index may normally be relied upon to depict reasonably realistic comfort
conditions without reference to accompanying wind effects.

Interdiurnal comfort spells are delimited according to the degree of heat discomfort present at the daytime extremes on the following basis:

1. Each period of 2 or more consecutive days having hot or sultry daytime physioclimatic extremes (Comfort Index H or S) is termed a _hot spell_, with the assumption that the average individual at times experiences considerable heat discomfort during such spells.

2. Each period of 2 or more consecutive days having warm daytime physioclimatic extremes (Comfort Index W) is termed a _warm spell_, with the assumption that the average individual experiences a relatively minor degree of heat discomfort during such spells.

3. Each period of 2 or more consecutive days having mild or cool daytime physioclimatic extremes is termed a _comfortable spell_, with the assumption that the average individual experiences no heat discomfort whatever during such a spell.

Single days or brief spans of days which cannot be assigned to comfort spells as defined above are termed _short cycle intervals_. These features are not considered
to be major interdiurnal variability patterns themselves, but rather are seen to separate the major patterns, which are the comfort spells themselves.

The Julys of the study period have comfort profiles consisting of 7 or 8 comfort spells and 1 to 4 short cycle intervals (Figure 6). The profiles are quite dissimilar, suggesting that a very complex comfort profile is characteristic of July.

**Hot spells**

Hot conditions are undesirable by definition, but the effect of such conditions occurring during several consecutive days or more can be especially debilitating. The frequency and duration of hot spells is therefore one aspect of the July comfort climate which merits special attention.

It is significant that no July of the study period was devoid of hot spells (refer to Figure 6). It seems that this type of spell is a characteristic feature of July comfort profiles in general. While the July 1966 profile reflects the occurrence of 3 hot spells, this number appears to be somewhat excessive, and the trend is in favor of a single hot-spell during July. The median length of the hot spells during the study period was 3 days and the longest were of 5 days duration.
JULY MONTHLY COMFORT PROFILES

1965

1966

1967

1968

Figure 6

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Warm spells

Warm conditions do not normally produce excessive heat discomfort or heat distress in the average individual, and they involve a relatively minor degree of heat discomfort when compared with hot or sultry conditions. Warm spells, therefore, are not nearly so undesirable as hot spells. The results of the investigation thus far suggest that warm spells represent periods of "typical" July daytime comfort conditions.

Each comfort profile of the study period Julys includes 4 warm spells (refer to Figure 6). Only 4 of the spells exceed 3 days in length and none is longer than 6 days. Thus, although warm spells occur frequently, they tend to be brief.

Comfortable spells

During comfortable spells, the daytime periods are devoid of conditions producing any degree of heat discomfort. These spells are therefore highly desirable features of the July comfort climate and their frequency and duration is of special interest.

Since at least 1 comfortable spell appears in each July comfort profile (refer to Figure 6), it would appear that this type of spell is a characteristic feature of
the July comfort climate. The median length of the comfortable spells in the profiles is 3 days, and only one July (1966) does not have a comfortable spell of at least 4 days duration.

Summary

Although a large variety of comfort conditions occur at the daytime comfort extremes during July, these conditions involve some degree of heat discomfort nearly 70 per cent of the time—including hot or sultry conditions about 20 per cent of the time. In the overview, the characteristic daytime physioclimatic extreme is probably warm with a neutral wind effect (Wn).

The comfort conditions of the nighttime extremes are, in general, much cooler than those of the daytime extremes; virtually all nighttime physioclimatic extremes fall into the mild to keen portion of the comfort continuum, and the probability of uncomfortably warm, hot, or sultry conditions seems to be something less than 2 per cent. Keen conditions with cool windchill (K-c) dominate the nighttime extremes to a very important degree, occurring nearly half the time.

July diurnal ranges are of many different types—about 38 in all—and none is likely to occur more often than about once a week on the average. About 3 out of 4
July diurnal ranges reflect marked day-night comfort contrasts (those spanning 3 or 4 comfort groups), and July nights almost invariably bring significant relief from any heat discomfort which may be occasioned during July days. Among the diurnal variability groups which occur frequently, the mild day/keen night (M₃) and warm day/keen night (W₄) sequences are the most common.

Each July consists of some unique combination of comfort spells and short cycle intervals. It would appear that a characteristic July comfort profile—one which suggests the central tendency of the interdiurnal structure—consists of a hot spell of about 3 days length, 4 warm spells of from 2 to 6 days (3 days median) duration, several comfortable spells of about 3 days duration, and perhaps 5 brief short cycle intervals.
CHAPTER VII

CONCLUSIONS

Geographers have long recognized the importance of the comfort factor in climate and have employed the physioclimatic approach with limited success as an analytical tool for geographic research. Important advances have been made in the application of the technique since World War II, but the large majority of existing researches—most of them small-scale map studies—are based on an out-dated, static concept of the comfort climate. Owing to the excessive use of mean data and the resulting obscurcation of variability features, local comfort climates have not been realistically described via the "traditional" physioclimatic approach. Recognizing this, a number of geographers have called for a new, more dynamic physioclimatic approach—one which recognizes and gives proper weight to the diurnal and interdiurnal variability features which figure importantly in the comfort climate. Few researches of this type, however, have been attempted. This investigation of January and July comfort climates at Grand Rapids constitutes a first attempt to describe local monthly comfort climates in a realistic fashion, avoiding the use of
mean data and emphasizing diurnal and interdiurnal variability characteristics of the comfort conditions.

The January Comfort Climate

Grand Rapids' January comfort climate is something of a paradox; it is at once characterized by both monotony and complexity. The monotony stems from a predisposition toward conditions producing moderate cold discomfort (cold with cold or very cold windchill), small diurnal ranges, and comfort profiles featuring cold spells which may sometimes persist for weeks on end. In short, the central tendency of comfort conditions and variability features suggests a certain lack of diversity—a tedious repetition of minor diurnal and interdiurnal deviations about an "average" comfort condition. On the other hand, there is a sufficient amount of complexity to this comfort climate to suggest that describing it solely in terms of its "typical" characteristics is to depict it in a very unrealistic fashion. Significant variability of the comfort condition can and does occur during January, and the lack of diversity implied by the means is, to an important degree, more apparent than real.

Among the several January variability features, three appear to be of overriding significance. First, a
wide range of comfort conditions occurs. Thus, while the "average" comfort condition is cold with cold or very cold windchill, it must be borne in mind that markedly different conditions commonly occur. Over a span of days or weeks, the Comfort Index may range all the way from cool to extremely cold, and windchill may range from cool to potential frostbite. Secondly, although diurnal ranges are small, and often as not confined to a single comfort group, no specific range is dominant. The characteristic range involves cold conditions with cold windchill at the daytime extreme and cold conditions with very cold windchill at the nighttime extreme, but this particular range only infers the central tendency of ranges which may vary markedly during the month. Finally, the interdiurnal variability of comfort conditions produces comfort spells which are of variable frequency, duration, and sequential distribution. Although January comfort profiles are not nearly so given to rapid interdiurnal fluctuations of the comfort condition as their July counterparts, there is simply no justification for viewing January as one long relatively featureless cold spell. January comfort profiles contain keen spells, very cold spells, and short cycle intervals of various types in addition to the cold spells which are considered normal for this time of year.
The July Comfort Climate

Grand Rapids' July comfort climate is multi-faceted and extremely complex. As in January, however, there are aspects of monotony which merit emphasis. There is a strong probability that July days will produce some degree of heat discomfort and July nights will bring relief from that discomfort. Beyond this sweeping generalization, there are few features of this comfort climate which strongly suggest repetitiveness.

Three variability aspects of the July comfort climate appear to be especially significant. First, a remarkably broad range of comfort conditions occur; the Comfort Index ranges from sultry to keen, and accompanying wind effects range from discomforting heat additions to very cool windchill. Wind effects, however, do not constitute the important cause of discomfort that they do in January.

Secondly, diurnal ranges are highly variable and almost always large—the marked day-night comfort contrasts so conspicuously absent in January are prevalent at this time of year. The characteristic range involves warm conditions with a neutral wind effect at the daytime extreme and keen conditions with cool windchill at the nighttime extreme, but numerous other ranges occur and no specific range is dominant. Finally, just as in
January, the interdiurnal variability of comfort conditions produces comfort spells and short cycle intervals of variable frequency, duration, and sequential distribution. July comfort profiles are much more complex than January profiles, however, reflecting rapid interdiurnal fluctuation, brief comfort spells, and numerous short cycle intervals. Hot spells and comfortable spells are found in the July profiles in addition to the warm spells which are normal for this time of year.

Evaluation of Research Methodology and Implications for Future Research

The research methodology employed in this investigation is conditionally suitable for the classification of "instantaneous" comfort conditions at frequent diurnal intervals and for the identification and description of salient diurnal and interdiurnal variability characteristics of local comfort climates. Nevertheless, the research design and classification procedure may be improved significantly and it would probably be wise in any event to alter the approach somewhat to suit specific research requirements. For reasons which should be apparent, and which will be explained in further detail below, it would probably be unwise to apply the identical research methodology at different locations and/or at different scales without qualification.
Future studies of similar purpose and design could most likely be based upon less frequent diurnal observations of the comfort condition with perhaps only token loss of accuracy. Many such studies might logically require only a representative daytime observation and a representative nighttime observation. Physioclimatic classification can be a tedious, time-consuming procedure, and superfluous observations should be eliminated wherever possible. No computer program was written to handle comfort classification procedures for this investigation, but this approach clearly has numerous advantages and could no doubt be effectively employed in those studies based on very large numbers of observations.

The Terjung physioclimatic classification scheme is, in general, quite suitable for studies employing a dynamic physioclimatic approach. There are, of course, a number of deficiencies and shortcomings in the scheme which have become apparent during the course of this research. One of the most obvious of these is the fact that it is extremely difficult to rank a list of comfort conditions in order from most comfortable to least comfortable—especially when the list includes conditions of several different comfort groups. In fact, there are no guidelines for this procedure at all. There are two primary reasons for this difficulty. In the first place, Terjung's Comfort
and Wind Effect Index categories are wide. There is, for example, no way to distinguish a warm Comfort Index bordering on hot from a warm Comfort Index bordering on mild; both are represented by the symbol "W," which implies identical comfort sensations. It must always be borne in mind that comfort conditions represented by identical Comfort and Wind Effect Indices do not produce identical comfort sensations, but rather roughly similar sensations. A second problem is that there are many pairs of combinations of the major physioclimatic elements which, although falling into separate comfort groups, are probably very nearly iso-sensory (producing like sensations of comfort). Thus, it must also be borne in mind that the differences in comfort sensations implied by dissimilar combinations of the Comfort and Wind Effect Indices may in some cases be more apparent than real.

The windchill nomogram used in the derivation of the Wind Effect Index is another vulnerable feature of the Terjung scheme. It does not apply to heat losses from (or heat additions to) clothed surfaces and it does not reliably assess the cooling power of the wind at wind velocities approaching calm. It is especially during the winter, when reliable assessment of windchill factors is most important, that the windchill nomogram is frequently untrustworthy. It is also quite clear that the effects
of sunshine have been crudely approximated in this investigation—a factor rendering all daytime observations of the Wind Effect Index suspect to a certain degree. There is much room for improvement in this procedure, and it would appear that the simple cloud cover criterion adopted for this study is of marginal value.

The dynamic approach to the study of local comfort climates constitutes an extremely fertile field for future research. Additional investigations of comfort climates at the local level seem very worthwhile, and they need not be restricted to the objectives of the present investigation. For example, the concept of comfort profiles, comfort spells, and short cycle intervals seems to offer intriguing possibilities for broad application. It is quite likely that a reliable scheme could be devised for mapping the distribution of comfort climates on the basis of interdiurnal variability characteristics, thereby providing an extremely valuable supplement to the existing physioclimatic maps based on mean data. In the overview, this is probably the one research area which will eventually yield the most meaningful results, significantly enhancing the value of the physioclimatic approach as an analytical tool for geographic research.
Conclusion

Local monthly comfort climates cannot be realistically described solely in terms of mean comfort conditions, nor in terms of mean diurnal ranges or characteristic comfort profiles. In order to obtain a realistic picture of a local comfort climate, it is necessary to recognize that it is a complex integration of variability features which are not accurately described by simple statements of central tendency such as the mean. It is therefore necessary to determine not only what is "typical" of the local monthly comfort climate, but also to determine the range of deviations from the mean and the probable extent of those deviations through various periods of time.
### APPENDIX A

#### WIND EFFECT INDEX SYMBOLIZATION KEY

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Heat Loss/Gain (Kcal/m²/hr)</th>
<th>Sensation Felt by the Majority</th>
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</thead>
<tbody>
<tr>
<td>-h</td>
<td>-1400 &amp; beyond</td>
<td>Exposed flesh freezes</td>
</tr>
<tr>
<td>-g</td>
<td>-1200 to -1399</td>
<td>Bitterly cold windchill</td>
</tr>
<tr>
<td>-f</td>
<td>-1000 to -1199</td>
<td>Very cold windchill</td>
</tr>
<tr>
<td>-e</td>
<td>-800 to -999</td>
<td>Cold windchill</td>
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<tr>
<td>-d</td>
<td>-600 to -799</td>
<td>Very cool windchill</td>
</tr>
<tr>
<td>-c</td>
<td>-300 to -599</td>
<td>Cool windchill</td>
</tr>
<tr>
<td>-b</td>
<td>-200 to -299</td>
<td>Pleasant wind effects</td>
</tr>
<tr>
<td>-a</td>
<td>-50 to -199</td>
<td>Warm wind effects</td>
</tr>
<tr>
<td>n</td>
<td>+80 to -49</td>
<td>Neutral wind effect</td>
</tr>
<tr>
<td>a</td>
<td>+81 to +159&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Warming sensation to skin</td>
</tr>
<tr>
<td>b</td>
<td>+81 to +159&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Discomforting heat addition</td>
</tr>
<tr>
<td>c</td>
<td>+160 and above&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Very discomforting heat addition</td>
</tr>
</tbody>
</table>

<sup>a</sup> Refer to Figure 2, Wind Effect Index.
<sup>b</sup> With dry-bulb temperature 86° through 90°F.
<sup>c</sup> With dry-bulb temperature 91°F and above.
<sup>d</sup> With dry-bulb temperature 97°F and above.

# APPENDIX B

## Comfort Index Possible Day/Night Combinations

<table>
<thead>
<tr>
<th>Range</th>
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<td>W/C</td>
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<td>EH\textsubscript{2}</td>
<td>W/K</td>
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<td>etc.</td>
<td>etc.</td>
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<tr>
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<td>M/M</td>
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<tr>
<td>S/H</td>
<td>S\textsubscript{2}</td>
<td>M/C</td>
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<tr>
<td>S/W</td>
<td>S\textsubscript{3}</td>
<td>M/K</td>
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<tr>
<td>etc.</td>
<td>etc.</td>
<td>M/CD</td>
</tr>
<tr>
<td>H/H</td>
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<td>etc.</td>
</tr>
<tr>
<td>H/W</td>
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<tr>
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</tr>
<tr>
<td>W/M</td>
<td>W\textsubscript{2}</td>
<td>etc.</td>
</tr>
</tbody>
</table>

## Wind Effect Index Possible Day/Night Combinations

| c/-a  | c\textsubscript{1} | -b/-b | -b\textsubscript{1} | -f/-f | -f\textsubscript{1} |
| etc.  | etc. | etc. | etc. | etc. | etc. |
| b/-a  | b\textsubscript{1} | -c/-c | -c\textsubscript{1} | -g/-g | -g\textsubscript{1} |
| etc.  | etc. | etc. | etc. | etc. | etc. |
| a/-a  | a\textsubscript{1} | -d/-d | -d\textsubscript{1} | -h/-h | -h\textsubscript{1} |
| etc.  | etc. | etc. | etc. | etc. | etc. |
| -a/-a | a\textsubscript{1} | -e/-e | -e\textsubscript{1} | etc. | etc. |
| -a/-b | a\textsubscript{2} | etc. | etc. | etc. | etc. |

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