PREDICTING PEDESTRIAN USE ON OUTDOOR URBAN PLAZAS UTILIZING CLIMATE/BEHAVIOR MODELS

by

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(ABSTRACT)

Over the past two decades, an increasing amount of research has been directed toward climatic influences on behavior and the built environment. The evidence from this research has lead to the development of recommended site interventions to improve energy performance in individual buildings and to mitigate extreme climate conditions in exterior public spaces in order to make these environments more comfortable.

"Comfort", as a measure of performance, is usually based upon one of the many indices of thermal comfort. These indices, however, have been developed specifically for use in indoor environments and were later readapted for exterior environments. Previous research has begun to show that standards designed for and developed in interior settings, are not necessarily applicable for use in exterior environments where climate is only partially controllable and behavior is less defined. Early preliminary studies have shown that considerable activity will occur outside of the boundaries formally established as

"comfortable" by any particular thermal index.

In contradiction to the traditional thermal performance measures that determine specific climatological conditions to support a particular behavior, this research uses two bio-comfort charts and a thermal indexing equation to establish what specific behaviors will occur under particular climate profiles.

This study takes an annual record of regional and site specific climate data and applies it to existing comfort prediction models to ascertain if such applications are legitimate and if these applications are capable of predicting the frequency and duration of observed social behavior in an outdoor urban setting.

Acknowledgements

Wittingly or unwittingly, numerous teachers, professionals and friends have contributed to this research project without whom I quickly would have become overwhelmed and discouraged by its scope. Thanks to the collective support, enthusiasm and the occasional swift-kick, this project and my graduate school career has been a rewarding experience.

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1.0 INTRODUCTION

> Is the next generation really destined to pass its existence in these immense geometrical barracks, living in standardized mass-production houses with mass-production furniture; conveyed at the same hours by the same trains to the same skyscrapers into identically similar offices?.....Poor creatures! What will they become in the midst of all this dreadful speed, this organization, this terrible uniformity? So much logic taken to its extreme limits, so much "science," so much of the "mechanical" everywhere present and challenging.... Here is enough to disgust one forever with "standardization" and to make one long for "disorder."
>
> (L'Architecte, Paris, 1925)

While the above article appeared in 1925 as a design review for what was currently happening in Paris, many people still hold these same attitudes towards the urban environment today. Nonetheless, cities continue to grow in both infrastructure, size and population. Many critics of urban life have declared that unmitigated growth has been a crucial element in the deterioration of cities. It is criticism of the city, as portrayed in the quoted article, that has kept designers and planners constantly striving to design and redesign the city to produce a better civic environment and enhance the urban lifestyle.

One of the ways the urban environment and lifestyle is enriched is through the use of outdoor public spaces. Whether these spaces are large recreation areas, small pocket parks between buildings, outdoor market squares, a small sitting area on a plaza next to an office tower or a sidewalk cafe, these outdoor environments contribute to the pleasures and enjoyment of life. These areas can be principal settings for relaxation and socializing in the urban environment.

Urban open space is a valuable, but often misused and underutilized design resource. When outdoor areas are of a poor quality for pedestrians, only a minimum of activity will occur. Badly designed spaces can be found in many large urban areas throughout the country. Plazas around tall office buildings that are wind-swept and barren and large open concrete plains that offer no shelter from the baking summer sun do not encourage pedestrians to linger and enjoy. When outdoor spaces are of a high quality for pedestrians, a much wider range of activities will occur because the place and situation invite people to stop, sit, eat, play, and talk (Gehl, 1980).

William Whyte's now famous study, The Social Life of Small Urban Spaces, provides excellent, conclusive research on design factors that can be used to influence increased behavior on urban plazas - food, water, sunlight, seating, nearby activity. While references are made in the study to sunlight and precipitation, his research is not about climate per se. Whyte is interested in design amenities and behavior. This analysis is useful information for designers of urban space; however, it does not provide criteria needed to influence people to stay for any length of time in comfort. How important is the fact that a vendor sells great hotdogs on a particular plaza if the consumer will only purchase the wares and leave because the plaza is climatically unacceptable. Our urban lifestyles are enriched only by being able to stop and linger and enjoy the urban plazas instead of hurrying back to the place from which we came. Wonderfully designed plazas in San Francisco and other cities, that included many of the Whyte's criteria to attract users, remain unused due to being windswept or lacking sufficient solar insolation to insure thermal comfort (Bosselmann et. al., 1984). The importance of this research project to predict the comfort ranges which may increase duration becomes evident when it is used in conjunction with studies to influence frequency.

Ultimately, this research will lead to the development of a tool for designers of urban open space to help create useable, high quality pedestrian places. The primary task of this study is to take an annual record of climate data and apply it to an existing indexing model and related bioclimatic comfort charts, which are used to predict behavior, to ascertain if such applications are legitimate for outdoor spaces and if these applications are capable of predicting the frequency and duration of observed, specific behavior types in an outdoor urban setting where physical design elements of a space are held constant. This comparison also allows for the preliminary establishment of behavior/climate profiles where particular types of behavior will or will not occur within a particular climatic range.

2.0 BACKGROUND

2.1 Behavior Types

Behavior that occurs in outdoor public spaces can be categorized into three (3) types: necessary, optional and social (Gehl, 1980). Necessary activities are those that are more or less compulsory - the individuals involved are required to participate. Such activities would include going to school or work, waiting for the bus or a friend. These activities take place throughout the year. Optional activities are pursuits that are participated in if there is a wish to do so and if time and place make it possible. This includes sunbathing or sitting on a bench to enjoy life. These activities will take place only when exterior conditions are optimal; when weather and place invite them (Gehl, 1980). This behavior category is often referred to as "climate dependent." This class of behavior is particularly important to urban design and planning since most of the leisure activities that are especially pleasant to pursue outdoors are found in this category. Social activities are those that depend on the presence of others in public spaces. These can also be termed "resultant" since, in nearly all instances, they evolve from activities linked to the previous two categories (Gehl, 1980). An increase in the amount of usership, especially optional and social activities, in an urban open space can result in economic and social benefits that are important to maintain the vitality of cities and to enrich the urban lifestyle.

2.2 Climate

One of the most influential factors of life's activities is the weather. The popularity of weather as a topic of daily conversation is certainly warranted. As Charles D. Warner so eloquently wrote in an editorial in 1897, "Everybody talks about the weather, but nobody does anything about it." The weather is everywhere. Forecasters predict future weather patterns to help guide and plan man's activities. One of the ultimate tasks of architecture is to "interpose itself between man and the natural environment...in such a way as to remove the gross environmental load from his shoulders" (Fitch, 1972). Climate is often seen as the most important and influential determinant of individual, cultural, technological and architectural development (Markham, 1947). Nothing impacts on human behavior outdoors more than weather. Seldom does one sit outside in the rain to have lunch; and even though the sun may feel warm on the skin, few people sunbathe with snow on the ground.

Many studies have been conducted to look at the effects of climate on architecture and the affects of architecture on the climate. This study is not about design decisions that affect climate or visa versa. Research and technology already exists in this area. Extensive research in the area of man's behavior and climatic conditions has also been completed but these have primarily been in interior settings under constantly held conditions. The investigations that have been completed on pedestrian behavior and climatic factors have focused on the potential threat posed by a singular and extraordinary condition such as wind and buildings (Cohen et al., 1979, 1977). The conclusions drawn from these studies have established guidelines to ameliorate these threats.

This type of information provides a powerful tool to designers of outdoor urban space. By mitigating windy conditions, and other unfavorable climatic factors, the comfortable use of exterior spaces can be extended over a longer period of time. Aside of these threatening climatic phenomenons, designers usually make intuitive design decisions for climate intervention in outdoor spaces. Information on exactly how much climate mediation is necessary to enhance pedestrian behavior is not readily available to designers and planners. At what point does shade become necessary? What wind speed is required to cool pedestrians during the warmer months? If the relationship between behavior and climate can be adequately described, it becomes possible to formulate a "predictive model which will allow behavior changes in public outdoor spaces to be predicted from varying climate profiles" (Song, 1987). Since the effects of certain physical features, such as windbreaks, are well understood in terms of their influence on climatic conditions, it is thus practical to assess design decisions for urban space from a cost/benefit perspective with a predictive model where climatic intervention and optional use are concerned.

2.3 Climate and Thermal Comfort

Man's physical and psychological state depends on the atmospheric environment in which labor and leisure activities occur and seldom does nature provide the optimal conditions. This "optimal physical and psychological state" is referred to as "thermal comfort". The concept of thermal comfort has always been difficult to define in any simple language. Thermal comfort, or thermal neutrality - which can be defined differently from person to person - is defined as a state in which a person expresses satisfaction with the thermal environment, i.e. that person would prefer neither a warmer nor a colder environment (Fanger, 1970). A person's thermal comfort is influenced by many factors including temperature, humidity, solar radiation, wind speed and clothing type (Givoni, 1969). In analyzing comfort for outdoor spaces, orientation and position within a space become factors.

If a large group of people are in a common climate, it would normally not be possible, because of biological variance, to satisfy every individual at the same time; one must then seek to attain "optimal" thermal comfort, i.e. a condition where the highest possible percentage of the group are in thermal comfort. (ASHRAE has set this level in their building performance standards at 80%.) Thus, optimal thermal comfort represents also the condition which most probably would create thermal comfort for an individual selected at random.

2.4 Measuring Thermal Comfort

There is insufficient space here, nor is this author qualified, to summarize the many theories of heat and cold stress that arose in the past century. Thermal comfort is essentially measured by using mathematical formulas that consider the different variables involved with comfort. Table 1 is a partial chronological summary of formulas that have been developed for rating heat stress and strain. From the experimental point of view, the study of thermal discomfort began in 1923 with the work of Houghten and Yaglou who studied the effect of combinations of ambient temperature (dry bulb) and relative humidity (wet bulb) producing "feelings of equal warmth" which they equated to "feelings of equal comfort" or discomfort (Gagge, 1977). These studies were made for the guidance of heating, ventilating and air conditioning engineers, and established the so-called "comfort zone" in terms of the "Effective Temperature" (ET) scale. From this initial investigation, numerous formulas developed to refine and modify the findings of Houghten and Yaglou. These include Thom's "Discomfort Index" used to establish air-conditioning loads from weather data, Belding and Hatch's "Heat Stress Index" that included heating loads and evaporative capacities of the environment, Lee and Henschel's "Index of Relative Strain" studied the effects of clothing and Givoni's "Index of Thermal Stress" which measures the efficiency of sweat for body cooling (Belding, 1970). The majority of the heat stress scales in Table 1 are derivatives of the original ET scale.

Table 1. Partial Chronological Summary of Indices

1905 - Wet-Bulb Temperature (Haldane)
A better single indicator of physiological effect than dry-bulb temperature.

1916 - Katathermometer (Hill et al)
Rate of cooling of a previously warmed thermometer with larger bulb correlated to human body.

1923 - Effective Temperature (Houghton, Yaglou)
Combinations of WB, DB and velocity which yield equal sensations of warmth.

1937 - Operative Temperature (Winslow, Herrington, Gagge)
Uses heat transfer coefficients to reduce the effects of temperature and velocity.

1945 - Index of Physiological Effect (Robinson et al)
At 3 activity levels, describes combinations of WB and DB which impose equivalent demands of sweat.

1947 - Predicted 4 Hour Sweat Rate (McArdle et al)
Uses sweating as indicator of strain and predicts 4 hour rates for combinations of temperature and air speed.

1955 - Heat Stress Index (Belding & Hatch)
Uses ratio of heat load and evaporative capacity of environment.

1957 - Discomfort Index (Thom)
Objective to determine air-conditioning loads from weather data.

1963 - Index of Relative Strain (Lee & Henschel)
Rationalization of effects of clothing.

1963 - Index of Thermal Stress (Givoni)
Predicts sweat from heat load, clothing and humidity on efficiency of sweating to cool the body.

1965 - Heat Strain Predictive System (Lustinec)
Predicts heat stress index under effects of clothing.

Each of the formulas are based on the theory that an index number, representing a level of climatic comfort or stress, can be calculated using mathematical models. This is a very complex and at times difficult task since human thermal comfort is in itself an intricate physiological function. The mathematical information is then used to formulate "bioclimatic" charts which graphically depict a range of comfort under different climate profiles.

2.5 Predicting Behavior

Trying to predict usership in designed spaces is one of the difficult tasks that designers encounter during the design process. What attracts people to a space? What factors influence people to remain in a space for any length of time? How many people can be in this space at the same time? What is the best arrangement of seating to encourage social interactions? This information, and much more, is important if the designer is to make sound decisions in determining the size, orientation, furnishing and arrangement of space. Numerous variables are involved such as the amount of people in the immediate vicinity at any given moment or the strength of attraction of the design amenities within a place.

Mathematical formulas and models are currently used by planners and builders to determine the necessary amount of user space required in certain situations. Many formulas are based on the amount of overall floor space in a facility - outdoor public space must be a certain percentage, set by city planners, of the total floor space. While these formulas provide outdoor public space, it does not necessarily guarantee quality useable open space. A majority of these models and formulas predict neither the amount of people that could use a space nor the types of behavior that could occur. However, some research has been done that relates the qualities of urban open space to usership. William Whyte (1980) has shown that the number of users can be increased in urban areas with the incorporation of certain design elements, such as water features, food vendors and seating, which act as "attractors."

2.6 Thermal Comfort and Behavior Prediction

The ability to predict behavior with thermal comfort formulas and bio-climatic charts has major significance in the design professions. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has used this type of information to establish building performance standards for indoor environments. These comfort range standards have allowed for efficient design and operation of offices and homes. In terms of outdoor urban spaces, the question becomes, is it possible to use similar comfort models to dictate design guidelines for users and pedestrians of outdoor spaces? The assertion of the comfort models is for interior environments where exposure to constant climatic conditions is over a prolonged period of time (Bork & Watts, 1985). Many of these models, however, have been readapted by researchers to include the outdoor environment even though exposure to climatic conditions is variable. While in interior environments, where conditions are easily manipulated through a variety of mechanical means, it is appropriate to determine at what comfort levels will optimal performance occur. It is more pertinent in exterior settings to determine what types of activities will or will not occur at specific climatic profiles (Song, 1987). The purpose of this study is to try to determine the model climatic profile for specific activity types using a mathematical comfort model.

Thermal comfort can be an aim in itself in line with other common demands for human well-being, but it can also be considered from the point of view of behavioral effectiveness. The relationship between user behavior and comfort involves a wide range of intricate and multifarious variables. Numerous investigations have been made to determine the influence of the thermal environment on man's performance of perceptual, intellectual and manual tasks. Even though the results of these investigations are not entirely unambiguous, it seems reasonable to presume that human performance, in general, is optimal when man is in thermal comfort or under mild thermal stress (Bell & Greene, 1982; Bell, 1981; Bell & Baron, 1974). The primary focus of these investigations has been under working conditions and in controlled environments; very little research has been completed on either leisure activities or in outdoor, uncontrolled environments.

2.7 Tools for Working Outdoors

Recent studies have found that the different climatic factors and their relationships to individual people can determine the type, frequency and duration of activity in outdoor spaces (Arens and Bosselmann, 1989; Song, 1987; Bork and Watts, 1985). If comfortable enough, a person may stop, sit and chat with friends, play or read a book outside. If unpleasant, a person may simply pass through a space on the way to a final destination. Research conducted at universities and laboratories, including Virginia Polytechnic Institute, have attempted to reduce complex climatic conditions of outdoor environments to a single measurable variable, or index, and relate it to social human behavior. This project tests the theory of model based behavior prediction by using an established indexing formula and bioclimatic chart.

In earlier studies conducted at Virginia Polytechnic Institute, which used Givoni's "Index of Thermal Stress" scale, it was concluded that as the stress index rises and falls, it becomes possible to predict the level of activity that may occur in an outdoor space (Song, 1987; Bork and Watts, 1985). The conclusions of these projects serves as the starting point for in this investigation which uses the same stress scale.

The findings of Song (1987), and Bork and Watts (1985) are related to results found in two (2) investigations observing wind effects on pedestrian behavior in downtown urban settings conducted by Cohen et. al. (1977) and Tacken (1989). Cohen's study concluded that a negative relationship exists between strong wind patterns in downtown Boston and certain types of pedestrian behavior. These conclusions were reaffirmed in Tacken's study which was conducted over a three (3) year period in the Netherlands. This study, in addition to supporting the 1977 study, concluded that a wind velocity reduction to four or five feet per second or less, in an urban environment, "would remove a share of the negative effects of the wind on the relaxation function of the city" (Tacken, 1989).

This study replicates and expands the earlier studies by Song (1987) and Bork and Watts (1985) by using the same mathematical model, Givoni's Index of Thermal Stress, and comparing its proficiency in predicting optional behavior with that of bioclimatic charts. While the previous studies observed outdoor behavior on the Virginia Polytechnic Institute campus, this investigation was conducted in a downtown urban environment. This research was directed over an entire annual cycle of climate variations, whereas the previous studies sampled behavior over the course of a few months. The three investigations together begin to develop a basis for the evolution of a behavior predictive model based on climatic profiles for outdoor environment.

3.0 MODELS FOR PREDICTING THERMAL COMFORT

The models chosen for analysis in this project include an indexing formula, the Index of Thermal Stress (ITS), and two (2) bioclimatic charts. The ITS formula is used in this study since previous research has begun to establish conclusive baseline data for developing a predictive model for optional behavior in outdoor spaces. The reuse of this formula builds upon these earlier conclusions and establishes validity for the findings through replication. The bioclimatic charts used here are well recognized and utilized in the design and engineering professions. Viktor Olgyay established his human comfort chart as a means of interpreting the desirability of climate change through design (Olgyay, 1963). After nearly thirty (30) years, this work remains an acceptable standard for architectural and engineering climate mitigation. The second bioclimatic chart in this project was developed by the same researcher who developed the ITS formula, Baruch Givoni, making sense that the two are considered together.

3.1 Index of Thermal Stress

Numerous formulas for summarizing the combined effects of two or more variables exist. Over the past few years, several studies comparing climate and behavior data have used the Index of Thermal Stress (ITS) as developed by Baruch Givoni in the mid-1960's. The premise of this formula is that sweating is an appropriate measure of heat stress. The ITS is suitable for measuring the contributions of several metabolic and climatic factors that impose simultaneous physiological strain on working and resting individuals (Givoni, 1969).

The ITS formula calculates a ratio between the required sweat rate and the potential for evaporative heat loss resulting from evaporation of sweat. This ratio is used as a correction factor for the efficiency of evaporative cooling in a particular clothing that is worn (Givoni, 1969). The index number is then calculated by multiplying the required evaporative cooling sweat rate by the reciprocal of the efficiency factor. Negative values of the ITS are indications of cold stress (Givoni, 1969) interpreted as "theoretical condensation that would have to occur on the body surface to maintain equilibrium" (Song, 1987). The importance of the ITS, as applied in this study, is the variability of the index value over the course of a year as it relates to observed optional behavior, not the actual measure of heat exchange for a human subject.

The general formula for the Index of Thermal Stress is:

$$S = \frac{[(M-W)+C+R]}{f}$$

where:

S = required sweat rate, in equivalent Kcal/hr

M = metabolic rate, Kcal/hr

W = metabolic energy converted into work, Kcal/hr

C = convective heat exchange, Kcal/hr

R = radiant heat exchange, Kcal/hr

f = cooling efficiency of sweating, dimensionless.

The metabolic heat production (M - W) is the difference between the metabolic rate and the energy converted into work. The work load (W) is assumed, by Givoni, to be an efficiency of 20% energy produced above the resting level of 100 kcal/hr metabolic rate. In the calculations for this research, all observed behavior was assumed to be at rest (everybody was sitting!) with no energy being transformed into work, except to eat lunch, thus M equals 100 Kcal/hr and W equals 0 Kcal/hr. The metabolic heat production portion of the above formula becomes (M - W) = (100 - 0) = 100 Kcal/hr.

Convective heat exchange (C) is computed by:

$$C = a * V^{0.3} * (t - 35)$$

where:

a = coefficient depending on clothing type

V = air velocity in meter/second

t = air temperature in C

The values for "a", for different types of clothing are shown in Table 2 as calculated by Givoni. For this research, coefficient values for all clothing variables is held constant for "light summer clothing" according to the table.

The radiant heat load due to solar radiation (R) is computed according to the formula:

$$R = I * K_{pe} * K_{cl}[1 - \alpha(V^{0.2} - 0.88)]$$

where:

I = solar intensity, Kcal/hr

Kpe = coefficient for posture and terrain

Kcl, a = coefficients for clothing type

V = wind speed, meters/second.

Values for clothing type are, again, taken from Table 2 for light summer clothing. The posture/terrain coefficient is from Table 3 also calculated by Givoni. It was assumed for this research that all subjects are sitting in the desert since all subjects are sitting and the terrain is an open concrete plaza - the urban desert.

The cooling efficiency of sweating (f) is the ratio of the evaporative cooling of sweat (E) to the latent heat of the sweat secreted (S), or E/S. The reciprocal of f (1/f) is multiplied by the required evaporative cooling sweat rate to produce the index number. 1/f is computed by:

$$\frac{1}{f} = e^{0.6}\left(\frac{E}{Emax^{-0.12}}\right)$$

where:

E = (M - W) ± C ± R, Kcal/hr

Emax = p * V^0.3 (42 - VP), Kcal/hr

and where:

p = coefficient depending on clothing

V = air velocity, meter/second

42 = vapor pressure of skin at 35 C

VP = vapor pressure of air, mm Hg.

Table 2. Clothing Coefficients for ITS Formula

Clothing	Coefficient			
	a	Kcl	a	p
Semi-nude: bathing suit and hat	15.8	1.0	0.35	31.6
Light summer clothing: underwear, short sleeve shirt, long trousers, hat	13.0	0.5	0.52	20.5
Military overalls over shorts	11.6	0.4	0.52	13.0

Source: Givoni, B., Man, Climate and Architecture, 1976)

Table 3. Solar Load Coefficients for Posture and Terrain

Posture	Terrain	Kpe
Sitting with back to sun	Desert	0.386
	Forest	0.379
Standing with back to sun	Desert	0.306
	Forest	0.266

The detailed general formula of the ITS becomes:

$$S = [(M-W)+aV^{0.3}(t-35)=I*K_{pe}*K_{cl}(1-\alpha(V^{0.2}-0.88))]\,e^{0.6}\left(\frac{E}{Emax^{-0.12}}\right)$$

A program to calculate the ITS value was developed using the BASIC programming language. A copy of the program appears in Appendix A at the end of this report.

3.2 Bioclimatic Charts

Like the development of the indexing formulas, over the years several researchers have developed charts on which climate conditions, namely temperature and humidity, can be plotted to allow designers to determine what types of corrective measures are needed to restore comfort conditions. These are often referred to as bioclimatic or comfort charts. One of the earliest and most often used comfort charts was established by Viktor Olgyay in the early 1960's (Figure 1). Similar bioclimatic charts have been developed, over the years, by numerous researchers, including Givoni (Figure 2). Both Olgyay's and Givoni's chart predict a "comfort zone" where people no longer have to adjust themselves physiologically or psychologically to maintain thermal comfort. These comfort zones can be adjusted for different clothing types and metabolic rates and expanded to encompass larger variation in climate profiles by mitigating the different climate factors, namely wind and solar radiation where solar radiation provides warmth in cool months and wind cools during warmer seasons. For the purposes of this research, the comfort charts used correspond closely to the ITS formula in that the metabolic rate is the same and the clothing coefficients represent similar clothing types. Further discussion of the use of bioclimatic charts can be found in the section 5.0.

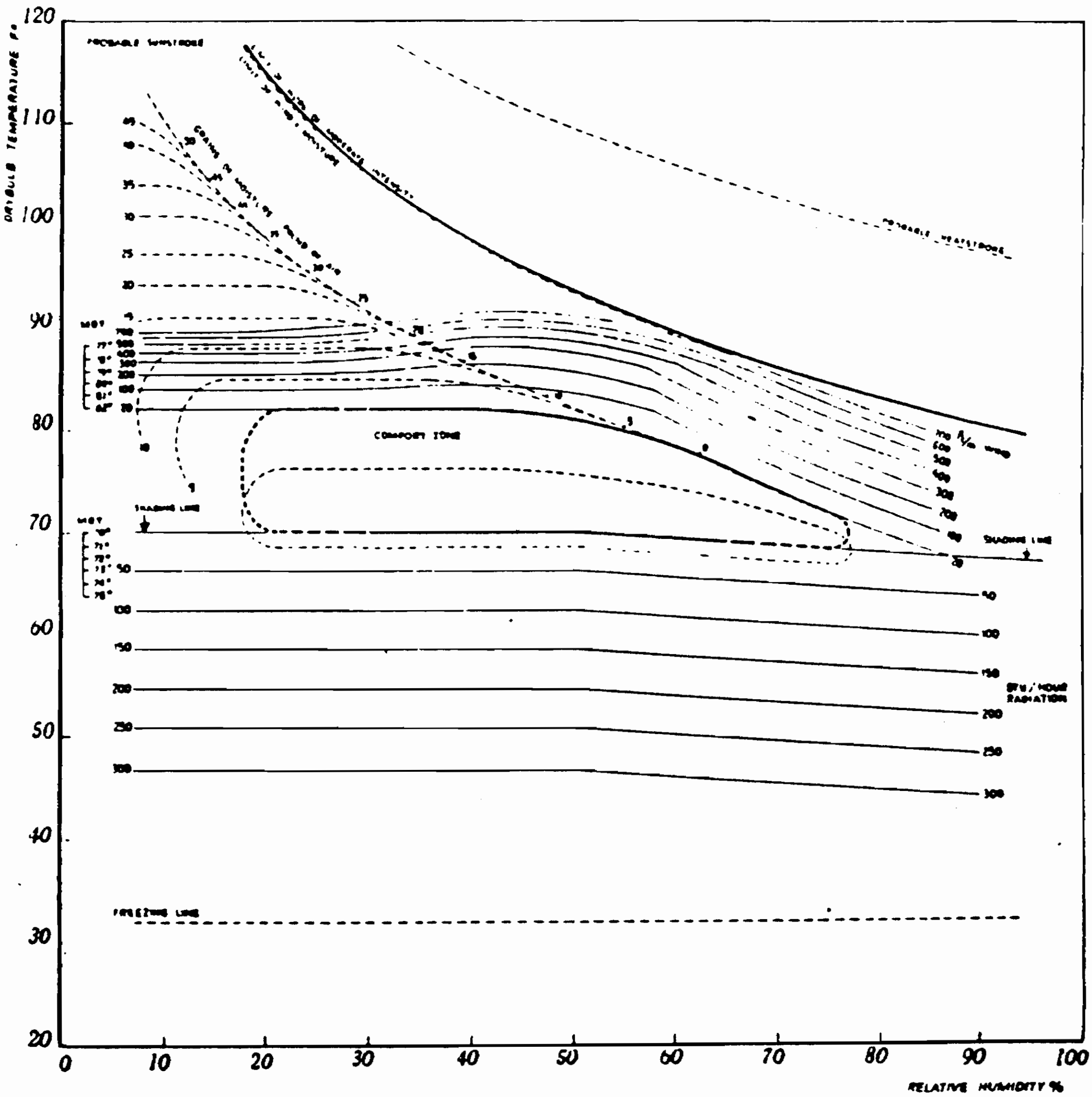
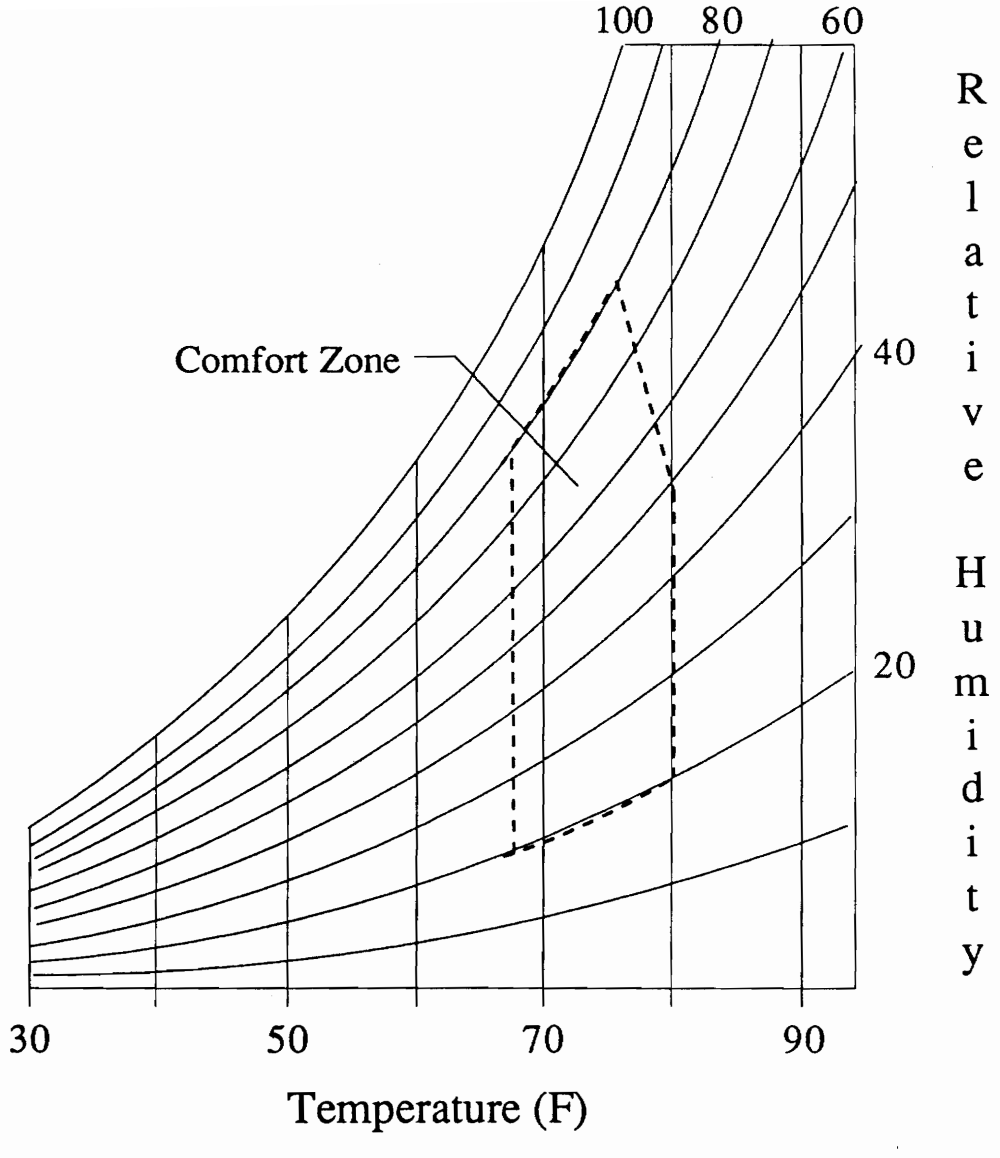


Figure 1. Olgyay's Bioclimatic Chart



Bioclimatic chart represents:
Metabolic rate = 1.0 (sitting, relaxed)
Clothing value = 0.8 (summer work clothing)

Figure 2. Givoni's Bioclimatic Chart (Summer Conditions)

4.0 METHODOLOGY

Since the long term objective of this work is to assess the feasibility of developing a model to assist in the evaluation of alternative designs, in terms of climatic factors, for urban spaces, it was essential that the site for this investigation be located in an urban environment. Although earlier works in this region have studied behavior on a particular plaza, the built environment surrounding the plaza and its effect on climatic conditions was not considered.

In southwest Virginia, where this university is located, the nearest urban environment is the City of Roanoke, with a population of nearly 100,000. The City of Roanoke serves as the business, financial and transportation center for the southwestern portion of Virginia. Roanoke is considered, by some urban standards, to be a "small" city; nonetheless, its characteristics are similar to other urban areas. The central business district is similar to many other urban centers with tall office buildings, and grid-type street patterns, which affect building and open space orientations.

4.1 Site Selection

An indepth analysis of downtown Roanoke was conducted to determine if any of its outdoor spaces could serve as a research site. Three (3) areas of criteria - logistics, climatic and behavioral - were developed and served as a site selection and analysis guide.

Behaviorally, the site had to encourage climate dependent, or optional, behavior activities. A qualifying area would serve as a gathering space with adequate seating where people would leisurely stop for a substantial amount of time. The climatic criteria essentially was that the plaza had to be exposed to the weather, included plenty of exposure to direct sunlight and a good sun/shade pattern. Logistically, the site had to be visually accessible for a video camera either from a nearby office or other facility. Security was also a concern for both the video recording equipment, located in an office, and weather data collection apparatus, placed on the plaza itself.

The site chosen was the rear patio space of the Blue Cross/Blue Shield office building (Figures 3 and 4). This downtown building is the regional office of Blue Cross/Blue Shield of Virginia (BC/BS) with several hundred employees. The orientation and design of the plaza is such that a video camera could easily be mounted inside the building looking onto the space, shade was provided by an overhead arbor planted with a well

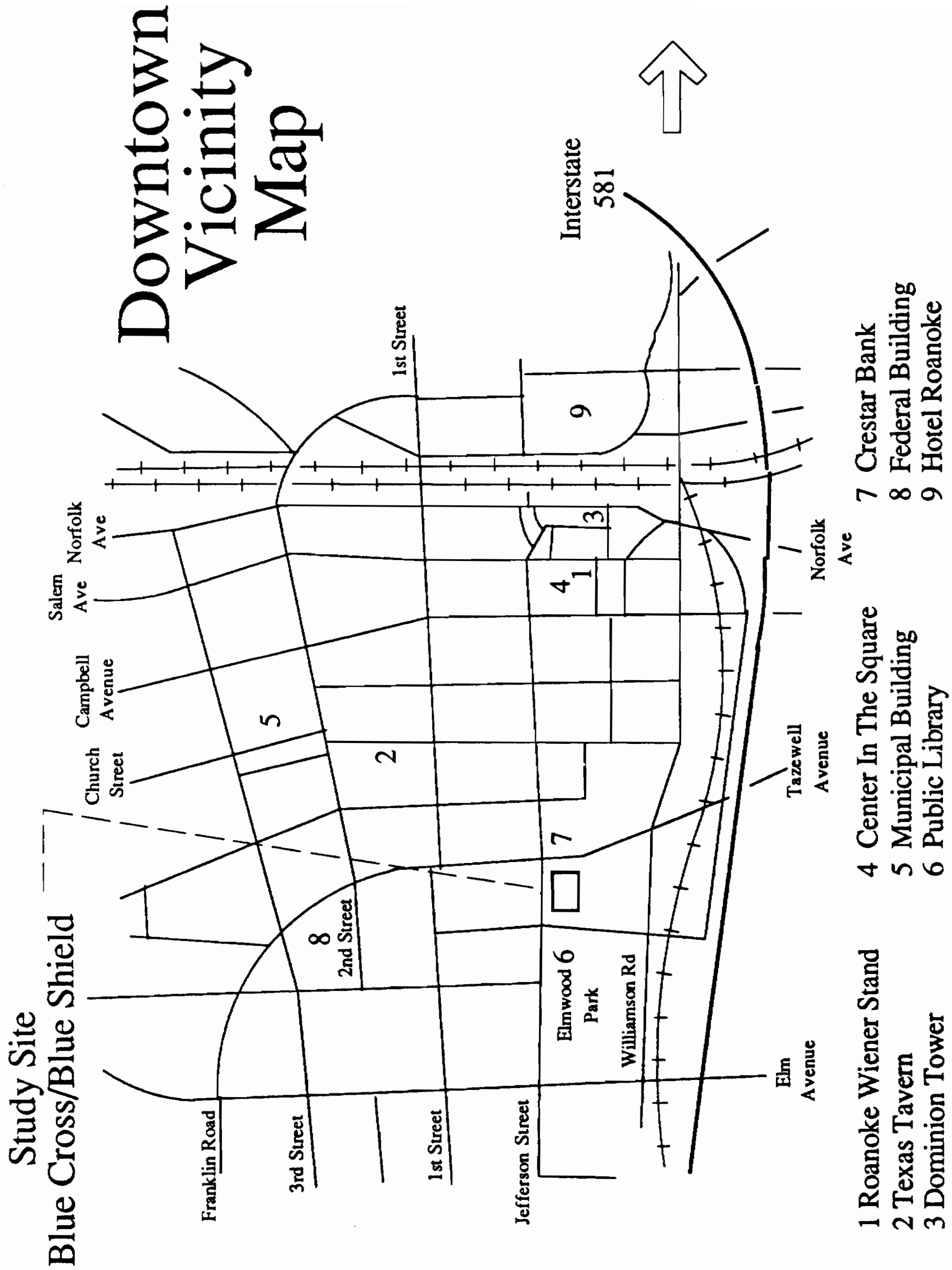


Figure 3. Downtown Roanoke Vicinity Map

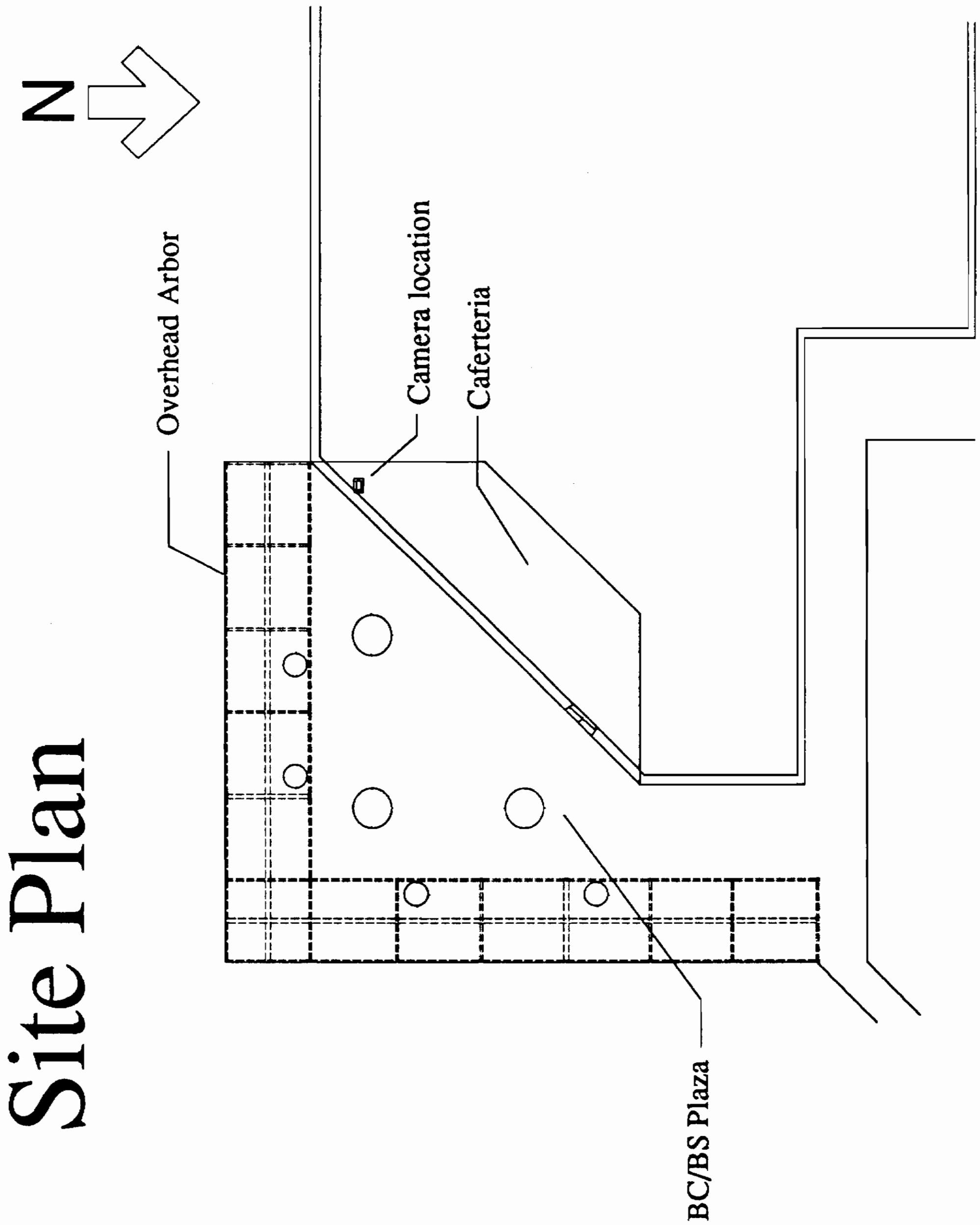


Figure 4. Site Plan - Blue Cross/Blue Shield Plaza

established Chinese Wisteria (Wisteria chinensis), 120 chairs and 30 tables are free-standing and movable, and there are no extraordinary attraction features, such as water. The location of the plaza on the southern side of the building is important in that the building itself, being nine (9) stories tall, did not cast a shadow pattern on the space. This is important, from a behavior observation viewpoint, in that the only shading is from the actual planned and designed arbor. The plaza space is accessible to both the office workers and the public; even though, the location of the site is less encouraging for public access than for the workers. The office cafeteria is located adjacent to the space with visual and physical access through a glass wall and doors; thus, the area is used by employees during lunch hours and other breaks.

After receiving permission from the executive board of BC/BS, a video recorder was installed inside the building and climatic instruments were located on the plaza itself.

4.2 Behavior Observation

Video taping was used since it provides a unobtrusive, naturalistic observation method that has been proven successful in similar climate/behavior relationship research (Song, 1987). An advantage of video over other observational techniques is that it provides significant methodological improvements to be made in the study of human behavior because it allows greater ease in the collection of data and more opportunity for repeated examination of the visual record (Summerfield, 1983).

The video camera and recorder were located inside the dining area and directed through the glass wall onto the site. This location provided security and weather protection for the video equipment over an extended period of time. The camera was located at a height of nine (9) feet above ground level. This provided restricted access, enough space for people to pass underneath the equipment inside the building without interference and produced an angle of inclination that allowed for viewing and analysis within the depth of the plaza. The cone of vision from the camera, with a wide angle lens, covered approximately sixty (60) percent of the total site (Figure 5). The area of coverage limitation was overcome by the limited points of access onto the plaza itself which allowed for users passing through the cone of vision of the camera to be accounted for, even though they were not necessarily visible during the entire observation period.

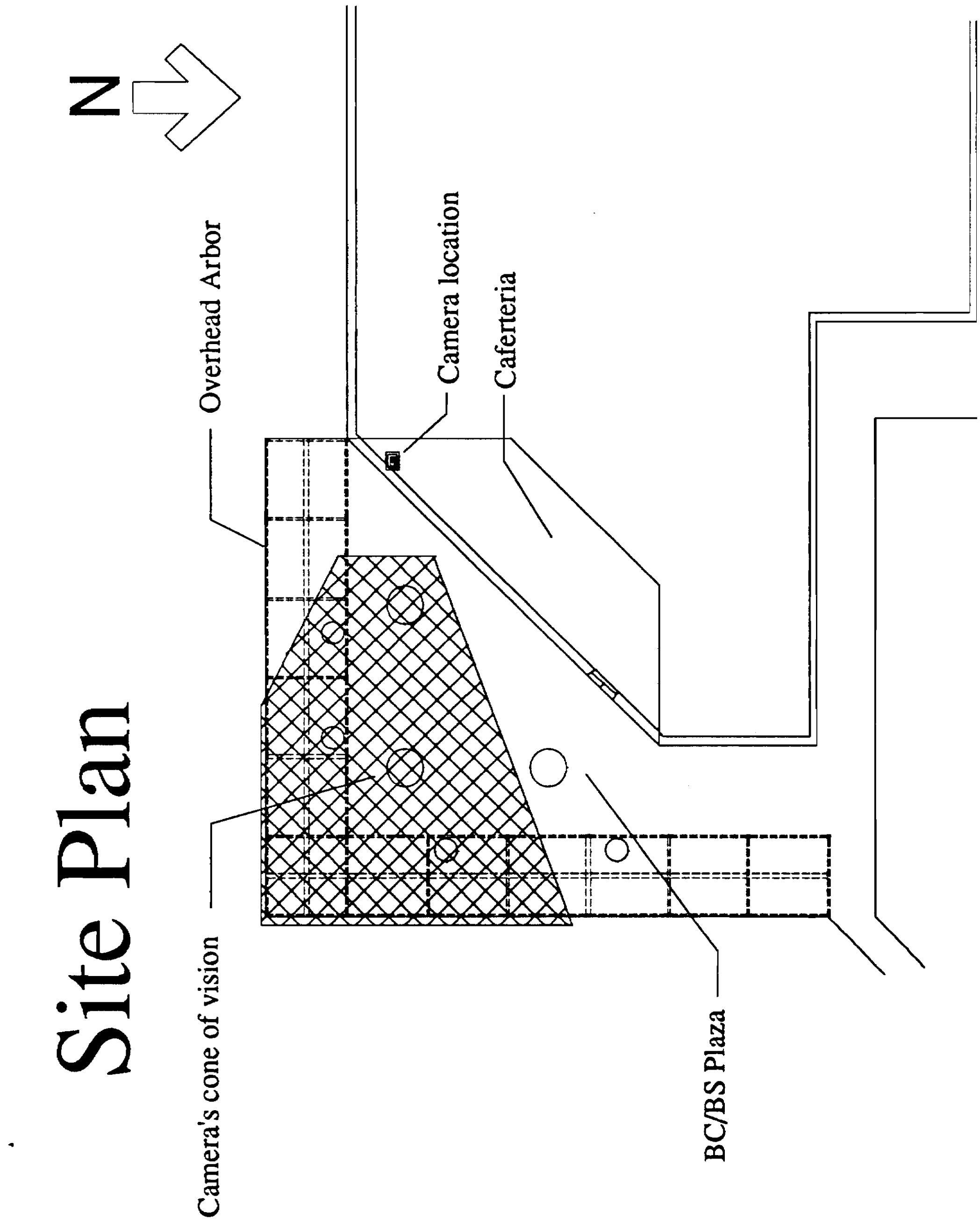


Figure 5. Video Camera Cone of Vision on Plaza

The days and time of observation were chosen based on information gathered from preliminary observations and interviews with personnel from Blue Cross/Blue Shield concerning scheduled breaks and peak hours of dining room use. Since the plaza is adjacent to and accessible from the dining area, the highest potential for use is during these times. Although the offices are open seven (7) days a week and the dining area is used from 11:00 am until 2:00 pm, the period of peak activity is Monday through Friday from 12:00 pm to 1:00 pm. The recorder was connected to a seven (7) day programming mechanism that allowed the equipment to record at specific times and intervals. Recording sessions were three (3) days per week - Monday, Wednesday, Friday - from 12:00 pm to 12:25 pm, ultimately providing 159 days of observation and a good statistical base. This investigation was conducted from 16 April, 1990 through 19 April, 1991.

Each video recording session was twenty-five (25) minutes in duration. All "optional" behavior events that occurred within the middle ten (10) minutes of the tape were measured for frequency and duration. Duration was measured in both total cumulative minutes and average minutes per person. Frequency was recorded as a simple head count of the total number of users on the plaza within the middle ten (10) minutes of taping. If a user's length of stay, or duration, began or ended within the middle ten (10) minutes, it was traced into the beginning or ending 7.5 minutes. Minimum duration was one (1) minute; maximum duration during the video session was twenty-five (25) minutes. The behavior information for each observation period - number of users, total minutes, average duration - was then correlated with the climatic data for the same period.

As each user entered into the camera's cone of vision on the plaza, behavior was categorized as either "optional" or "necessary." If the user's behavior was optional, it was counted and duration measurements begun. If a user's behavior was necessary or if could not be determined to be optional or necessary, it was disregarded in this study.

Of the 159 days of this study, 125 days were used in analysis. Thirty-four (34) days were discarded from the observation set because of video malfunctions, precipitation or special events on the plaza. One day was lost to snow on the plaza, 12 days were dropped due to rain during the observation period, 7 days eliminated because of special events, 3 days were holidays with nobody working in the office and 11 days were not accounted for due to video equipment malfunction or power outages in the building where the video equipment was set.

Days that had special events on the plaza were eliminated from the study since they skewed the behavior frequency data by introducing an extraneous variable - an attractive element. Thus, the people observed on the plaza were not necessarily drawn outside due to the climate. After being outside, people stayed on the plaza but the weather conditions were not the influencing factor to bring them out.

Of the 125 days in the analysis, 56 days (45%) had behavior observations; the remaining 69 days (55%) had no users on the plaza. The days that had people on the plaza, referred to in this report as "user days," were analyzed for the number of people (frequency) and duration of stay as observed on the video tapes. The complete data set of climatic factors and observed behavior measurements can be seen in Table 4, pages 41 through 44.

4.3 Weather Data

Climatic data for this project was collected at two (2) locations providing two (2) climatic data sets for comparison. Climatic data from the Roanoke Regional Airport, Woodrum Field, located 4.3 miles from the BC/BS plaza (Figure 6), served as the macroclimatic, or large-scale regional, information. This data was provided by the National Climatic Data Center of the National Oceanic and Atmospheric Administration and provided on an hourly basis. Site specific measurements were collected on the study plaza and were used as mesoclimatic, or small-scale site specific, data. This data was collected continuously, twenty-four (24) hours per day. The hourly data from the two (2) sites were then compared to determine what affect, if any, the surrounding built environment had on the climatic conditions of the plaza. This comparison allowed for "holes" in mesoclimate data to be filled when equipment failed. The data collected included temperature, relative humidity, solar radiation, barometric pressure, wind direction and wind speed.

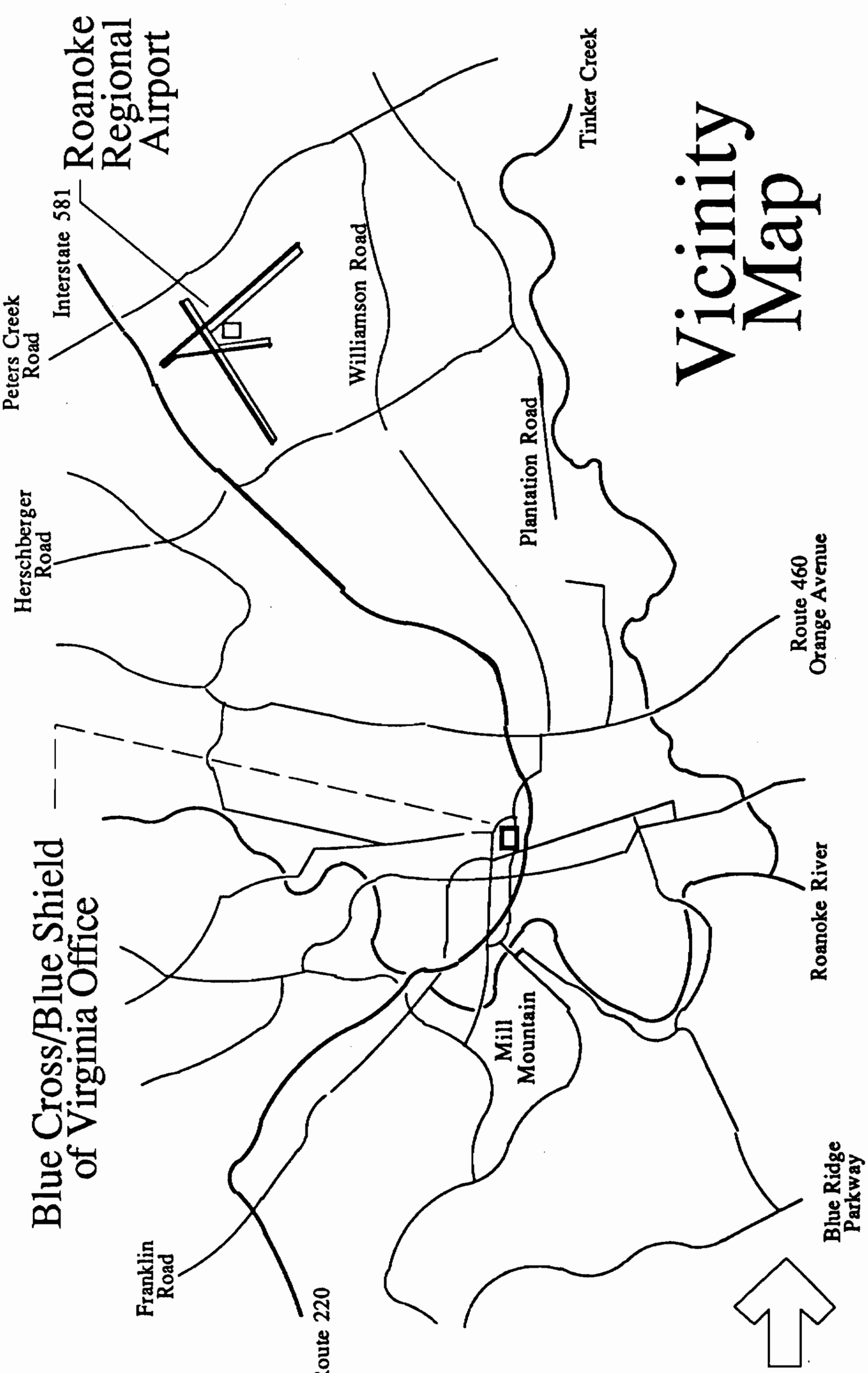


Figure 6. Roanoke Vicinity Map

The weather instruments, enclosed in a Stevenson Shield for protection, were placed on the plaza of study so that the instrument receptors were at or near user level. Since nearly all of the plaza users were seated, the collection devices were placed from eighteen (18) to thirty-four (34) inches above ground level. Due to several difficulties with equipment, which are discussed below, some mesoclimatic data was missing. Nonetheless, the data that was recorded on the plaza was compared to the readings from the Roanoke airport. The data from the plaza and the airport was then separately entered into Givoni's formula to calculate an Index of Thermal Stress (ITS) for each location. The theory and method of computation for the ITS was discussed in section 3.1 of this report. The values used in the ITS calculations corresponded to the time of day the video taping began - 12:00 pm. This index, as well as each individual climatic factor -temperature, relative humidity, solar radiation, wind speed - was compared to the behavior frequency and duration measurements from the video taping sessions.

The equipment used to collect climatic data was borrowed from several different departments within the university community. Obtaining permission and clearance from the various departments for the use of their equipment for a one (1) year period, was difficult and time consuming. As a result, the instruments were not on the plaza until five (5) months after the video taping had begun. Due to initial calibration periods, recalibration and repair time of some of the equipment, the period of climate data collection on the BC/BS plaza is incomplete. Manufacturing delays in a new anemometer resulted in the collection of wind data for the plaza being delayed another four (4) months. Thus, the comparison of macro- and mesoclimatic data was necessary.

4.4 Data Analysis: Behavior versus Climate

Each climatic factor - temperature, relative humidity, wind speed, solar radiation and barometric pressure - and the ITS were plotted against the behavior data - frequency and duration - to determine the strength of the relationships. A statistical method, univariant regression analysis, was used to determine the strength or weakness of the relationships between the climate factors, the ITS values and observed behavior. A chi square test was used to evaluate the reliability of the sampling method. Histograms, or bar charts, allowed for the analysis and determination of behavior threshold levels for different heat stress levels. The resulting appraisals from these analysis can be found in the "Results" section of this report.

5.0 RESULTS

5.1 Airport versus Downtown Climate Conditions

Over the last eight (8) months of this study, weather data was collected on the study site and obtained for the entire year from the regional airport. These two data sets measured essentially the same variables for the respective locations. A statistical comparison of the two data sets, airport versus downtown, allowed for the filling of holes in the study site data which resulted from various technical and logistical problems.

Both collection sites recorded the climate information continuously every day. The record of the climate conditions at 12:00 pm were compared to one another to determine what relationships, if any, existed between the two sites. The noon time comparison was used since it corresponded with the beginning of the behavior observation period on the BC/BS plaza.

Charts for the recording devices were changed once per week. Occasionally, recording devices would run out of chart paper or the paper would come off track and jam the inside of the recording mechanism; or a recorder would not be turned on after charts had been changed resulting in lost data.

Statistical expansion of the site specific data was possible through a regression analysis determining the correlations, Y-intercepts and the slope of the regression lines. With this appraisal, it was possible to fill in all the blank data periods except for wind speed. The airport climate data and the related, completed site specific data is shown in Table 4. The general relationships between the climatic factors at the airport and downtown is discussed below.

In comparing the two sets of climate measurements, it is possible to observe the effects the downtown setting has on the mesoclimate. Temperature and solar radiation tended to be higher downtown than at the airport. This was anticipated due to the "urban heat island" phenomenon. Because of the nature of the construction materials, radiant heat from the buildings and roads will increase temperature readings in a downtown setting. During this study, at 12:00 p.m., the mean temperature difference was 1.7 degrees centigrade higher on the plaza than at the airport. A correlation value of 0.9607 indicates a strong relationship between temperatures at the two sites. To establish the temperature for blank data days on the BC/BS plaza, 1.7 degrees was added to the temperature reading from the airport.

Likewise, solar radiation also has a strong correlation between the two sites ($r = 0.9546$). The same construction materials that affected temperature downtown, also have reflective properties that slightly increased radiation levels on the average of 0.05 langleys/minute.

Table 4. Climate and Behavior Data   Note: All data for 12:00 pm

DATE	DAY	TEMPERATURE (C) Airport	BC/BS	WIND VELOCITY (KmPH) Airport	BC/BS	RELATIVE HUMIDITY Airport	BC/BS	SOLAR INSOLATION (Langs/min) Airport	BC/BS	BAROMETRIC PRESSURE (inHg)	INDEX OF THERMAL STRESS Airport	BC/BS	PLAZA BEHAVIOR TOTAL USERS	TOTAL USER DURATION	AVERAGE USER DURATION	SEATED ORIENTATION SUN	SHADE	DAYS
Apr 16 1990	M	19.8	21.5	13.0	3.0	68%		1.15	1.20	28.78	-8.7	132.6	7	166	24	6	1	1
Apr 18 1990	W	10.6	12.3	13.0	3.0	32%		1.36	1.36	29.17	-130.7	62.1	0					2
Apr 20 1990	F	17.2	18.9	5.6	3.0	52%		0.94	0.99	29.12	0.3	74.9	0					3
Apr 23 1990	M	24.4	26.1	14.8	3.0	42%		1.33	1.38	28.86	78.9	206.3	0					4
Apr 25 1990	W	28.3	30.0	18.5	3.0	37%		1.14	1.19	28.89	100.6	218.1	20	286	14			5
Apr 27 1990	F	28.3	30.0	5.6	3.0	37%		1.24	1.29	28.78	179.2	232.9	2	14	7	0	3	6
Apr 30 1990	M	17.2	18.9	11.1	3.0	81%		1.26	1.31	28.68	-16.5	122.3	0					7
May 02 1990	W	20.0	21.7	5.6	3.0	62%		0.71	0.76	28.90	8.1	69.5	6	106	18	4	2	8
May 04 1990	F	18.3	20.0	20.4	3.0	90%		0.41	0.46	28.87	-166.3	7.6	0					9
May 07 1990	M	18.9	20.6	14.8	3.0	40%		1.33	1.38	28.85	-14.9	150.1	6	95	16	6	0	10
May 09 1990	W	22.2	23.9	29.6	3.0	54%		0.87	0.92	28.82	-78.1	115.7	5	80	16	5	0	11
May 11 1990	F	17.8	19.5	18.5	3.0	35%		1.35	1.40	28.79	-53.7	141.8	30	603	20	23	7	12
May 14 1990	M	22.8	24.5	11.1	3.0	50%		1.24	1.29	28.89	62.7	176.7	0					13
May 16 1990	W	27.8	29.5	22.2	3.0	59%		1.00	1.05	28.75	68.3	192.3	3	35	12	0	3	14
May 18 1990	F	22.2	23.9	33.3	3.0	24%		1.35	1.35	28.74	-41.9	186.8	6	127	21	6	0	15
May 21 1990	M	24.4	26.1	13.0	3.0	56%		1.23	1.28	28.60	73.9	191.5	1	14	14	1	0	16
May 23 1990	W	22.2	23.9	0.0	3.0	53%		0.76	0.81	28.79	197.0	99.4	0					17
May 25 1990	F	17.2	18.9	5.6	3.0	73%		0.19	0.24	28.91	-101.3	-36.3	0					18
May 28 1990	M	13.9	15.6	5.6	3.0	100%		0.16	0.21	28.64	-146.90	-74.6	0					19
May 30 1990	W	19.4	21.1	16.7	3.0	56%		1.12	1.17	28.75	-45.9	124.1	0					20
Jun 01 1990	F	20.6	22.3	14.8	3.0	66%		1.10	1.15	29.01	-17.5	133.4	8	128	16	0	8	21
Jun 04 1990	M	22.8	24.5	22.2	3.0	53%		1.01	1.06	28.61	-20.1	142.6	2	27	14	2	0	22
Jun 06 1990	W	26.7	28.4	7.4	3.0	51%		1.29	1.34	28.81	154.2	223.9	5	54	11	0	6	23
Jun 08 1990	F	29.4	31.1	0.0	3.0	59%		1.12	1.17	28.89	247.0	226.4	8	124	16	0	8	24
Jun 11 1990	M	22.8	24.5	14.8	3.0	46%		1.20	1.25	28.82	37.3	170.7	6	134	22	6	0	25
Jun 13 1990	W	23.9	25.6	7.4	3.0	54%		1.02	1.07	28.94	79.1	155.3	1	13	13	1	0	26
Jun 15 1990	F	22.8	24.5	0.0	3.0	87%		0.24	0.29	28.70	118.3	28.5	0					28
Jun 18 1990	M	27.8	29.5	20.4	3.0	74%		1.10	1.15	28.69	81.1	207.1	2	20	10	0	2	27
Jun 20 1990	W	27.2	28.9	11.1	3.0	49%		1.19	1.24	28.70	119.6	214.3	8	141	18	0	8	29
Jun 22 1990	F	23.3	25.0	14.8	3.0	68%		1.01	1.06	28.67	23.0	147.7	9	175	19	2	7	30
Jun 25 1990	M	25.6	27.3	5.6	3.0	43%		1.23	1.28	28.87	145.2	203.8	7	118	17	3	4	31
Jun 27 1990	W	30.0	31.7	0.0	3.0	44%		1.23	1.28	28.82	259.7	248.8	5	89	18	1	4	32
Jun 29 1990	F	31.1	32.8	22.2	3.0	47%		1.03	1.08	28.84	136.4	230.5	3	42	14	1	2	33
Jul 02 1990	M	25.0	26.7	16.7	3.0	45%		1.25	1.30	28.77	66.8	200.6	2	43	22	2	0	34
Jul 04 1990	W	31.7	33.4	18.5	3.0	46%		1.22	1.27	28.87	169.1	264.7	0					35
Jul 06 1990	F	30.6	32.3	14.8	3.0	50%		0.63	0.68	28.74	94.8	166.1	0					36
Jul 09 1990	M	33.3	35.0	11.1	3.0	50%		1.17	1.22	28.86	211.1	273.7	3	56	19	0	3	37
Jul 11 1990	W	33.3	35.0	13.0	3.0	52%		1.18	1.23	28.78	204.4	275.2	6	90	15	0	6	38
Jul 13 1990	F	26.7	28.4	25.9	3.0	72%		0.93	0.98	28.82	29.5	170.6	4	56	14	0	4	39
Jul 16 1990	M	27.2	28.9	9.3	3.0	47%		1.28	1.33	29.01	147.0	227.6	8	140	18	2	6	40
Jul 18 1990	W	28.9	30.6	11.1	3.0	58%		1.20	1.25	29.01	152.3	233.1	0					41

Table 4 (continued). Climate and Behavior Data

													PLAZA BEHAVIOR					
		TEMPERATURE (C)		WIND VELOCITY (KmPH)		RELATIVE HUMIDITY		SOLAR INSOLATION (Langs/min)		BAROMETRIC PRESSURE (inHg)	INDEX OF THERMAL STRESS		TOTAL USERS	TOTAL USER DURATION	AVERAGE USER DURATION	SEATED ORIENTATION		DAYS
DATE	DAY	Airport	BC/BS	Airport	BC/BS	Airport	BC/BS	Airport	BC/BS		Airport	BC/BS				SUN	SHADE	
Jul 20 1990	F	29.4	31.1	11.1	3.0	59%		1.07	1.12	28.87	143.8	219.0	2	38	19	0	2	42
Jul 23 1990	M	28.3	30.0	18.5	3.0	57%		0.87	0.92	28.69	70.1	178.1	3	47	16	1	2	43
Jul 25 1990	W	27.8	29.5	11.1	3.0	50%		1.17	1.22	28.94	129.2	217.4	0					44
Jul 27 1990	F	28.3	30.0	18.5	3.0	50%		1.34	1.35	28.95	126.7	247.7	1	18	18	0	1	45
Jul 30 1990	M	28.3	30.0	9.3	3.0	62%		1.19	1.24	28.74	151.2	225.5	12	225	19	3	9	46
Aug 01 1990	W	25.0	26.7	9.3	3.0	48%		1.17	1.22	28.87	99.0	188.8	3	42	14	0	3	47
Aug 03 1990	F	27.8	29.5	13.0	3.0	55%		1.08	1.13	28.88	112.5	204.1		NO DATA				48
Aug 06 1990	M	24.4	26.1	13.0	3.0	85%		0.40	0.45	28.77	-33.3	68.6		NO DATA				49
Aug 08 1990	W	23.9	25.6	9.3	3.0	60%		0.58	0.63	28.94	9.3	90.1		NO DATA				50
Aug 10 1990	F	26.1	27.8	9.3	3.0	59%		1.23	1.28	28.83	120.8	208.9		NO DATA				51
Aug 13 1990	M	28.9	30.6	18.5	3.0	59%		1.08	1.13	28.86	109.6	215.4		NO DATA				52
Aug 15 1990	W	26.7	28.4	22.2	3.0	73%		0.82	0.87	28.88	52.3	154.4		NO DATA				53
Aug 17 1990	F	26.7	28.4	0.0	3.0	66%		1.18	1.23	28.91	278.1	207.7		NO DATA				54
Aug 20 1990	M	30.6	32.3	14.8	3.0	66%		1.11	1.16	28.88	141.5	237.2		NO DATA				55
Aug 22 1990	W	20.6	22.3	7.4	3.0	95%		0.29	0.34	28.84	-70.2	13.4		NO DATA				56
Aug 24 1990	F	23.9	25.6	11.1	3.0	87%		1.27	1.32	28.85	84.5	192.3		NO DATA				57
Aug 27 1990	M	30.6	32.3	11.1	3.0	53%		1.16	1.21	28.83	160.8	244.6	3	63	21	0	3	58
Aug 29 1990	W	27.2	28.9	22.2	3.0	58%		0.71	0.76	28.65	21.7	143.2	9	171	19	0	9	59
Aug 31 1990	F	24.4	26.1	14.8	3.0	59%		0.90	0.95	28.92	34.7	147.1	0					60
Sep 03 1990	M	28.7	30.4	14.8	3.0	56%		1.21	1.26	28.92	120.5	232.6	11	224	20	0	11	61
Sep 05 1990	W	27.2	28.9	5.6	3.0	56%		1.10	1.15	28.92	144.5	200.9	0					62
Sep 07 1990	F	32.2	33.9	13.0	3.0	48%		1.22	1.27	28.65	192.0	269.8	11	190	17	0	11	63
Sep 10 1990	M	27.2	28.9	13.0	3.0	55%		1.04	1.09	28.87	92.0	192.1	7	131	19	0	7	64
Sep 12 1990	W	26.7	28.4	9.3	3.0	67%		0.41	0.50	28.95	30.6	143.9	7	138	20	2	5	65
Sep 14 1990	F	26.1	27.8	13.0	3.0	63%	60%	0.94	1.07	28.74	64.1	177.8		NO DATA				66
Sep 17 1990	M	18.3	19.4	25.9	3.0	42%	48%	1.34	1.20	28.94	-77.7	96.3	0					67
Sep 19 1990	W	16.1	15.6	13.0	3.0	95%	96%	0.38	0.30	28.82	-164.2	-61.2	0					68
Sep 21 1990	F	19.4	16.7	13.0	3.0	74%	72%	0.52	0.77	28.91	-99.3	19.7	2	30	15	2	0	69
Sep 24 1990	M	16.1	16.1	14.8	3.0	47%	44%	1.25	1.30	28.88	-72.7	92.1	0					70
Sep 26 1990	W	23.3	22.8	18.5	3.0	50%	48%	1.22	1.27	28.64	20.1	156.3	0					71
Sep 28 1990	F	22.2	20.6	11.1	3.0	63%	62%	1.07	1.12	28.97	29.5	111.5	4	73	18	0	4	72
Oct 01 1990	M	19.4	16.7	11.1	3.0	54%	65%	1.18	1.23	28.89	4.9	87.9	2	38	19	2	0	73
Oct 03 1990	W	20.6	15.6	16.7	3.0	55%	60%	1.27	1.32	29.08	-4.4	89.9	10	173	17	5	5	74
Oct 05 1990	F	23.8	22.8	11.1	3.0	43%	46%	1.18	1.23	28.96	68.8	150.4	5	84	17	0	5	75
Oct 08 1990	M	22.8	23.8	0.0	3.0	83%		0.97	0.77	28.95	225.7	64.8	0					76
Oct 10 1990	W	22.8	24.1	20.4	3.0	76%		0.67	0.65	28.81	-57.7	13.2	0					77
Oct 12 1990	F	22.2	18.2	9.3	3.0	88%		0.79	0.98	28.78	6.9	44.7	0					78
Oct 15 1990	M	21.7	22.8	24.1	3.0	54%		1.07	0.89	28.79	-49.8	100.0	2	44	22	2	0	79
Oct 17 1990	W	19.4	18.8	18.5	3.0	66%		1.05	1.00	29.05	-63.7	70.2	2	34	17	2	0	90
Oct 19 1990	F	12.8	12.8	20.4	3.0	49%		1.10	1.24	28.88	-185.5	43.3	2	12	6	2	0	81
Oct 22 1990	M	13.3	13.8	5.6	3.0	100%	100%	0.84	0.89	28.83	-57.2	-2.4	0					82

Table 4 (continued). Climate and Behavior Data

DATE	DAY	TEMPERATURE (C) Airport	TEMPERATURE (C) BC/BS	WIND VELOCITY (KmPH) Airport	WIND VELOCITY (KmPH) BC/BS	RELATIVE HUMIDITY Airport	RELATIVE HUMIDITY BC/BS	SOLAR INSOLATION (Langs/min) Airport	SOLAR INSOLATION (Langs/min) BC/BS	BAROMETRIC PRESSURE (inHg)	INDEX OF THERMAL STRESS Airport	INDEX OF THERMAL STRESS BC/BS	PLAZA BEHAVIOR TOTAL USERS	PLAZA BEHAVIOR TOTAL USER DURATION	PLAZA BEHAVIOR AVERAGE USER DURATION	SEATED ORIENTATION SUN	SEATED ORIENTATION SHADE	DAYS
Oct 24 1990	W	17.2	17.8	11.1	3.0	43%	32%	0.78	0.83	28.67	-77.0	39.9	1	17	17	1	0	83
Oct 26 1990	F	10.0	11.1	29.6	3.0	43%	36%	0.22	0.27	28.70	-403.3	-111.8	0					84
Oct 29 1990	M	13.3	12.8	13.0	3.0	31%	37%	0.60	0.65	29.03	-180.5	-38.0	0					85
Oct 31 1990	W	20.0	15.0	7.4	3.0	33%	41%	0.89	0.94	29.02	-3.6	27.5	0					86
Nov 02 1990	F	21.7	17.4	9.3	3.0	39%	52%	0.62	0.67	28.03	-16.1	-18.6	0					87
Nov 05 1990	M	20.6	21.7	22.2	3.0	57%	62%	0.49	0.57	28.56	-113.8	41.2	0					88
Nov 07 1990	W	12.8	12.8	13.0	3.0	50%	48%	0.62	0.60	28.83	-186.2	-42.6	0					89
Nov 09 1990	F	6.1	6.7	9.3	3.0	60%	51%	0.39	0.35	28.93	-281.9	-146.6	0					90
Nov 12 1990	M	15.0	16.7	20.4	3.0	30%		0.72	0.78	28.87	-185.3	21.2	0					91
Nov 14 1990	W	12.8	14.5	7.4	3.0	27%		0.78	0.77	29.17	-103.4	-1.3	0					92
Nov 16 1990	F	18.9	20.6	14.8	3.0	47%		0.72	0.72	28.93	-87.9	52.1	0					93
Nov 19 1990	M	11.1	11.1	11.1	3.0	45%	41%	0.57	0.63	28.84	-200.3	-67.6	3	33	11	3	0	94
Nov 21 1990	W	12.2	13.3	0.0	3.0	49%	75%	0.44	0.44	29.04	143.5	-64.3	0					95
Nov 23 1990	F	18.3	20.6	25.9	3.0	54%		0.71	0.72	28.52	-158.1	52.1		NO DATA				96
Nov 26 1990	M	19.4	20.0	0.0	3.0	38%		0.58	0.69	28.91	185.7	41.6	0					97
Nov 28 1990	W	20.6	21.1	9.3	3.0	82%		0.27	0.27	28.83	-79.7	-9.3	7	146	21	4	3	98
Nov 30 1990	F	7.2	14.4	11.1	3.0	32%		0.71	0.75	29.20	-240.0	-6.8	2	28	14	0	2	99
Dec 03 1990	M	6.1	7.2	5.8	3.0	100%	100%	0.65	0.73	28.89	-242.2	-84.0	0					100
Dec 05 1990	W	3.3	7.2	22.2	3.0	42%	35%	0.69	0.70	28.98	-430.6	-88.5	0					101
Dec 07 1990	F	7.8	8.3	5.6	3.0	50%	46%	0.71	0.71	28.86	-146.4	-75.6	0					102
Dec 10 1990	M	16.7	17.2	33.3	3.0	29%	33%	0.64	0.66	28.79	-228.7	8.5	0					103
Dec 12 1990	W	15.6	13.9	9.3	3.0	41%	41%	0.72	0.71	28.87	-95.3	-17.8	1	11	11	0	1	104
Dec 14 1990	F	6.1	6.1	20.4	3.0	49%	47%	0.59	0.67	29.13	-363.6	-104.5	0					105
Dec 17 1990	M	5.6	5.6	11.1	3.0	70%	66%	0.12	0.07	28.91	-350.2	-200.7	0					106
Dec 19 1990	W	12.2	14.4	14.8	3.0	57%	41%	0.21	0.18	28.83	-265.8	-91.9	0					107
Dec 21 1990	F	7.2	8.9	11.1	3.0	100%	97%	0.11	0.13	29.04	-317.4	-156.9	0					108
Dec 24 1990	M	1.1	3.3	33.3	3.0	49%	33%	0.59	0.63	28.81	-570.8	-139.7	0					109
Dec 26 1990	W	3.3	4.4	7.4	3.0	30%	24%	0.41	0.43	29.23	-279.8	-158.5	0					110
Dec 28 1990	F	1.7	3.4	0.0	3.0	96%	87%	0.41	0.31	29.14	88.2	-187.3	0					111
Dec 31 1990	M	6.7	8.4	20.4	3.0	86%		0.37	0.42	29.04	-387.0		0					112
Jan 02 1991	W	7.8	9.5	11.1	3.0	58%		0.25	0.18	29.03	-301.5	-143.0	0					113
Jan 04 1991	F	4.4	6.1	7.4	3.0	46%		0.20	0.17	29.02	-300.4	-180.2	0					114
Jan 07 1991	M	3.9	4.4	13.0	3.0	96%	92%	0.05	0.03	29.09	-405.6	-219.5	0					115
Jan 09 1991	W	5.0	5.6	11.1	3.0	70%	65%	0.27	0.30	29.10	-329.9	-165.7	0					116
Jan 11 1991	F	2.2	2.8	7.4	3.0	82%	87%	0.17	0.10	29.01	-340.7	-225.7	0					117
Jan 14 1991	M	6.7	6.1	14.8	3.0	67%	46%	0.69	0.72	28.87	-293.2	-96.9	0					118
Jan 16 1991	W	10.0	10.0	5.6	3.0	100%	91%	0.11	0.12	28.48	-201.8	-146.9	0					119
Jan 18 1991	F	7.2	9.4	40.7	3.0	49%	39%	0.75	0.77	28.88	-463.8	-55.3	0					120
Jan 21 1991	M	0.6	3.9	35.2	3.0	49%	35%	0.67	0.72	28.60	-590.8	-119.9	0					121
Jan 23 1991	W	2.2	3.9	18.5	3.0	44%	37%	0.71	0.76	28.81	-413.2	-113.8	0					122
Jan 25 1991	F	1.7	5.6	13.0	3.0	36%	35%	0.70	0.75	29.05	-374.0	-97.6	0					123

Table 4 (continued). Climate and Behavior Data

DATE	DAY	TEMPERATURE (C) Airport	TEMPERATURE (C) BC/BS	WIND VELOCITY (KmPH) Airport	WIND VELOCITY (KmPH) BC/BS	RELATIVE HUMIDITY Airport	RELATIVE HUMIDITY BC/BS	SOLAR INSOLATION (Langs/min) Airport	SOLAR INSOLATION (Langs/min) BC/BS	BAROMETRIC PRESSURE (inHg)	INDEX OF THERMAL STRESS Airport	INDEX OF THERMAL STRESS BC/BS	PLAZA BEHAVIOR TOTAL USERS	PLAZA BEHAVIOR TOTAL USER DURATION	PLAZA BEHAVIOR AVERAGE USER DURATION	SEATED ORIENTATION SUN	SEATED ORIENTATION SHADE	DAYS
Jan 28 1991	M	12.2	13.9	18.5	3.0	52%	51%	0.79	0.79	28.70	-159.6	-6.0	2	32	16	2	0	124
Jan 30 1991	W	12.2	12.8	5.6	3.0	69%	76%	0.61	0.72	28.64	-129.4	-111.6	0					125
Feb 01 1991	F	7.2	9.4	13.0	3.0	19%	17%	0.80	0.82	29.36	-255.0	-47.8	0					126
Feb 04 1991	M	16.7	15.0	7.4	3.2	21%	27%	0.77	0.82	29.10	-50.6	9.7	12	219	18	7	5	127
Feb 06 1991	W	11.1	10.0	13.0	1.6	96%	100%	0.28	0.33	28.95	-256.1	-115.1	0					128
Feb 08 1991	F	9.4	7.8	18.5	0.0	52%	56%	0.71	0.76	28.78	-282.0	-73.3	0					129
Feb 11 1991	M	5.0	6.7	22.2	4.8	26%	24%	0.88	0.92	28.72	-413.7	-60.7	0					130
Feb 13 1991	W	8.3	5.6	7.4	0.8	49%	52%	0.13	0.14	28.49	-206.9	-190.1	0					131
Feb 15 1991	F	-3.9	-0.6	40.7	0.8	42%	37%	0.42	0.50	28.27	-747.9	-200.5	0					132
Feb 18 1991	M	3.3	1.7	7.4	0.0	92%	100%	0.11	0.16	29.00	-323.9	-228.2	0					133
Feb 20 1991	W	16.1	15.9	14.8	0.8	78%	86%	0.21	0.26	28.83	-196.3	-84.6	0					134
Feb 22 1991	F	15.1	15.6	22.2	1.6	19%	22%	0.34	0.39	28.71	-224.6	-48.0	0					135
Feb 25 1991	M	9.4	9.4	0.0	3.2	54%	54%	0.26	0.19	28.73	94.1	-141.1	0					136
Feb 27 1991	W	3.9	7.2	22.2	1.6	42%	38%	0.67	0.69	28.82	-421.3	-90.0	0					137
Mar 01 1991	F	13.9	14.4	7.4	0.0	42%	53%	0.04	0.03	28.93	-187.0	-114.5	0					138
Mar 04 1991	M	5.6	8.3	29.6	2.4	55%	43%	0.99	1.02	28.20	-409.9	-29.3	0					139
Mar 06 1991	W	13.9	12.2	27.8	9.7	42%	46%	0.09	0.09	28.35	-323.1	-128.4	0					140
Mar 08 1991	F	5.0	4.4	14.8	1.6	39%	45%	0.29	0.30	28.74	-375.0	-178.3	0					141
Mar 11 1991	M	6.7	9.4	18.5	0.8	35%	37%	0.97	1.00	28.86	-300.5	-21.0	0					142
Mar 13 1991	W	3.3	1.7	9.3	1.6	96%	100%	0.12	0.13	28.48	-354.2	-232.9	0					143
Mar 15 1991	F	8.3	8.9	18.5	4.0	40%	36%	1.05	1.05	28.85	-291.5	-18.7	0					144
Mar 18 1991	M	15.0	16.7	18.5	0.8	60%		0.80	0.81	28.46	-170.6	25.6	0					145
Mar 20 1991	W	14.4	16.1	22.2	2.4	34%		0.82	0.90	28.81	-203.2	32.8	6	113	19	6	0	146
Mar 22 1991	F	17.8	19.5	11.1	0.8	87%		0.62	0.67	28.74	-89.3	33.5	1	25	25	0	1	147
Mar 25 1991	M	16.7	21.7	22.2	0.0	32%	25%	1.19	1.24	28.83	-118.5	139.1	13	226	17	12	1	148
Mar 27 1991	W	20.0	22.2	11.1	0.0	55%	47%	0.51	0.53	28.66	-71.0	40.4	0					149
Mar 29 1991	F	11.7	10.6	7.4	0.0	90%	98%	0.14	0.14	28.38	-203.7	-137.6	0					150
Apr 01 1991	M	15.0	16.7	25.9	3.2	25%	23%	1.13	1.18	28.85	-119.0	80.0	0					151
Apr 03 1991	W	12.8	13.3	9.3	3.2	34%	42%	1.15	1.20	29.25	-123.8	48.5	0					152
Apr 05 1991	F	15.6	14.4	0.0	3.2	78%	82%	0.49	0.51	29.01	-167.8	-42.5	0					153
Apr 08 1991	M	26.1	25.6	0.0	2.4	45%	53%	0.78	0.82	28.79	2.7	117.3	8	139	17	6	2	154
Apr 10 1991	W	21.1	21.7	29.6	3.2	23%	28%	1.15	1.21	28.66	-37.8	134.8	16	235	15	8	8	155
Apr 12 1991	F	14.4	11.7	9.3	4.8	30%	42%	0.71	0.73	29.06	-137.4	-37.5	1	4	4	0	1	156
Apr 15 1991	M	7.8	10.0	9.3	5.6	95%	93%	0.29	0.31	29.10	-273.8	-118.1	0					157
Apr 17 1991	W	25.6	26.7	14.8	0.8	31%	31%	1.03	1.11	28.98	16.2	170.4	15	239	16	7	8	158
Apr 19 1991	F	7.2	7.8	11.1	3.2	91%	89%	0.61	0.66	29.05	-208.3	-88.3	0					159

The elevated level of insolation has both a positive and negative effect on plaza users, which is discussed later in this report. The calculation of solar levels on the study plaza was similar to determining temperature readings. On blank data days, 0.05 langleys were added to the recorded solar radiation levels at the airport.

Unlike temperature and solar radiation, relative humidity was lower downtown than at the airport. Since relative humidity is a function of temperature and moisture content of the air, this association was not surprising. If moisture levels are constant through the course of a day, as temperature increases, relative humidity will decrease. With higher temperatures downtown, it reasons that relative humidity levels will be lower in the same setting.

As mentioned earlier, the difference in barometric pressure between the airport and the BC/BS plaza was insignificant. Barometric pressure, in part, is a function of altitude from mean sea level. Since the collection sites are separated by less than seventeen (17) feet in elevation, the differences in barometric pressure is negligible. Thus, for this investigation, barometric pressure was considered to be equal at the airport and plaza site.

Wind was the most difficult to correlate between the two sites. While the origin of the wind at the airport was predominately from the West and Southwest, downtown wind direction was nearly evenly distributed around the compass (Figure 7). A low correlation value of 0.2361 did not allow for prediction of downtown wind directions at pedestrian level based on airport wind information. The distribution of the on-site wind direction data around the compass may be attributable to turbulence and downwash of wind patterns due to building shape and orientation in the downtown setting.

Wind speeds were more difficult to predict with a lower correlation value of 0.1514 indicating almost no relationship between the two sites. While it is possible to look at the wind data and notice the large overall difference in velocities between wind at the airport and downtown, it is not possible to predict wind speeds from this data. The difference in velocities is large, with wind speeds ranging from 0 to 45 kilometers/hour at the airport and 0 to 6 kilometers/hour on the plaza.

While wind has been shown to be major factor in optional behavior motivation in earlier studies, its significance is not evident here. The impact of good design decisions to affect wind is evident, however. The orientation and design of the BC/BS office building in conjunction with the design of the plaza helps to reduce the negative effects of high wind speed and turbulence on plaza users. The difference in wind speed at the airport and on the plaza is evident from the windrose as shown in Figure 7. If wind speeds had been more pronounced on the BC/BS plaza, or if more than two months of data had been recorded, it is the belief of this researcher that findings similar to those of Bork and Watts and Song would have been realized.

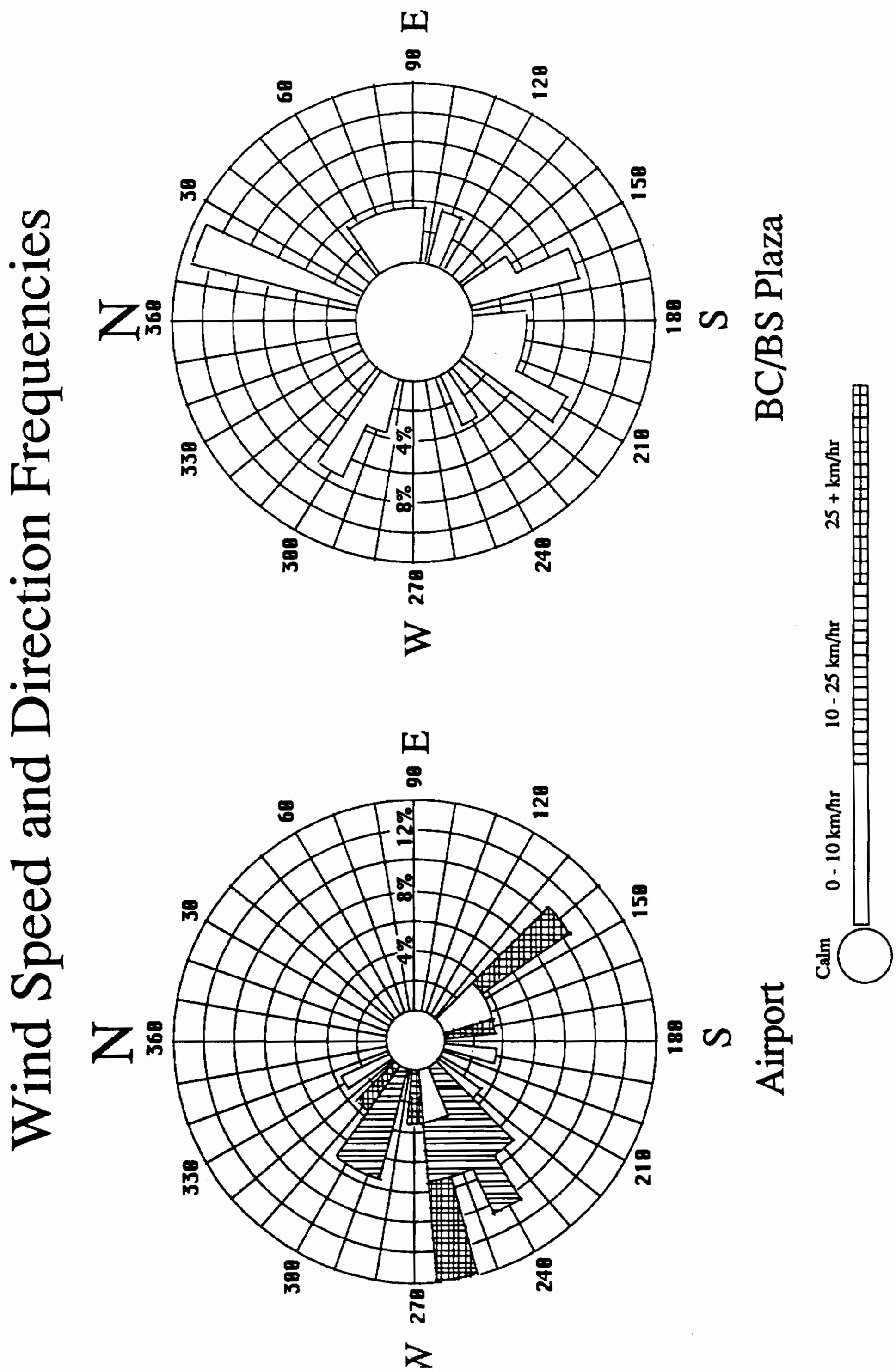


Figure 7. Windroses for Roanoke Regional Airport and Blue Cross/Blue Shield Plaza

With the uncertainty of predicting wind speed and since the data set for the plaza needed to be completed for an entire annual cycle, for purposes of analysis with the ITS formula the wind speed on the plaza was held as a constant. Previous studies have shown that negative wind effects may be eliminated by reducing speeds to approximately 4 feet/second, or 4 kilometers/hour (Tacken, 1989). In reviewing the wind data for the BC/BS plaza, average wind speeds were between 2 to 3 kilometers per hour. With this information, it was determined that the constant for wind speed on the plaza would be set at 3 kilometers per hour for purposes of analysis with the thermal stress index.

Once the climate data set was expanded and completed for the BC/BS plaza, the climate data sets were reduced to include only those days for which behavior was being observed on the plaza. The final 159 days of observation and climate data, less the days discarded from the study due to equipment malfunction, precipitation and special events, were then analyzed by plotting behavior frequency and duration against four (4) climatic factors - temperature, solar radiation, humidity and pressure - and the Index of Thermal Stress.

5.2 Chi Square Test

A chi square test was used to determine if the differences between user (days with people on the plaza) and non-user days (days with nobody on the plaza) was due to sampling error or differences in climate conditions. The chi square test provides a statistic based upon the differences between observed and expected frequencies and if the difference is significant at particular levels. On the basis of the chi square test, it can be determined whether the observed frequencies differ significantly from the expected frequencies based upon the null hypothesis. If the difference is significant, the null hypothesis - behavior is not affected by climate - is rejected. If they do not differ noticeably, then it is concluded that the difference in frequencies obtained from the sample is due to the sampling error.

For the chi square analysis, behavior data was simplified into user and non-user days, 1 and 0, respectively. This simplification created 69 non-user days and 56 user days. The two most significant factors in the regression model, temperature and solar radiation, were broken down into categories of low, medium and high with "1" being low and "3" being high. This provided nine (9) possible combinations between temperature and solar radiation levels. Each day of the analysis was then placed into the corresponding combination based on the temperature and solar radiation conditions for that particular day.

It was expected that once the days were placed into the corresponding cells, or combinations, the high number of non-user days would correspond with the lower solar radiation and lower temperature combinations. This would indicate to designers that these days are of a major significance in climate intervention. Conversely, it was hoped that a high number of user days would coincide to a combination of high temperature and high solar radiation levels. As can be seen from Table 5, the corresponding tables show this situation to be relatively true.

The tables for user and non-user days do not show as strong a correspondence as expected, but the relationship is noticeable. For the user category, fifty (50) percent of the days had a combination of high solar and high temperature levels. Another twenty-three (23) percent of the days were in the medium temperature/high radiation cell. Over seventy percent of the user days corresponded to these two combinations. On the other side, the distribution is more subtle. Only 12 of the 69 non-user days related to the low temperature/low solar radiation combination. Seventy-eight (78) percent of the non-user day do coincide with the four lowest combinations, low temperature/low solar, low temperature/medium solar, low solar/medium temperature and medium solar/medium temperature. The frequency of occurrence for each combination is then tabulated and the expected counts are calculated to determine the chi square value for each cell. From a table of chi square values, the required value needed for significance at the level P = 0.05 with eight (8) degrees of freedom is 26.12. The value for the calculated chi square from

Table 5. Chi Square Charts

Filter 10: IN/OUT =1
Page 1 /Numeric/Counts/Table Pct/Exp. Value/

TEMP_C	INSOL_LG 1	2	3	Total
1	0	2	1	3
	0.0	4.2	2.1	6.3
	0	1	2	3
2	1	6	11	18
	2.1	12.5	22.9	37.5
	1	4	14	18
3	1	2	24	27
	2.1	4.2	50.0	56.3
	1	6	20	27
Total	2	10	36	48
	4.2	20.8	75.0	100.0
	2	10	36	48

Filter 10: IN/OUT =0
Page 1 /Numeric/Counts/Table Pct/Exp. Value/

TEMP_C	INSOL_LG 1	2	3	Total
1	12	15	1	28
	19.4	24.2	1.6	45.2
	9	14	5	28
2	8	13	7	28
	12.9	21.0	11.3	45.2
	9	14	5	28
3	0	2	4	6
	0.0	3.2	6.5	9.7
	2	3	1	6
Total	20	30	12	62
	32.3	48.4	19.4	100.0
	20	30	12	62

Table 6. Chi Square Statistic and Values

```
MTB > print c1-c6

 ROW     C1    C2     C3     C4    C5     C6

   1     27     1     20      7     2      4
   2      2     1      8     11     3     24

MTB >
MTB > chis c1-c6

Expected counts are printed below observed counts

              C1          C2          C3          C4          C5          C6
    1         27           1          20           7           2           4
           16.08        1.11       15.53        9.98        2.77       15.53

    2          2           1           8          11           3          24
           12.92        0.89       12.47        8.02        2.23       12.47

Total         29           2          28          18           5          28

ChiSq =    7.413 +     0.011 +     1.288 +     0.891 +     0.215 +     8.558
           9.228 +     0.013 +     1.604 +     1.109 +     0.268 +    10.653
                                                                  =   41.251
```

Table 6 is 41.25. Because the obtained chi square is larger than the value required, the null hypothesis is rejected and it is concluded that the results from this study are not due to sampling error.

It is quite obvious that the major contributors to the high calculated chi square value are the two (2) cells at each extreme end of the table. These cells correspond to low temperature/low solar radiation and high temperature/high solar radiation combinations. These combinations are significant to designers. While it is difficult to alter low temperature/low radiation combinations through design decisions, climate profiles of high temperature and high solar radiation can be mitigated, if necessary, with design elements.

5.3 Behavior versus Climate Factors

Univariant regression analysis was used to determine the strength of the relationships between the individual climatic factors and the observed frequency, total duration minutes and average duration of behavior. None of the factors proved to have a very strong relationship with any of the measured behavior. This was not surprising due to the interrelatedness of the individual climate factors. Any single factor can not be considered as the primary contributor to the regression model since all the climate factors are related to one another. Thus, it becomes extremely difficult in this method of analysis to simply use climate, or any individual factor of climate, as a predictor of behavior in outdoor spaces.

The most significant relationship is between the observed behavior and temperature which had the highest correlation coefficients (r) and the lowest significance probability value (PR>F) which indicates that temperature is more of a contributor to the regression model than the other factors. This relationship is graphically depicted by the scatterplots for the various climate factors in Figures 8 to 11. The near level regression lines in all of the graphs, except for temperature, indicate the insignificance of the relationship between the individual factors to behavior frequency and duration. Even though the correlation coefficient values are higher than for the other factors, the ability for temperature to act as a predictor (simple r squared or the correlation coefficient squared) for behavior frequency and duration is quite low with the highest prediction success rate being sixty (60) percent.

None of the other climate factors, relative humidity, solar radiation or barometric pressure, show any significance in relationship to behavior frequency or duration. The corresponding values for correlation, probability and prediction are summarized in Table 7. The regression analysis for the individual climate factors and the observed behaviors is located in Appendix B.

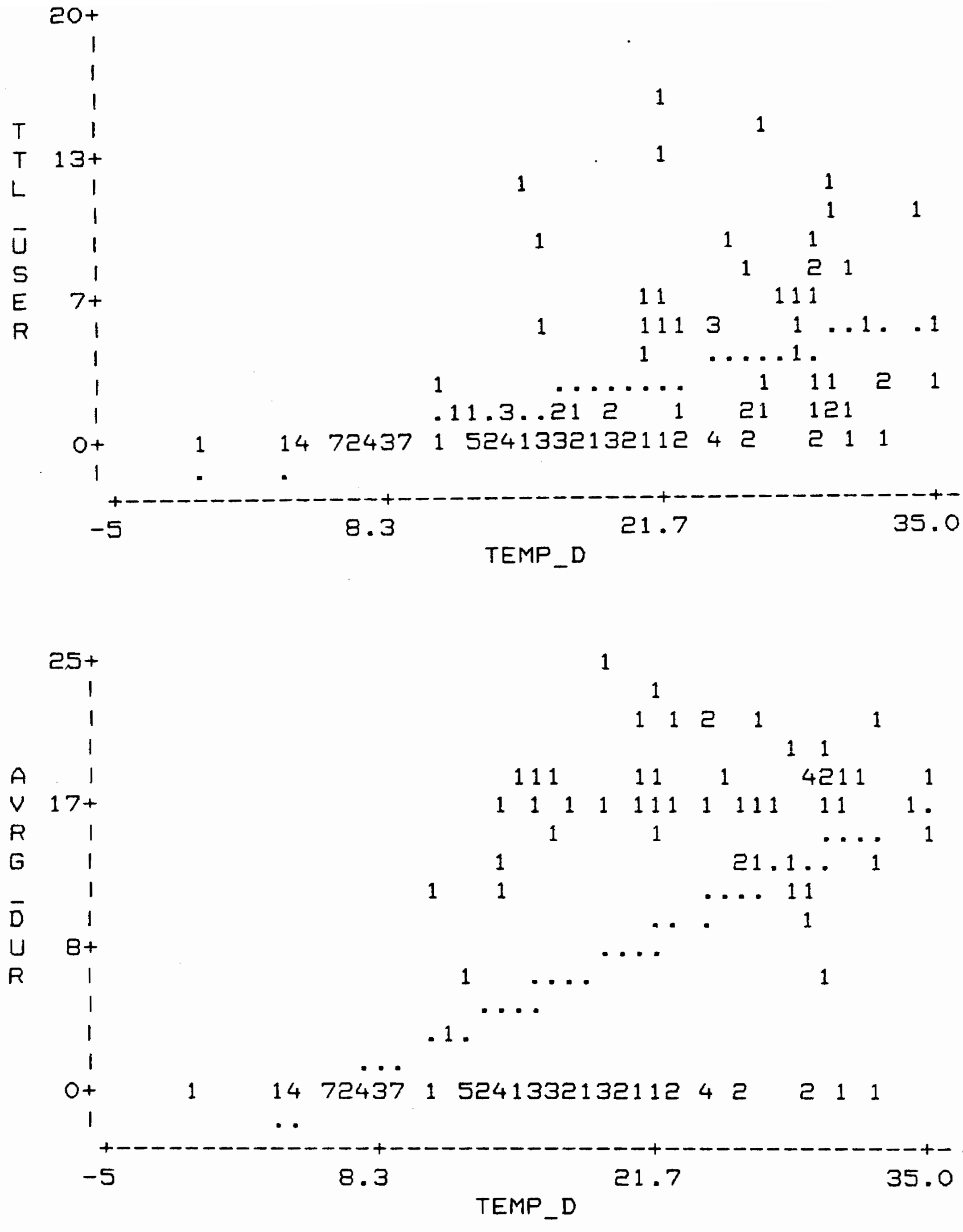
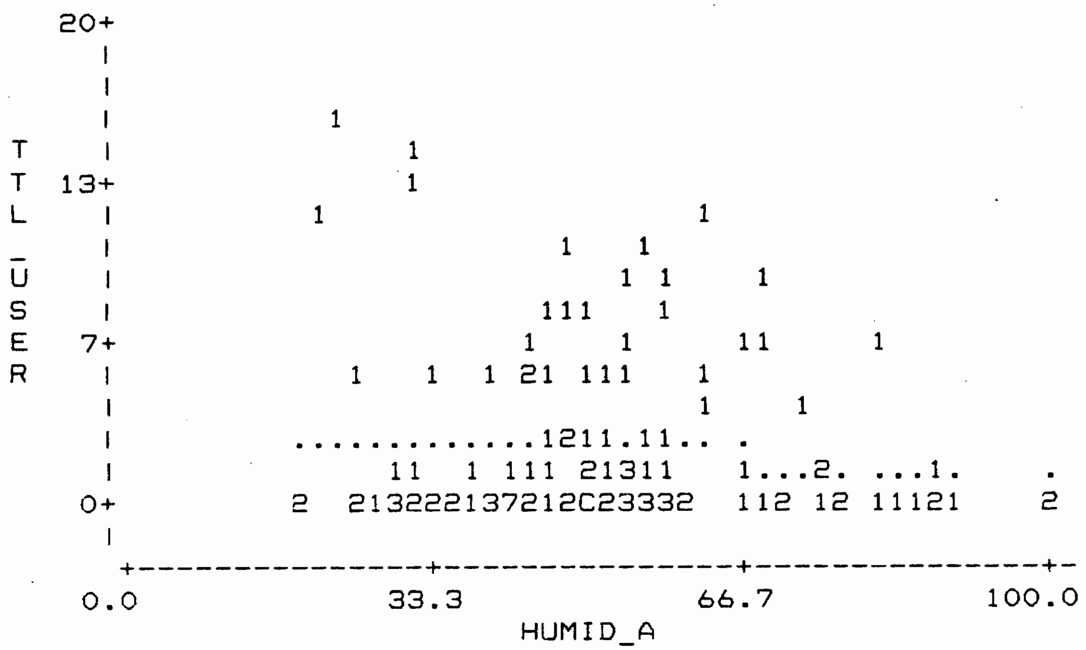


Figure 8. Frequency versus Temperature (top)

Average Duration versus Temperature (bottom)



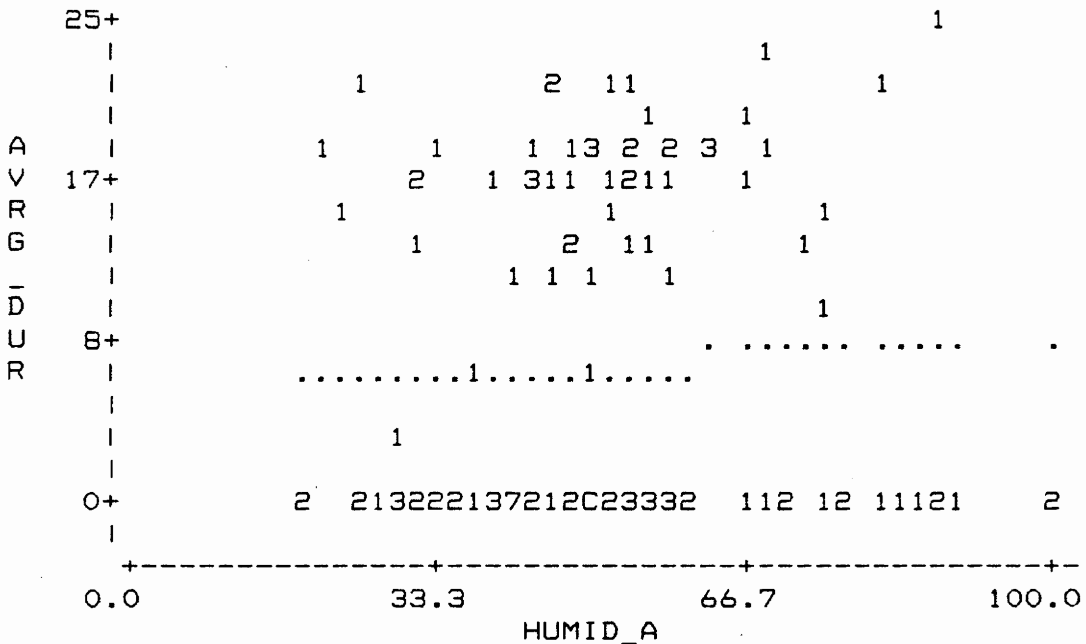


Figure 9. Frequency versus Relative Humidity (top)

Average Duration versus Relative Humidity (bottom)

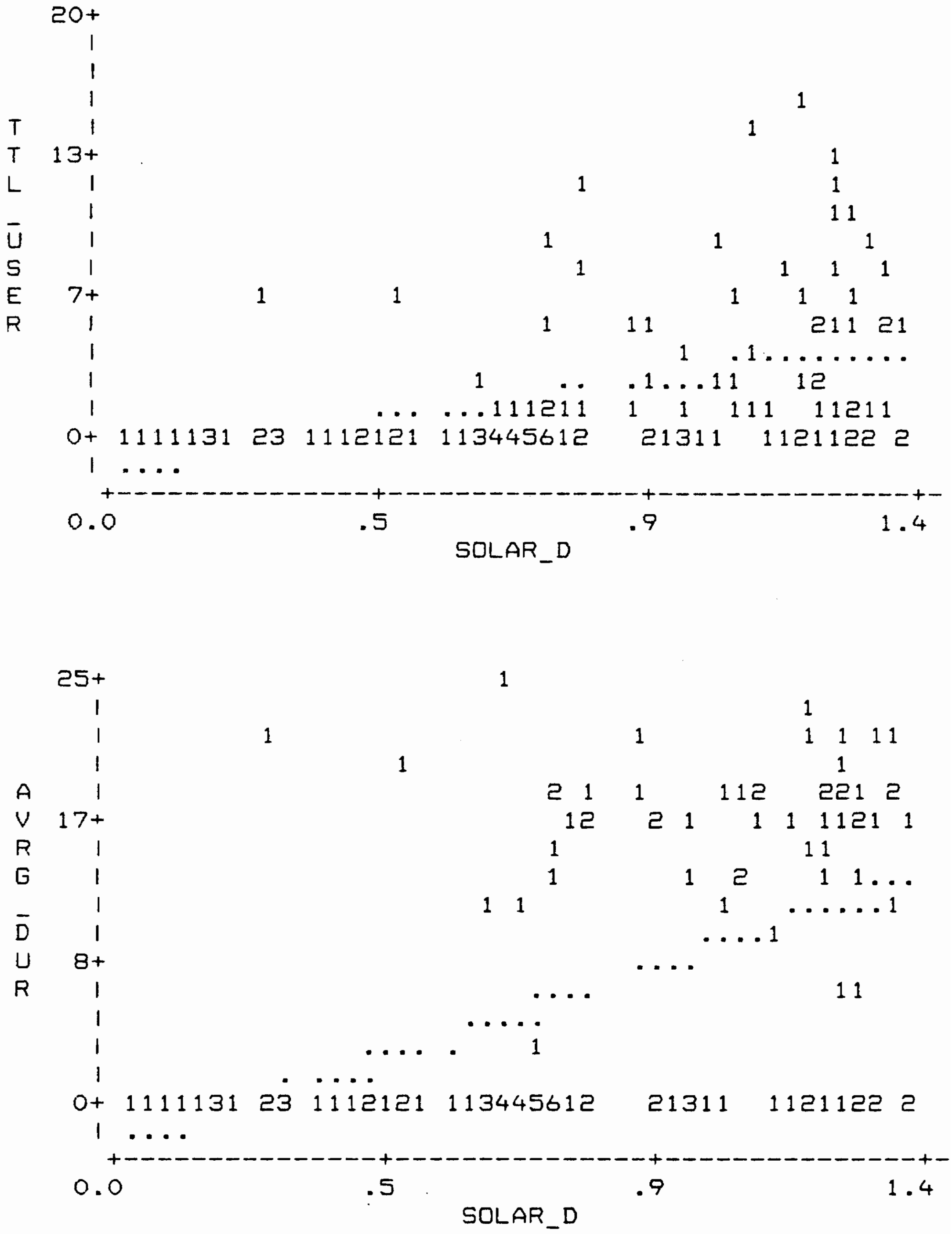
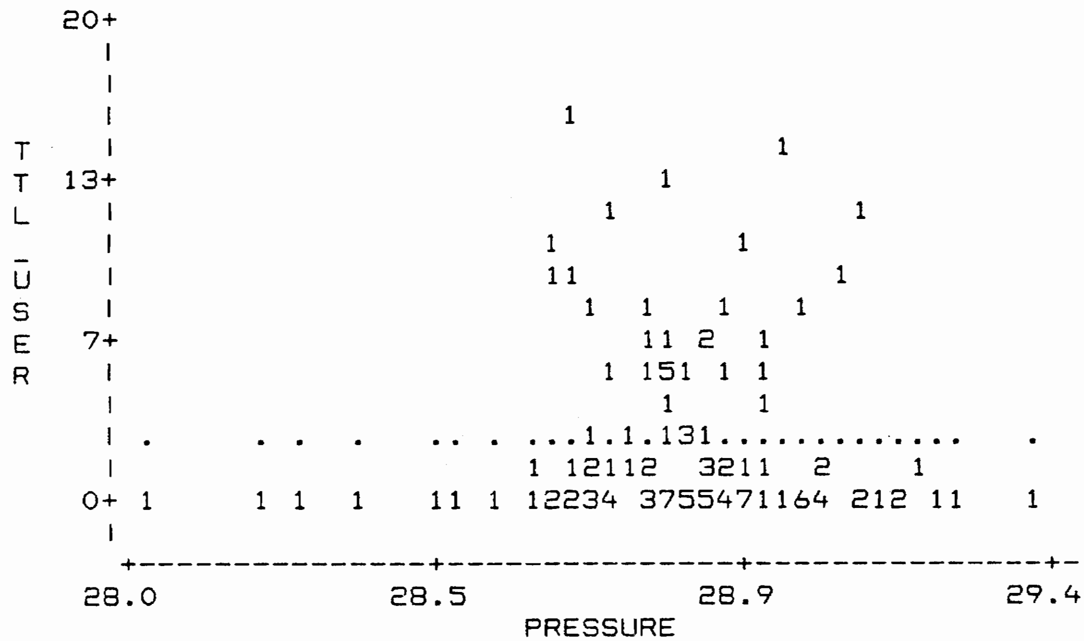


Figure 10. Frequency versus Solar Insolation (top)

Average Duration versus Solar Insolation (bottom)



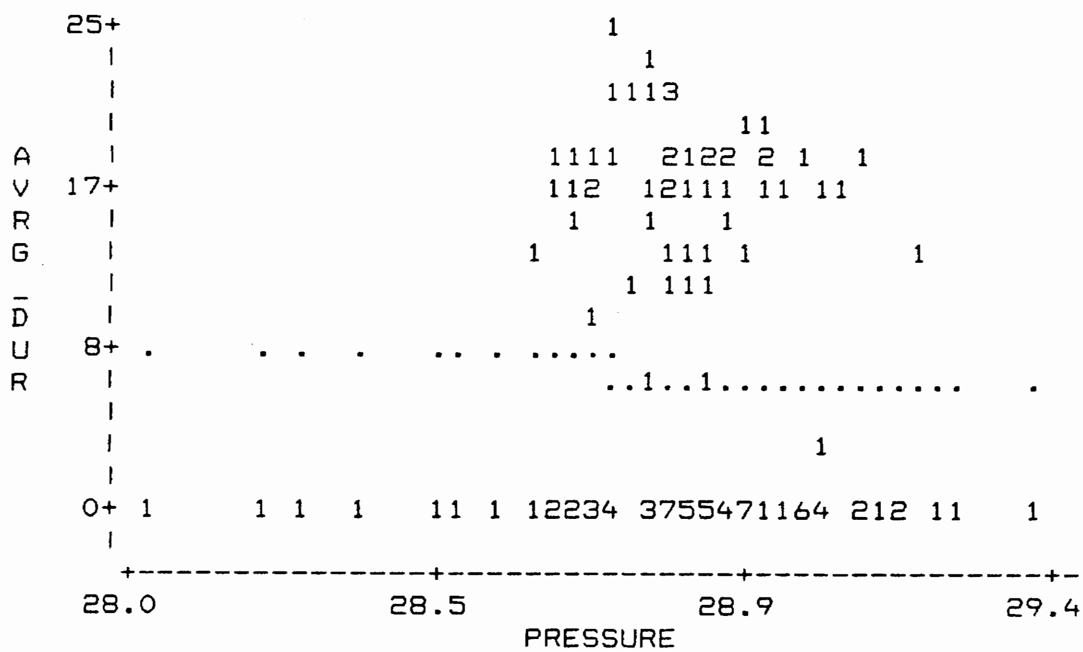


Figure 11. Frequency versus Barometric Pressure (top)

Average Duration versus Barometric Pressure (bottom)

Table 7. Summary of Corresponding Correlation Coefficients, Probabilty Values and Prediction Rates.

Frequency

	Correlation Coefficient (r)	Probability Values (PR>f)	Prediction Success Rate (r * r)
Temperature	0.7370	0.0068	54%
Relative Humidity	-0.4290	0.4161	18%
Solar Insolation	0.4741	0.5280	22%
Barometric Pressure	0.0422	0.7135	0.1%
ITS	0.5178	0.0001	27%

Average Duration

	Correlation Coefficient (r)	Probability Values (PR>f)	Prediction Success Rate (r * r)
Temperature	0.7736	0.0043	60%
Relative Humidity	-0.3374	0.6690	11%
Solar Insolation	0.4332	0.5200	18%
Barometric Pressure	0.0760	0.7770	0.5%
ITS	0.6224	0.0001	39%

5.4 Bioclimatic Charts as Predictors of Behavior

The 159 days of the annual cycle in this study were plotted on the bioclimatic charts developed by Olgyay and Givoni to determine what percentage of days fell within the respective comfort zones. The 125 days of analysis were then plotted on Givoni's chart to compare user and non-user days to the comfort zone limits.

Figure 12 shows all the days of the annual cycle plotted on Olgyay's bioclimate chart. Of the 159 days, only 25 (15.7%) fall within the given comfort zone. The comfort zone was then expanded, as shown in Figure 13, based on conclusions of earlier studies and typical climatic conditions within the geographic region in which this study was completed. Typically, for the winter months of December and January, the average solar radiation levels approximate 150 BTUs/hr. Winter months were used since solar radiation is at its lowest level in this region and radiant warming tends to be more critical. Previous studies by Arens and Tacken, cited earlier in this report, conclude that the negative affects of wind may be eliminated with a reduction of wind speed to 4 or 5 feet/second, or 300 feet per minute. These two factors, radiation and wind, expand Olgyay's comfort zone vertically into higher temperature ranges, since wind has a cooling effect during warmer conditions, and lower temperature ranges due to the sun's warming abilities under cool weather conditions. Once expanded, sixty-one (61) percent of all days (97/159) are within the comfort zone. Givoni in his research, however, concluded that

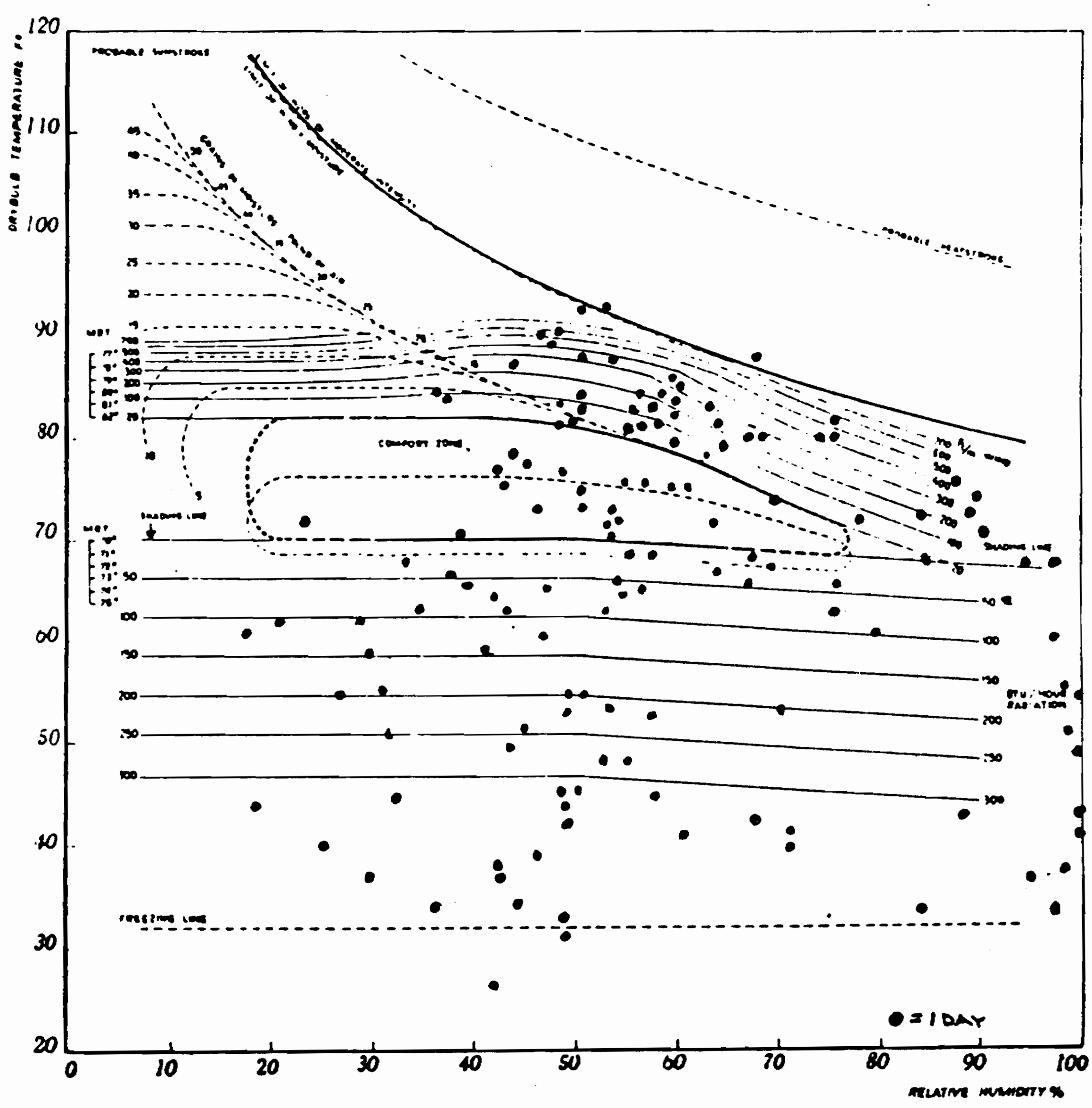


Figure 12. Olgyay's Bioclimatic Chart and All Days of Annual Cycle

Note: All data for 12:00 pm on BC/BS plaza

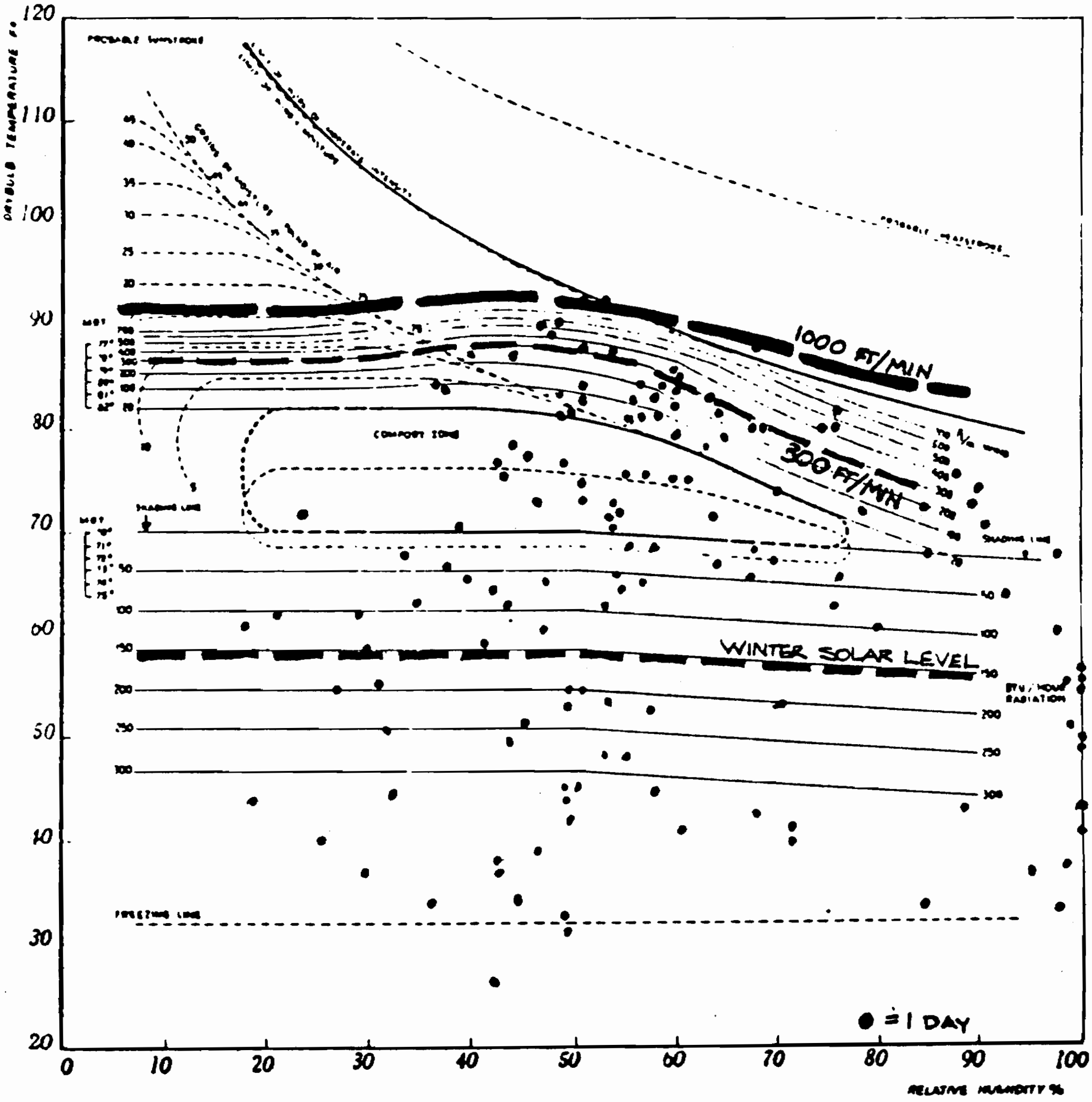


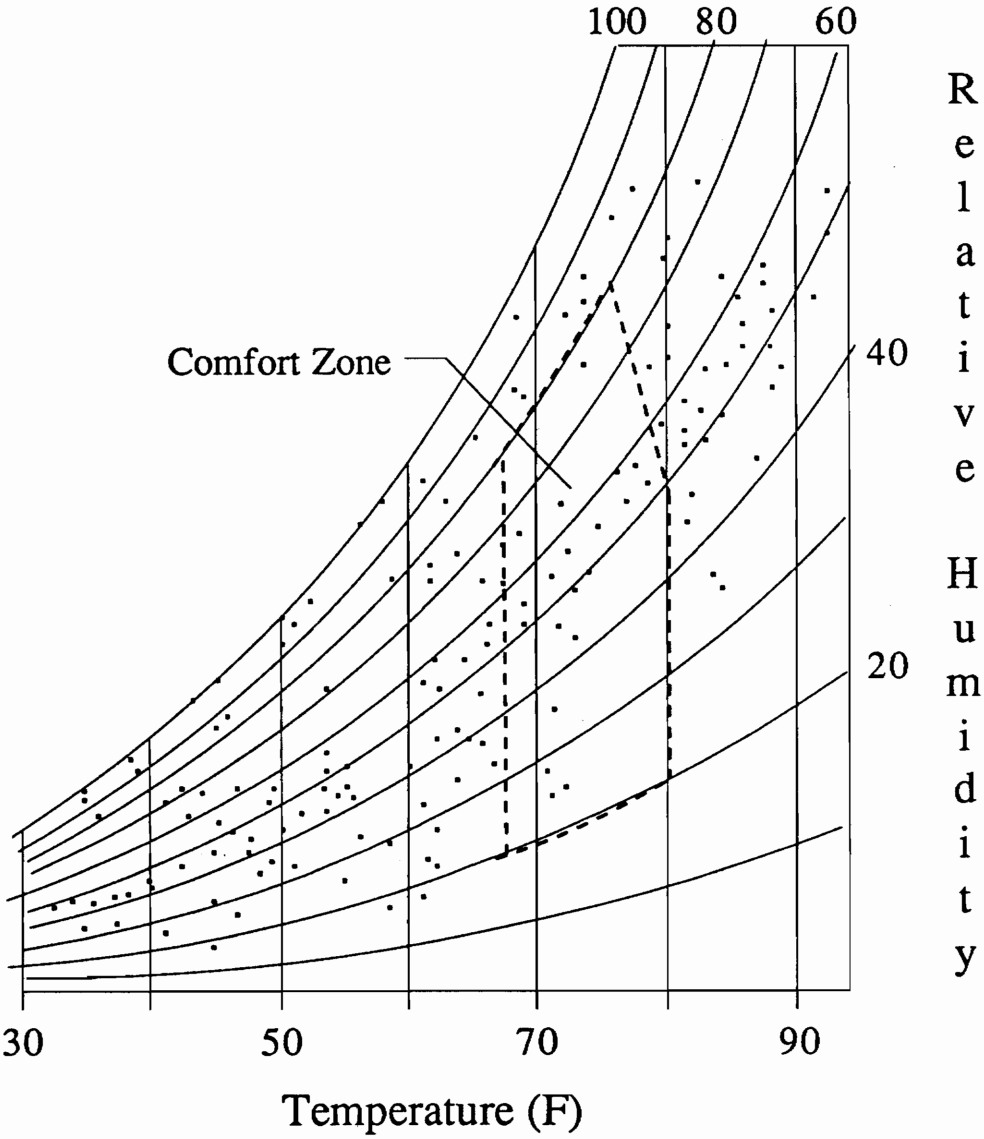
Figure 13. Olgyay's Expanded Bioclimatic Chart

Note: All data for 12:00 pm on BC/BS plaza

wind speeds up to 1000 feet/minute are necessary to maintain thermal comfort during extremely warm, humid conditions. If Olgyay's zone is expanded further to this wind level, 104 out of 159 days (65%) are within the comfort zone.

The same analysis process was used on Givoni's bioclimatic chart. Figure 14 shows that only twenty-one (21) percent of the 159 days are encompassed by his comfort zone. If the zone is expanded, as shown in Figure 15, using the same guidelines for solar radiation and wind speed as for Olgyay's chart, similar results occur. With an average of 1100 BTUs/day of solar radiation and wind speeds controlled to 300 feet/minute, Fifty-seven (57) percent (90/159) of the days are theoretically comfortable. If wind is expanded to 1000 feet/minute, the results are exactly the same as for Olgyay's expanded chart - 104 of the 159 days (65%) are within the comfort zone.

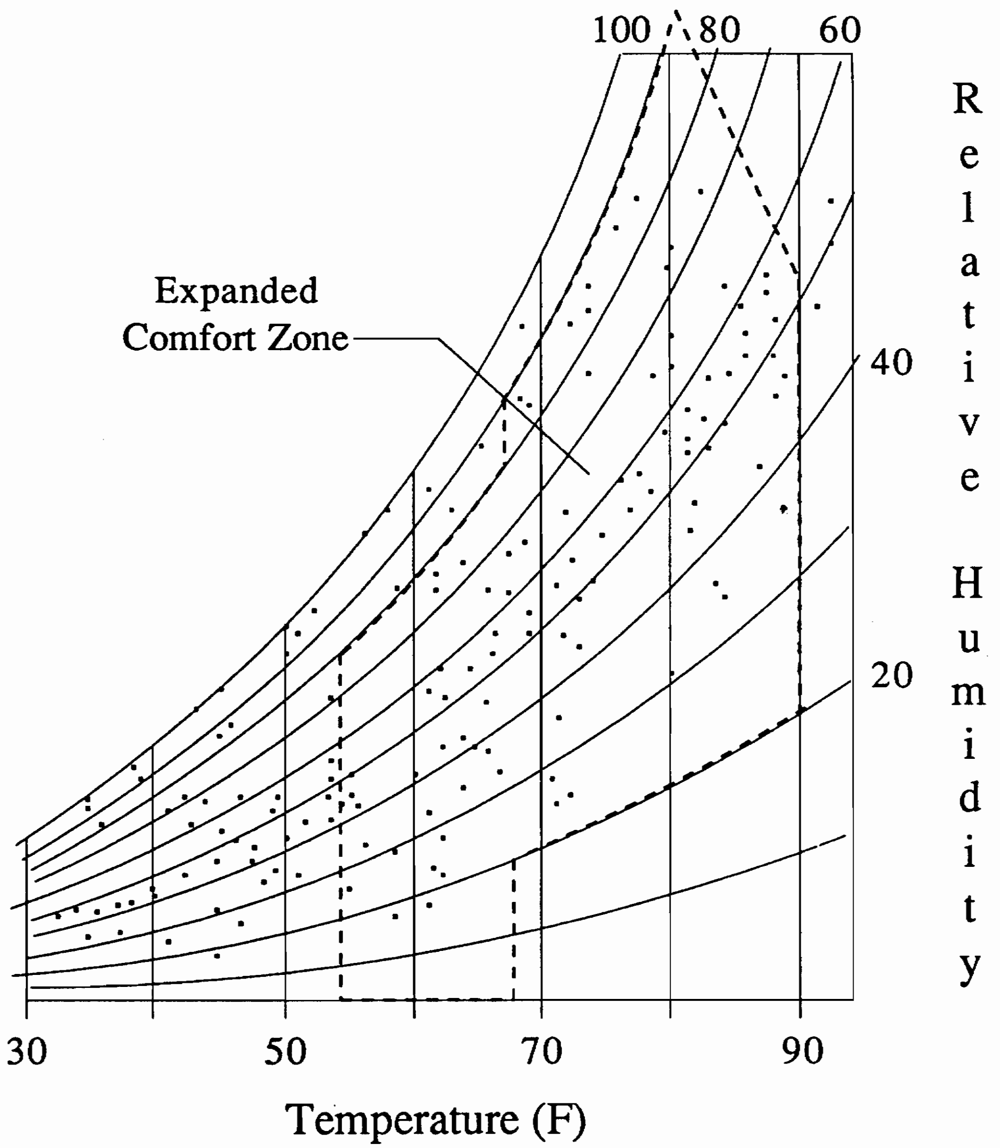
Using Givoni's bioclimatic chart with an expanded comfort zone, the sixty (60) user days and sixty-five (65) non-user days were plotted (Figure 16). Of the 125 analysis days, 69% are located on the chart within the comfort zone - 65% of all days in the annual cycle were within the comfort zone. Of the eighty-seven (87) days of analysis within the comfort zone, 57% (50/87) of them are user days. While the goal of a designer of outdoor spaces is to make design decisions that will increase the occurrence of days within the comfort zone, the ability of the bioclimatic chart to predict behavior is limited since the percentage of the days used within the comfort zone is not very indicative.



Bioclimatic chart represents:
Metabolic rate = 1.0 (sitting, relaxed)
Clothing value = 0.8 (summer work clothing)

Figure 14. Givoni's Bioclimatic Chart and All Days of Annual Cycle

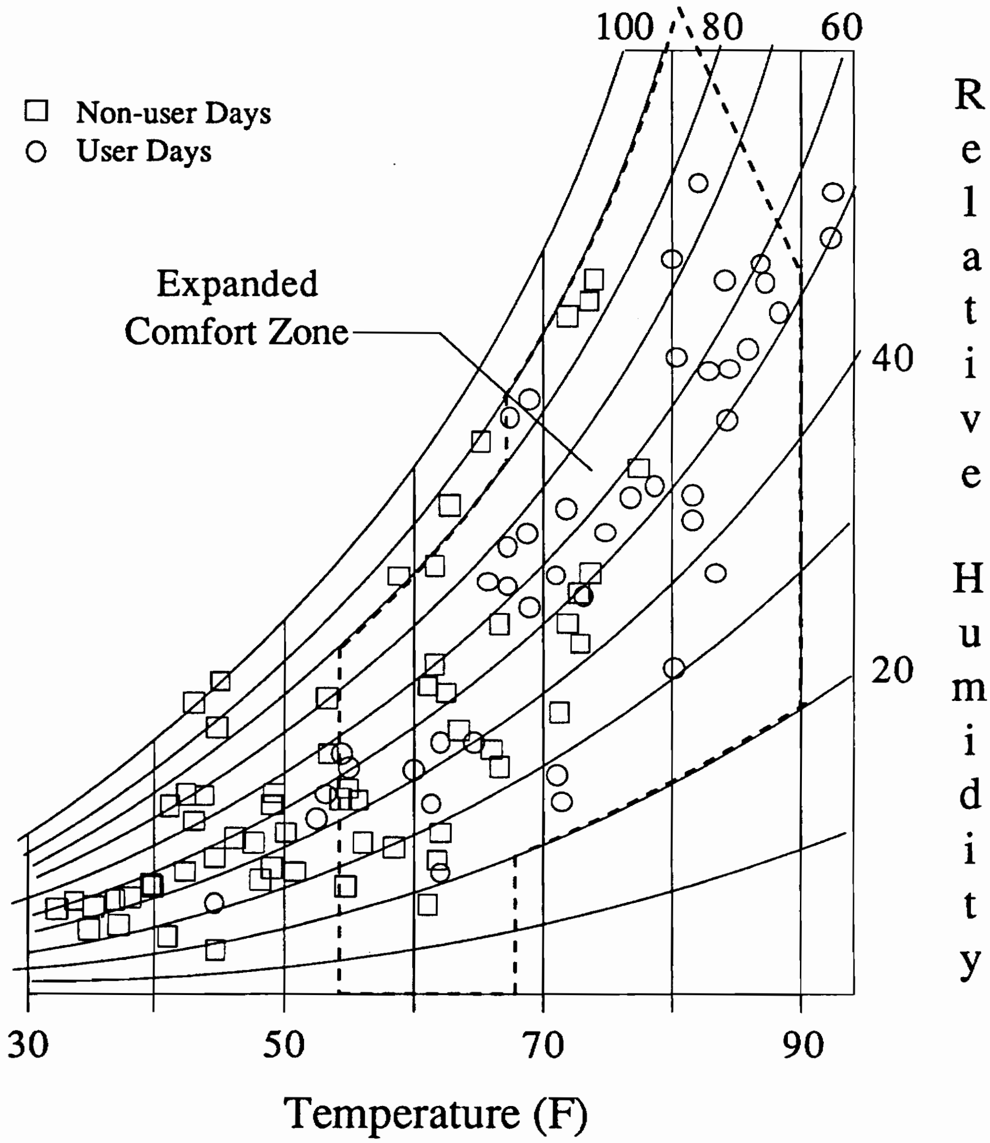
Note: All data for 12:00 pm on BC/BS plaza



Bioclimatic chart represents:
Metabolic rate = 1.0 (sitting, relaxed)
Clothing value = 0.8 (summer work clothing)

Figure 15. Givoni's Expanded Bioclimatic Chart

Note: All data for 12:00 pm on BC/BS plaza



Bioclimatic chart represents:
Metabolic rate = 1.0 (sitting, relaxed)
Clothing value = 0.8 (summer work clothing)

Figure 16. Givoni's Bioclimatic Chart With All Analysis Days

Note: All data for 12:00 pm on BC/BS plaza

What is significant from the plot on the bioclimatic chart is that the thirty-eight (38) analysis days outside the comfort zone included only six (6) user days - three (3) each outside the high and low parameters of comfort. These six (6) days account for less than eleven (11) percent of all user days. While the bioclimatic chart may not be a high predictor of behavior, the fact that less than eleven (11) percent of the user days are outside the comfort zone suggests that if climate can be ameliorated enough to pull the days into the comfort zone, then the opportunity for outdoor activity to occur will increase.

5.5 Index of Thermal Stress

The extreme difficulty in relating human responses to the outdoor thermal environment by any single climatic factor, as shown by the univariant regression analysis previously discussed, and the unreliability of the bioclimatic chart has been the basis for years of research by scientists from various fields to try and develop a universal indexing system to express human thermal comfort.

The Index of Thermal Stress, as used in this study and discussed in section 3.1, was calculated for both the regional airport and the study plaza using the representative climate information. Over the course of an annual cycle of climatic change, the values for the ITS, as summarized in Figure 17, ranged from -748.0 to 260.0 Kcal/hr at the

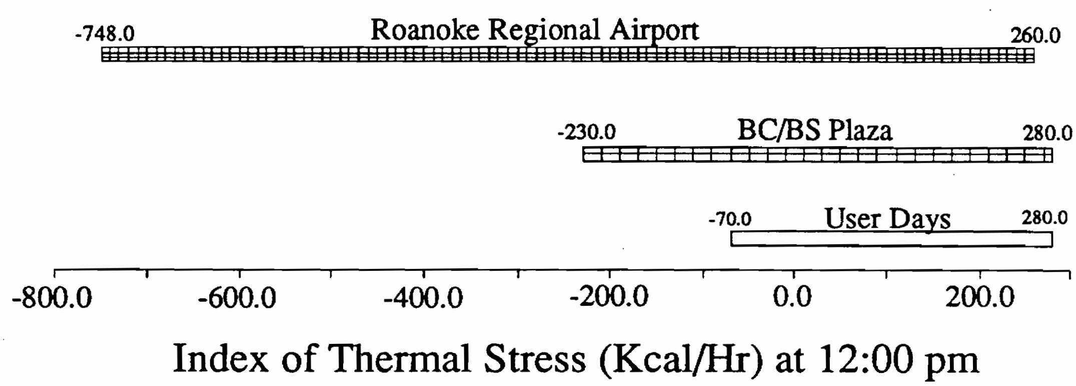


Figure 17. Comparison of Index of Thermal Stress Values

Note: All values correspond to 12:00 pm weather conditions.

airport; while the ITS range on the plaza was from -230.0 to 280.0 Kcal/hr which shows a significant reduction of the ITS range due to the surrounding buildings and infrastructure near the BC/BS plaza. This range can be reduced even further if it is considered for user days only. For days when people were observed on the plaza, the ITS range decreases to -70.0 to 280.0 Kcal/hr. This ITS range for user days begins to establish thresholds beyond which optional behavior, as observed in this investigation, will no longer occur. This is discussed further in the next section.

Frequency, total duration minutes and average duration were plotted against the ITS values in a univariant regression similar to that used for the individual climate factors. The results of the plot and statistical analysis, as shown by the summary in Table 7, is similar to the other regression analysis in that the association between observed behavior and the ITS is no better as a model than the regression analysis with the different climate factors. The correlation coefficient is much less than that of temperature for all behavior measurements indicating that this is a less than strong relationship.

5.6 Histograms

Histograms were created to help illustrate the relationships between ITS values and behavior frequency and duration. Figure 18 shows total number of users, or total frequency, plotted against ranges of the ITS values. This graph also illustrates the percentage of all users within each ITS range seated in either sun or shade.

As mentioned earlier in this section, the ITS values on the plaza ranged from -230.0 to 280.0 Kcal/hr; however, no users were observed on the plaza when the ITS level dropped below -70.0 Kcal/hr. All observed activity on the BC/BS plaza occurred within the range of -70.0 to 280.0 Kcal/hr as shown on the barchart. It is obvious in this graphic how quickly the observed frequency accelerates as the ITS value approaches 100.0 Kcal/hr and how rapidly it decelerates as the ITS value climbs to 250.0 to 300.0 Kcal/hr. This exemplifies the climatic threshold levels beyond which behavior frequency is influenced.

Figure 18 also depicts the percentage of people oriented in sun or shade seating. As is demonstrated, up to a 100.0 or 150.0 Kcal/hr ITS level the majority of visitors to the plaza preferred to sit in the sun. Beyond this point, the proxemics of the plaza change quickly to compensate, with cooling shade, for higher heat stress levels brought on by higher temperatures and solar radiation levels. In this study, for all observation days with an ITS value larger than 200.0 Kcal/hr, the average temperature was 31 degrees

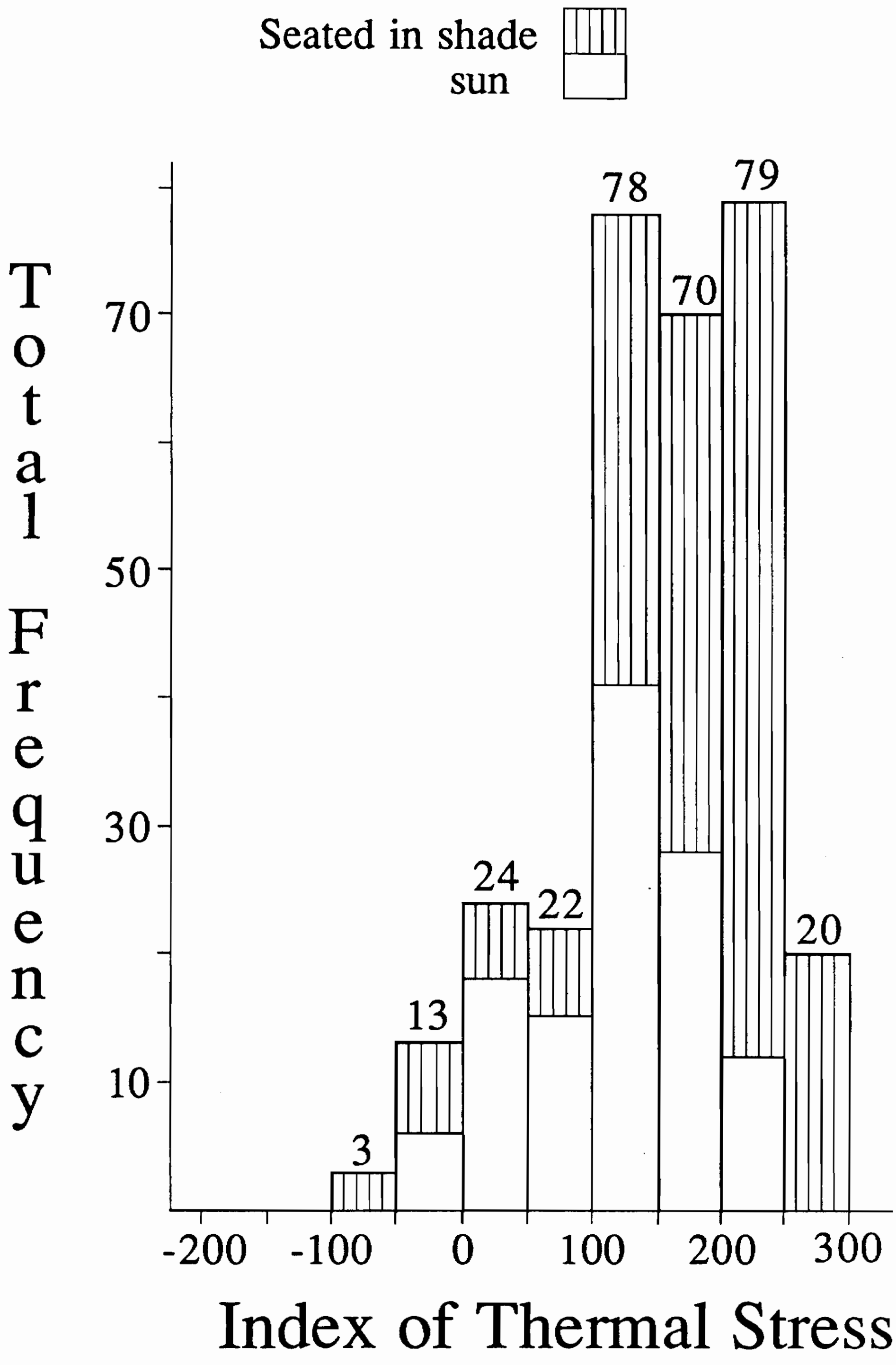


Figure 18. Total Number of Users versus Index of Thermal Stress

centigrade with an average solar level of 1.24 langleys per minute. At this level of heat stress, a substantial portion of the plaza users, eighty-five (85) percent or higher, preferred seats in the shade.

Similar results are evident from the histogram of total duration minutes observed for the same ITS ranges, Figure 19. As ITS values increased past a point of 100.0 Kcal/hr total duration minutes accelerated quickly and decelerated quickly as ITS values reached 250.0 Kcal/hr. Below -50.0 Kcal/hr, the average duration for visitors on the BC/BS plaza was just under eleven (11) minutes; above this level, average duration for users climbed to eighteen (18) minutes. This also establishes as threshold level beyond which duration of optional behavior, as observed in this investigation, is influenced.

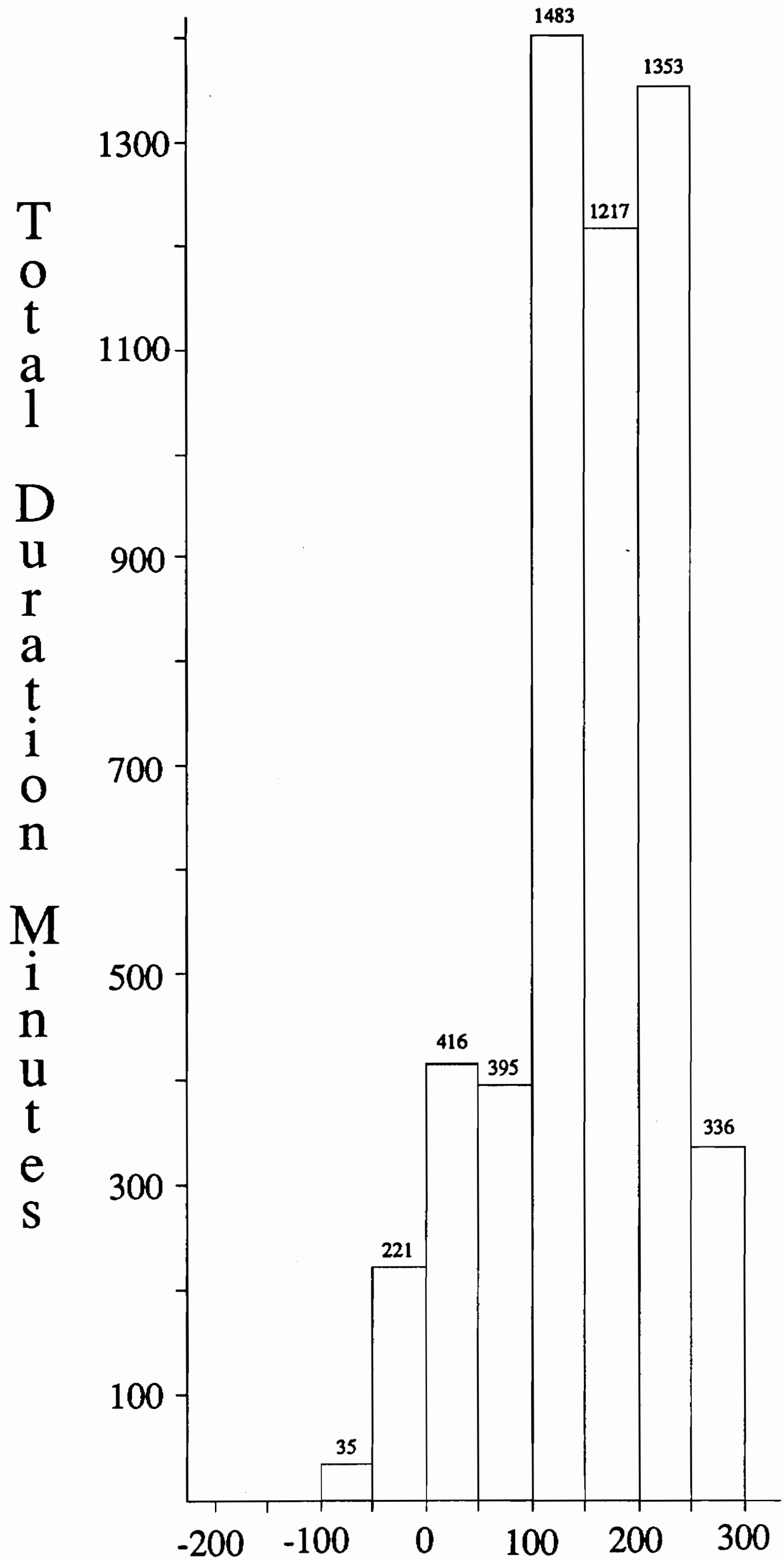


Figure 19. Total Duration Minutes versus Index of Thermal Stress

6.0 CONCLUSIONS

Models for predicting climate/behavior relationships have been appraised in an outdoor urban setting to determine their validity and accuracy. The observed frequency and duration characteristics of optional behavior have been empirically related to individual climate factors and the Index of Thermal Stress.

As observed in the statistical analysis of this investigation, and supported by earlier research, the number of people and their duration of stay on the plaza increased during days of moderate warmth and increased sunshine. After bad weather or on cooler days, sunlight may induce people outdoors for additional warmth. However, during high temperature levels, increased solar radiation can also induce people to stay indoors or head for the shade. The enticement of shade during this climate profile is evident from the frequency histogram, Figure 18.

Barometric pressure and humidity were statistically insignificant in influencing behavior; earlier studies do, however, show significant effects on behavior caused by higher humidity levels. It can also be observed from the scatterplots for humidity that the occurrence of the observed behavior quickly decelerates as humidity approaches seventy-five (75) percent.

While wind speed played no effective role in this project, previous research conclusively showed the effects of pedestrian level wind on user behavior. The fact that the effect of wind was negligible during this yearlong investigation is evidence of the impact of how good design decisions can mitigate climatic factors. The design, orientation and layout of the Blue Cross/Blue Shield office building and its adjacent plaza was such that the high, and detrimental, wind speeds at the airport were ameliorated. The late installation of the anemometer during this research did not allow accurate conclusions to be developed regarding wind and optional behavior patterns.

The empirical relationships established herein and in previous research begin to enable the formulation of new predictive models for optional behavior. These models are needed by designers and planners to make sound decisions in determining the size, orientation and arrangement of urban spaces. Two (2) existing models were tested here to establish their respective successes in predicting behavior - bioclimatic charts and the Index of Thermal Stress (ITS).

While the bioclimate charts are easy to use and understand, their use may not enhance predictions of behavior since all the different climatic factors that influence behavior during various times of the year are not totally considered. For instance, the bioclimatic charts assume that days or users to the left or below the comfort zone, indicating cold stress, are in conditions of no wind and ample solar radiation. Unfortunately, such conditions during cooler seasons are not the norm - wind usually exists in outdoor environments thus creating wind chill that may not be compensated by insolation. Climate mitigation through design may increase the number of days within a comfort zone and thus increase the number of useable days, but this research has shown that there is no guarantee that duration will be enhanced if the days are within the comfort zone. The bioclimate charts tend to be too generalized for behavior prediction.

Since all climatic conditions are not represented on the bioclimate charts, it is not possible to relate Givoni's ITS formula to the comfort zones represented on his chart. This is due to the numerous iterations that are possible from the different climate variables. The bioclimatic charts, thus, can only be considered as a very generalized predictor of increased duration since all factors are not considered. Design decisions that insure a high number of days of the year within the comfort zones can increase the number of days that may be useable; but the fact that those days are in the zone does not indicate possibly higher levels of duration.

Evidence to support the use of the ITS formula to predict behavior frequency and duration is somewhat better in this research than it is for the use of bioclimate charts. The fact that ITS values ranged from -70.0 to 280.0 Kcal/hr at 12:00 p.m. for all user days (days with someone on the study plaza) begins to show very general thresholds where optional behavior will be triggered. Based on this evidence, when using the ITS formula a comfort range that can be targeted by designers and planners of outdoor urban space to encourage behavior can be established.

It is concluded, from the results of this investigation, that this range should be from -50.0 to 250.0 Kcal/hr. The 159 days of the annual cycle plotted on the bioclimatic charts yielded sixty-five (65) percent (104/159) of those days within the expanded comfort zones on both Olgyay's and Givoni's charts. Similarly, of the days of the annual cycle, 110, or sixty-nine (69) percent, are within the hypothesized ITS comfort range, -50.0 to 250.0 Kcal/hr. Likewise, the 125 days used in this analysis display comparable results - seventy (70) percent within Givoni's expanded comfort chart versus seventy-one (71) percent within the proposed ITS comfort range. Due to the relatedness of the two (2) comfort zones, it is appropriate to ask which is the better predictor of frequency and duration of optional behavior.

This proposed range accounts for ninety-three (93) percent of both user days and total duration minutes. Only seven (7) percent of the user days are outside of this range which indicates the importance of design decisions to increase the number of days within this realm. It would be safe to speculate that the users within the range of -50.0 to 250.0 were thermally comfortable since the average duration for all visitors within this range is over seventeen (17) minutes, which can be a long time to sit outside if uncomfortable.

Results similar to those of the bioclimatic charts for predicting frequency of behavior are seen in the predictive use of the newly established ITS range. Within the ITS comfort range, fifty-eight (58) percent (52/89) of the days are user days, days with someone on the plaza, while fifty-seven (57) percent (50/87) of the days within Givoni's bioclimatic comfort zone are user days. The difference between the two models is in the analysis of the number of actual user days that were within the respective comfort zones. On Givoni's bioclimatic chart, only seventy-nine (79) percent of the user days are within the comfort zone. Within the ITS comfort range, established here, are ninety-three (93) percent of the user days. Only seven (7) percent of the user days fall outside the ITS range.

Indexing formulas, according to this research, may be a better tool for designers and planners to use. The evidence from this project shows how optional behavior activities quickly accelerate or decelerate as index values approach threshold levels. If designers of urban spaces, using the Index of Thermal Stress, can mitigate climate to the extent that a high percentage of the days of the year have an ITS value within the thresholds -50.0 to 250.0 Kcal/hr, not only will the number of possible user days increase, but so will the likelihood that users will be comfortable while visiting these sites over an extended period of time, especially if shade is provided for plaza users to compensate for higher stress levels as the ITS value approaches the shading threshold between 150.0 and 200.0 Kcal/hr.

7.0 DISCUSSION

While the results of this investigation may indicate varying levels of success when trying to predict pedestrian behavior using different models, the ability to predict behavior based upon these results is still a complex, and possibly difficult, task. While this research clearly shows behavior/climate thresholds that assist in predicting outdoor behavior, its applications are still in the exploratory stage.

The similarities of findings between this project and earlier projects by Song (1987), and Bork and Watts (1985), emphasizes the need for designers of outdoor spaces to heed climatic conditions in design decisions. The numbers here, and in prior studies, show that optional behavior, especially its duration, is influenced by temperature and solar radiation. The similar high correlation values between duration and these two climate factors, evident in this and earlier studies, supports this conclusion (Table 8).

A large portion of the differences in the findings with earlier research may be attributed to the type of plazas studied. The library plaza on the Virginia Polytechnic Institute campus was used in the early studies by Song (1987) and Bork and Watts (1985). This space is such that behavior will take place on the library plaza nearly every day; whether the behavior is optional or necessary was found to be correlated to the climatic conditions

Table 8. Comparison of Correlation Coefficients Between Similar Research Projects

Frequency Correlations

Researcher: Song		Warner
0.1083	Temperature	0.7370
-0.3901	Relative Humidity	-0.4290
-0.2507	Wind Velocity	
-0.1294	Solar Radiation	0.4741
	Barometric Pressure	0.0422

Average Duration Correlations

Researcher: Song		Warner
0.6029	Temperature	0.7736
0.1063	Relative Humidity	-0.3374
-0.1343	Wind Velocity	
0.4918	Solar Radiation	0.4332
	Barometric Pressure	0.0760

Index of Thermal Stress Correlations

Researcher: Song		Warner
0.0619	Frequency	0.5178
0.6060	Average Duration	0.6224

at the time. But this is a space in which people pass though to a final destination; it is seldom realized as a final destination itself. The BC/BS plaza, in contrast, is considered to be a final destination. The peak activity on the library plaza can occur at nearly any time during daylight hours, while peak activity periods are realized only during "lunch hours" on the plaza in downtown Roanoke. This causes the plaza to become a destination - people go outside to sit and eat, or just to sit, and then they go back inside to go to work. People do not pass through the BC/BS plaza to a different place. This may suggest that climate mitigation is more of a factor to influence duration of stay rather than influencing frequency of use.

Two tools to establish thermal comfort - the Index of Thermal Stress (ITS) and bioclimatic charts - are used in this research project to try to predict optional behavior. The bioclimatic charts, developed by Olgyay and Givoni and discussed in earlier chapters, while easy to use, do not consider all of the simultaneous seasonal climatic factors involved in thermal comfort. This has major significance on the use of this tool as a predictor.

Both charts primarily use ambient temperature and relative humidity to establish the comfort zones. Wind velocity is considered as a cooling mechanism during climate profiles of high temperature and high humidity. While cooling breezes are important, the wind also plays a significant role as wind chill in cooler seasons. Days that are characteristically below the comfort zone on Olgyay's bioclimatic chart, and to the left of Givoni's comfort zone, will be pushed further away or out of the zone if wind chill is considered. While solar insolation is considered as a warming mechanism in cool conditions, the highest possible levels of solar radiation available during the cool seasons of year may not sufficiently expand the comfort zone to recapture the days pushed out or away from the comfort zone by wind chill.

Similar results occur above the comfort zone in warmer weather conditions but for different reasons. High ambient temperatures combined with high humidity levels produce higher levels of thermal discomfort. This is compounded with the addition of high solar radiation levels. The increased radiation will force days characteristically above Olgyay's comfort zone, and right of Givoni's comfort zone, to be pushed further away unless ample shade is provided or wind velocities are increased significantly to compensate for the increased sweat levels that will develop. At some point, however, the increased wind speeds themselves begin to have negative effects on participants (Table 9) thus escalating the desire, and attractiveness, of shade.

It should be noted here that there are two types of shade - shade from structures and buildings and shade from plant materials. While shade patterns cast by buildings and structures will alleviate conditions of high solar insolation, they do not have the characteristic cooling effect of shade from transpiring plants. The fact that plants release

Table 9. Wind Scales and Related Effects

Beaufort Wind Scale

Beaufort Number	Wind Speed (mph)	Atmospheric and Behavioral Effects
0, 1	0 - 3	Calm, no critical wind
2	4 - 7	Wind felt on face
3	8 - 12	Wind extends light flag; rain is disturbed; clothing flaps
4	13 - 18	Dust, dry soil, loose paper raised; hair disarranged
5	19 - 24	Force of wind felt on body; drifting snow becomes airborn; limit of agreeable wind on land

Arens Wind Scale

Wind Speed	Effects observed or Deduced
0 mph	Calm, no noticeable wind
	Wind felt on face
4.4	Clothing flaps
8.8	Newspaper reading becomes difficult
13.2	Hair disarranged, dust and paper raised, rain and sleet driven
17.6	Control of walking begins to be impaired
	Violent flapping of clothes, progress into wind slightly slowed
22.0	Umbrella used with difficulty
26.4	Blown sideways, inconvenience felt walking into wind, hair blown straight
	Difficult to walk steadily, appreciably slowed into wind
	Noise on ears unpleasant
30.8	Almost halted into wind, tottering downwind
35.2	Difficulty with balance in gusts
	Unbalanced, grabbing at supports
41.8	People blown over in gusts
48.4	Can not stand

Source: Arens, Edward, Designing for an Acceptable Wind Environment, 1981.

moisture through transpiration causes their shade to feel cooler thereby possibly alleviating greater levels of thermal discomfort. While Olgyay and Givoni indicated a level, based on temperature, at which shading should be provided, it may be inaccurately located. This belief is based to the observed behavior of this research and since all climatic factors are not considered simultaneously. Givoni's and Olgyay's bioclimatic charts have shading lines - temperature levels at which shade should be provided - at 68 or 70 degrees fahrenheit (20 - 21 degrees centigrade). Based on the data from this research, shade does not become a truly important factor influencing behavior until temperature levels approach 30 degrees centigrade (85 F). At this temperature level, the majority of plaza users will orient themselves in shaded areas. This information can be important to designers of outdoor spaces in aiding decisions for orientation of shade patterns based on the time of day and the time of year. During warmer seasons, shading may not be necessary for the early hours of the day before temperature and solar radiation levels reach their respective daily peaks. By mid-day however, these levels may dictate shading to insure thermal comfort of pedestrians. The orientation and angle of the sun at mid-day can indicate installation locations for shading structures or plants to reduce thermal stress.

During the course of this research, two (2) factors were held constant for thermal stress calculations - clothing and wind. Both of these factors, if variable throughout the year, could have significant influence on the calculated ITS values. Wind was held constant, as discussed earlier, since site specific data collection did not begin until ten (10) months into the study. Replication of this project with a full annual cycle of site specific wind data is essential before conclusive judgments can be made on the influence of wind on optional pedestrian behavior. The accuracy of the ITS values that may have been lost due to the constant wind speed may be minimal since the average wind speeds that were recorded was 2.3 miles/hour while a constant speed of 1.9 miles/hour (3.0 kilometers/hour) was used in calculations. Nonetheless, the ITS values would be different than those calculated here. It is this researchers belief, however, that the range of the ITS values over the course of an annual cycle either at the airport, the plaza or for "user days" would be no different than those observed in this project.

Clothing may have a more significant affect on thermal comfort over the course of the annual cycle than observed. A clothing value for light summer clothes - underwear, short sleeve shirt, long pants, hat - was used throughout this investigation. In observing the video tapes, it can be noted that cyclic clothing changes correspond with the cyclic change of season. Sweaters and light jackets become more conspicuous during early Spring and again in the late Fall. Since clothing changes, clothing values should change also. The ability to calculate new values based on clothing material and human physiology is beyond the scope of this researcher at this time. An attempt should be made in future research, however, to incorporate this cyclic clothing change into the ITS formula, or any other indexing formula.

The bioclimatic charts used in this research project, as discussed earlier, are derivatives of charts and formulas used to calculate thermal comfort levels for interior environments. Their ability to accurately predict thermal comfort and pedestrian behavior was tested here to determine their legitimate use in outdoor settings. The relative inability to reliably predict optional pedestrian behavior demonstrates the need for new predictive models that can be used by designers and planners of outdoor spaces. With the data collected and conclusions established herein, it may be possible to begin to develop a new thermal comfort chart that is derived from observed behavior and climate data in an exterior environment. This project, and earlier research also conducted using the ITS formula, clearly contribute to the future development of a new prediction model that should be embraced by designers and planners so that newly created and redesigned outdoor urban environments will be able to contribute positively to the urban lifestyle.

8.0 FUTURE RECOMMENDATIONS

The findings of this research project represent a large step forward to the establishment of speculative tools that may be used to influence climate and behavior relationships. While this quantitative examination goes beyond earlier studies by being conducted over an entire annual cycle of climatic change, it may be limited to the specific study plaza at the Blue Cross/Blue Shield office in downtown Roanoke. The threshold levels discussed herein may also be limited to this geographical region of southwest Virginia.

It is recommended that this research be replicated at different sites, possibly within different regions, to clearly determine if the climate/behavior thresholds established here are conclusive. Regionally different annual climatic profiles would serve as an excellent and legitimate test of the thresholds and ITS comfort range. Replication would also allow for accurate determination of the effects of pedestrian level winds and changing clothing values on outdoor optional behavior.

Continued investigation by researchers to establish a universal formula to measure thermal comfort will lead to developing and testing of new formulas in the future. Results from this project and others can be compared to adjust or validate the herein concluded behavior thresholds. Since the climate and behavior data for an annual cycle is recorded here, a comparison between new indexing formulas would be uncomplicated.

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APPENDICES

Appendix A

"Basic" program for calculating the Index of Thermal Stress

```
10 PRINT "program to calculate givoni's index of thermal stress"
20 PRINT "assumes the following"
30 PRINT
40 PRINT
50 PRINT
60 REM assigned values are as follows
70 MET=100
80 ALPHA=11.6
90 KCL=0.4
100 A=0.52
110 KPE=0.386
120 P=13
130 PRINT" "
140 PRINT" "
150 PRINT "please input the following"
160 PRINT "temperature in degrees C"
170 INPUT TA
180 PRINT "wind velocity in kilometers per hour"
190 INPUT VKMHR
200 PRINT "solar insolation in langleys per minute"
210 INPUT INLANG
220 PRINT "vapor pressure in inches of mercury"
230 INPUT VPIM
240 VMSEC=VKMHR*0.28
250 INKCAL=INLANG*1080
260 VPMMHG=VPIM*25.4
270 C=ALPHA*(VMSEC^0.3*(TA-35))
280 R=INKCAL*KCL*KPE*(1-A(VMSEC^0.2-0.88))
290 E=MET+R+C
300 EMAX=P*VMSEC^0.3*(42-VPMMHG)
310 POW=0.6*(E/EMAX-0.12)
320 S=E*EXP(POW)
330 PRINT "the index of thermal stress is "S
340 PRINT " "
350 PRINT " "
360 LPRINT "the index of thermal stress is "S
370 PRINT "do you wish to continue - enter yes or no"
380 INPUT CONTINUE$
390 IF CONTINUE$ = "yes" THEN 130
400 END
```

Appendix B

Individual Climatic Factors and ITS Regression Reports

Regression Analysis of Relationship Between Frequency and Temperature.

Dependent Variable:	FTL_USER		
Independent Variable:	TEMP_D		
Parameter Estimate	.6033753571773388		
%100% Conf. Int. for b	-17.17211	18.37886	(t = 100.000)
Std. Parameter Estimate	.6639512		
Standard Error	.1777548	Variance of Parameter	3.159678E-02
T for Parameter = 0	3.394424	Prob. Level	0.0068
Simple Correlation	0.7370	Simple R Squared	0.5432
Partial Correlation	0.7317	Partial R Squared	0.5354
		Sequential R Squared	0.5432
		Overall R Squared	0.6540
Sequential Sum Squares	286.639	Model Sum of Squares	345.1257
Last Sum Squares	210.4027	Total Sum of Squares	527.7333
Mean	15.44	R Squared with other Xs	0.0956
Standard Deviation	6.756034	Variance Inflation	1.105696
Diagonal of Inverse	1.73031E-03	Tolerance	0.9044

Regression Analysis of Relationship Between Average Duration and Temperature.

Dependent Variable:	AVRG_DUR		
Independent Variable:	TEMP_D		
Parameter Estimate	.7777556342589961		
%100% Conf. Int. for b	-20.41387	21.96938	(t = 100.000)
Std. Parameter Estimate	.7142974		
Standard Error	.2119163	Variance of Parameter	.0449085
T for Parameter = 0	3.670108	Prob. Level	0.0043
Simple Correlation	0.7736	Simple R Squared	0.5984
Partial Correlation	0.7576	Partial R Squared	0.5739
		Sequential R Squared	0.5984
		Overall R Squared	0.6574
Sequential Sum Squares	453.3569	Model Sum of Squares	496.0598
Last Sum Squares	349.5927	Total Sum of Squares	757.6
Mean	15.44	R Squared with other Xs	0.0956
Standard Deviation	6.756034	Variance Inflation	1.105696
Diagonal of Inverse	1.73031E-03	Tolerance	0.9044

Regression Analysis of Relationship Between Frequency and Relative Humidity.

Dependent Variable:	TTL_USEF		
Independent Variable:	HUMID_D		
Parameter Estimate	-.0682121926201693		
%100% Conf. Int. for b	-10.48575	10.30932	(t = 100.000)
Std. Parameter Estimate	-.2075117		
Standard Error	.1039753	Variance of Parameter	1.081087E-02
T for Parameter = 0	-.8483954	Prob. Level	0.4161
Simple Correlation	-.4290	Simple R Squared	0.1841
Partial Correlation	-0.2591	Partial R Squared	0.0671
		Sequential R Squared	0.6379
		Overall R Squared	0.6540
Sequential Sum Squares	47.98609	Model Sum of Squares	345.1257
Last Sum Squares	13.14364	Total Sum of Squares	527.7333
Mean	42.2	R Squared with other Xs	0.4216
Standard Deviation	14.44299	Variance Inflation	1.728956
Diagonal of Inverse	5.920273E-04	Tolerance	0.5784

Regression Analysis of Relationship Between Average Duration and Relative Humidity.

Dependent Variable:	AVRG_DUR		
Independent Variable:	HUMID_D		
Parameter Estimate	-5.459327251635597D-02		
%100% Conf. Int. for b	-12.45035	12.34117	(t = 100.000)
Std. Parameter Estimate	-.1071866		
Standard Error	.1239576	Variance of Parameter	1.536549E-02
T for Parameter = 0	-.4404189	Prob. Level	0.6690
Simple Correlation	-.3374	Simple R Squared	0.1138
Partial Correlation	-0.1379	Partial R Squared	0.0190
		Sequential R Squared	0.6418
		Overall R Squared	0.6574
Sequential Sum Squares	22.90457	Model Sum of Squares	498.0598
Last Sum Squares	5.03427	Total Sum of Squares	737.6
Mean	42.2	R Squared with other Xs	0.4216
Standard Deviation	14.44299	Variance Inflation	1.728956
Diagonal of Inverse	5.920273E-04	Tolerance	0.5784

Regression Analysis of Relationship Between Frequency and Solar Insolation.

Dependent Variable:	TTL_USER		
Independent Variable:	SOLAR_D		
Parameter Estimate	2.453060832135809		
%100% Conf. Int. for b	-372.7549	377.661	(t = 100.000)
Std. Parameter Estimate	.1661964		
Standard Error	3.752079	Variance of Parameter	14.0781
T for Parameter = 0	.6537671	Prob. Level	0.5290
Simple Correlation	0.4741	Simple R Squared	0.2247
Partial Correlation	0.2025	Partial R Squared	0.0410
		Sequential R Squared	0.6490
		Overall R Squared	0.6540
Sequential Sum Squares	5.894518	Model Sum of Squares	345.1257
Last Sum Squares	7.805336	Total Sum of Squares	527.7333
Mean	.8013333	R Squared with other Xs	0.4645
Standard Deviation	.4159648	Variance Inflation	1.867524
Diagonal of Inverse	.7709479	Tolerance	0.5355

Regression Analysis of Relationship Between Average Duration and Solar Insolation.

Dependent Variable:	AVRG_DUR		
Independent Variable:	SOLAR_D		
Parameter Estimate	2.982270970160165		
%100% Conf. Int. for b	-444.3341	450.2987	(t = 100.000)
Std. Parameter Estimate	.168635		
Standard Error	4.473164	Variance of Parameter	20.0092
T for Parameter = 0	.6667028	Prob. Level	0.5200
Simple Correlation	0.4332	Simple R Squared	0.1877
Partial Correlation	0.2063	Partial R Squared	0.0426
		Sequential R Squared	0.6545
		Overall R Squared	0.6574
Sequential Sum Squares	9.600066	Model Sum of Squares	498.0598
Last Sum Squares	11.53637	Total Sum of Squares	757.6
Mean	.8013333	R Squared with other Xs	0.4645
Standard Deviation	.4159648	Variance Inflation	1.867524
Diagonal of Inverse	.7709479	Tolerance	0.5355

Regression Analysis of Relationship Between Frequency and Barometric Pressure.

```
Dependent Variable:        TTL_USER
Independent Variable:      PRESSURE

Parameter Estimate         -1.737094574630532
%100% Conf. Int. for b     -461.5545         458.0803      (t =   100.000)
Std. Parameter Estimate    -.0747943
Standard Error              4.598174       Variance of Parameter     21.14321
T for Parameter = 0        -.3777792       Prob. Level               0.7135

Simple Correlation          0.0422         Simple R Squared          0.0018
Partial Correlation        -0.1186         Partial R Squared         0.0141
                                           Sequential R Squared      0.6540
                                           Overall R Squared         0.6540

Sequential Sum Squares      2.606124       Model Sum of Squares      345.1257
Last Sum Squares            2.606124       Total Sum of Squares      527.7333

Mean                        28.80133       R Squared with other Xs   0.1172
Standard Deviation          .2643555       Variance Inflation        1.132808
Diagonal of Inverse         1.157849       Tolerance                 0.8828
```

Regression Analysis of Relationship Between Average Duration and Barometric Pressure.

```
Dependent Variable:        AVRG_DUR
Independent Variable:      PRESSURE

Parameter Estimate         -1.595395631937667
%100% Conf. Int. for b     -549.7818         546.591       (t =   100.000)
Std. Parameter Estimate    -5.733248E-02
Standard Error              5.481864       Variance of Parameter     30.05083
T for Parameter = 0        -.2910316       Prob. Level               0.7770

Simple Correlation          0.0760         Simple R Squared          0.0058
Partial Correlation        -0.0916         Partial R Squared         0.0084
                                           Sequential R Squared      0.6574
                                           Overall R Squared         0.6574

Sequential Sum Squares      2.19829        Model Sum of Squares      498.0598
Last Sum Squares            2.19829        Total Sum of Squares      757.6

Mean                        28.80133       R Squared with other Xs   0.1172
Standard Deviation          .2643555       Variance Inflation        1.132808
Diagonal of Inverse         1.157849       Tolerance                 0.8828
```

Regression Analysis of Relationship Between Frequency and the Index of Thermal Stress.

Dependent Variable:	TTL_USER		
Independent Variable:	ITS_D		
Parameter Estimate	1.444183717362184D-02		
%100% Conf. Int. for b	-.1998589	.2287426	(t = 100.000)
Std. Parameter Estimate	.5177535		
Standard Error	2.143008E-03	Variance of Parameter	4.592482E-06
T for Parameter = 0	6.73905	Prob. Level	0.0000
Simple Correlation	0.5178	Simple R Squared	0.2681
Partial Correlation	0.5178	Partial R Squared	0.2681
		Sequential R Squared	0.2681
		Overall R Squared	0.2681
Sequential Sum Squares	454.5019	Model Sum of Squares	454.5019
Last Sum Squares	454.5019	Total Sum of Squares	1695.468
Mean	48.9796	R Squared with other Xs	0.0000
Standard Deviation	132.0354	Variance Inflation	1
Diagonal of Inverse	4.588906E-07	Tolerance	1.0000

Regression Analysis of Relationship Between Average Duration and the Index of Thermal Stress.

Dependent Variable:	AVRG_DUR		
Independent Variable:	ITS_D		
Parameter Estimate	4.104428940219563D-02		
%100% Conf. Int. for b	-.4224946	.5045832	(t = 100.000)
Std. Parameter Estimate	.6223834		
Standard Error	4.635389E-03	Variance of Parameter	2.148683E-05
T for Parameter = 0	8.854551	Prob. Level	0.0000
Simple Correlation	0.6224	Simple R Squared	0.3874
Partial Correlation	0.6224	Partial R Squared	0.3874
		Sequential R Squared	0.3874
		Overall R Squared	0.3874
Sequential Sum Squares	3671.101	Model Sum of Squares	3671.101
Last Sum Squares	3671.101	Total Sum of Squares	9477.206
Mean	48.9796	R Squared with other Xs	0.0000
Standard Deviation	132.0354	Variance Inflation	1
Diagonal of Inverse	4.588906E-07	Tolerance	1.0000

Vita

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Education

1991 Master of Landscape Architecture, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

1986 Bachelor of Science - Horticulture, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Professional Experience

1991 - Susan Hall and Associates, Coral Gables, Florida; Landscape Architect.

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1985 - 1988 Laurel Creek Nursery, Ltd., Blacksburg, Virginia; Landscape Designer and Estimator.

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1984 Department of Horticulture, Virginia Polytechnic Institute and State University, Blacksburg, Virginia; Designer - Virginia Tech Horticultural Gardens.

1978 - 1980 Snow's Garden Center, Charlottesville, Virginia; Landscape Crew Foreman.

Academic Positions

1989 - 1990 Virginia Polytechnic Institute and State University, Graduate Tecahing Assistant; Instructed classes in Basic Landscape Technology (1989, 1990) and Site Planning and Development (1989).

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Professional Organizations

1991 - American Society of Landscape Architects, Associate Member.

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1990 Outstanding Graduate Teaching Assistant, Department of Landscape Architecture.

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