EVALUATION OF BUILDING AND OCCUPANT RESPONSE TO TEMPERATURE AND HUMIDITY: NON-TRADITIONAL HEAT STRESS CONSIDERATIONS

A COMPARISON OF DIFFERENT CONSTRUCTION TYPES USED BY THE TEXAS DEPARTMENT OF CRIMINAL JUSTICE

A Dissertation

by

JOSEPH TOREY NALBONE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2004

Major Subject   Interdisciplinary Engineering

EVALUATION OF BUILDING AND OCCUPANT RESPONSE TO TEMPERATURE AND HUMIDITY: NON-TRADITIONAL HEAT STRESS CONSIDERATIONS

A COMPARISON OF DIFFERENT CONSTRUCTION TYPES USED BY THE TEXAS DEPARTMENT OF CRIMINAL JUSTICE

A Dissertation

by

JOSEPH TOREY NALBONE

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Approved as to style and content by:

James C. Rock (Chair of Committee)	David Busbee (Member)
David N. McMurray (Member)	Leon H. Russell (Member)
N. K. Anand (Head of Department)	

December 2004

Major Subject: Interdisciplinary Engineering

ABSTRACT

Evaluation of Building and Occupant Response to Temperature and Humidity:

Non-Traditional Heat Stress Considerations

A Comparison of Different Construction Types Used by the

Texas Department of Criminal Justice. (December 2004)

Joseph Torey Nalbone, B.S., Baylor University:

M.S., University of Texas at Dallas

Chair of Advisory Committee: Dr. James C. Rock

This study examined the effects of construction types on the indoor environment of selected prison facilities in the State of Texas. Three collocated facilities of the Texas Department of Criminal Justice were monitored for temperature, relative humidity and barometric pressure over a period of fifteen months. The objectives of the study were to examine the response of the built environment to the stressors of ambient conditions, characterize the influence of the construction method for each facility and study the responses of the occupants of the buildings. From the data, an apparent temperature was calculated and then compared to the data collected by the regional National Weather Service facility for ambient conditions. A relationship between the type of facility and the resulting indoor environmental conditions was established. The construction materials chosen for a particular facility affected not only the rate of heating of the indoor environment but also the maximum temperature, apparent temperature and thermal variation experienced by the occupants. The peak temperature and relative humidity were higher in the metal facilities when compared to the concrete facility. Therefore, the difference in occupant living conditions was considerable when the internal environmental conditions (temperature and humidity) were compared between construction types. The concrete construction also moderated the changes in the occupant environment through a lag of internal conditions behind those of the external environment. This resulted in a slower apparent temperature rise over the course of the day in the concrete buildings and a delay in the internal high temperature of the day. Finally, the data shows that measures of aggression vary with the seasonal changes, Increasing in the warming months and decreasing in the cooling months. This increase in the metal constructed facilities is greater than the rate of increase found in the concrete constructed facility.

To Spunky

ACKNOWLEDGMENTS

Indeed, many people should be recognized for their guidance and encouragement in the preparation of this dissertation. I am particularly grateful to Dr. James C. Rock, my committee chair and the other members of the committee, Drs. David Busbee, David McMurray, and Leon Russell.

A great deal of thanks goes to the administration and staff of the Texas Department of Criminal Justice (TDCJ) Institutional Division who assisted in numerous ways in this research. Resources to purchase the data-logging environmental monitors were provided by the Facilities Division in conjunction with their new construction monitoring emphasis. I especially want to express my gratitude to those in the TDCJ administration during the data collection phase of this work. I appreciate the cooperation of Mr. Wayne Scott the TDCJ Executive Director, Mr. Art Mosley, Deputy Executive Director and Mr. Gary Johnson, Institutional Division Director for their support and providing access to the TDCJ units chosen for the study. In the early stages of study, design Ms. Tia Henegan also provided invaluable perspective during the field placement of the monitors and early data collection. Then in the later development of this manuscript, Meredith Burgess and Katie Grabner provided valuable assistance in the reduction and manipulation of the data to ease the analysis and graphical representation.

I also want to recognize the support and encouragement I received from two colleagues during the final stages of this dissertation. Drs. Ron Dodson and Jeffrey Levin never gave up on me. Each continued to support, in their own way, my aspirations and goals with this project. Their sage counsel, friendship and unwavering support was there every time I needed a boost to go a little farther, dig a little deeper or to assist in the performance of a reality check on my priorities.

I would like to thank all my friends and well-wishers for their prayers and support. They came through, especially when the stamina and creativity was lacking.

Finally, I wish to express my gratitude and affection to my family. First, my two daughters Adrienne and Sarah who have grown up during their Dad’s graduate education. They seemed to understand the importance and were willing to give me the time when needed. Although I was trying to work on my studies, I never expected them to take second place to this or any other project. Both always seemed to have a good word to offer whenever one was needed. I reserve however, the deepest appreciation for my wife, Katherine to whom this dissertation is dedicated. She never seemed to understand my reasons for wanting to embark on this journey. Undaunted, she was always there to give the desired level of assurance, thoughtful encouragement, and was there to consistently motivate me forward, in her own unique way. I am very appreciative of her final review of this manuscript for errors and grammar sense. An objective party is handy when you can’t see the forest for the trees.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

CHAPTER I

INTRODUCTION AND BACKGROUND

This research has examined the responses of buildings and occupants to the ambient temperature and humidity changes in the southeastern part of Texas. Several studies have been conducted on the issue of heat stress in human populations. From this collection of studies, the effects of heat stress on workers is well documented in the literature and under occupational conditions, this physical hazard to human health has been well characterized and studied.(1,2) Traditional heat stress factors are used by this study. The factors include air temperature, air velocity and humidity, physiological heat from metabolism and radiated heat from work and surfaces in the surrounding area. Within a built environment during sedentary or low activity levels the contributors to the overall heat load are reduced to primarily the ambient environment (temperature and humidity) and to whatever the sources of heat exchange exist as part of the building structure and mechanical systems. This research investigated the response of prison buildings to local meteorology (temperature and humidity) defined by a recognized climactic zone within the state. These buildings, as described, are designed to use natural and forced air exhaust ventilation to control the indoor environment. These mechanical systems, however, do not include a mechanism for removing insensible or latent heat from the internal environment.

This dissertation follows the style and format of the *Journal of Occupational and Environmental Hygiene*.

Another factor that is measurable and affects security in a prison is the aggression of inmates against each other and the correctional staff. This study compares measured environmental response of the prison buildings with a measure of inmate aggression available from each of the subject facilities, Uses of Force. This indicator is one measure of aggression (violence) within the prison system that is consistently reported by every Texas State Prison facility as part of their monthly statistics. The effects of ambient temperature on aggression has been studied extensively[3-11] and the evidence of these studies is used to evaluate the heat effects on the inmate population of the selected facilities.

BRIEF HISTORY OF PRISON BUILDINGS

Prison design in the past largely reflected the local social and cultural practices. Many of the earliest records of confinement (incarceration) include structures that were not originally designed to house prisoners. Records of prisons began among the ancient Greeks and Romans. Prisons were places to hold persons prior to their execution or banishment. They were also used as places of punishment for failure to pay debts or for political dissent. Some of the original confinement structures also arose from the need for religious imprisonment. Violators of Canonical law were subjected to arrest and taken for confinement and seclusion. Often a religious order would establish a satellite in a geographic location that was less desirable. Individuals of the religious order would then be transferred to these locations for infractions of the order. These locations were therefore regarded as punitive facilities. These became the facilities where an offender would have the opportunity to reflect and become penitent (hence the name penitentiary)[12].

Early structures were crude, of simple cage design or subterranean enclosures within a fortress or castle. Cells were often constructed as rooms without doors or windows but with a high vaulted ceiling. Of these facilities, few details of their design and construction are well documented.[13] The common design features of these early prisons were their sizeable and secure construction. Notable fortifications used as prisons include the Tower of London in England and the Bastille in France. One of these ancient fortifications of pertinent interest to this study is the Doge's Palace in Venice.[14] It seems that during the early 16th century, space in the Doge's Palace for housing prisoners was diminishing. In order to house more prisoners, a decision was made to construct prison buildings adjacent to the Palace, yet connected by a bridge. The construction was completed in 1610. The construction of this new facility addressed the issue of detention conditions, especially since the government had decreed that adequate space, air and light would be afforded to the prisoners housed within. However, certain prisoners continued to be housed in the Palace in areas known as the Wells and the Leads, due to their location within the Palace.[14] These areas were essentially the dungeons and they were lightless, lacked adequate ventilation, and were stifling hot in the summer and damp cold in the winter.

The design and construction of dedicated prison facilities continued to progress slowly, but is was not until the 18th century and a review of world prisons by John Howard (*State of the Prisons 1777 to 1792*) that the real conditions of penitentiary life became known.[13] Even in the new country of America, prisons were operated by a local official who used whatever resources were available to run his institution and seemed to make money in the process. Howard found, in general, that buildings were in disrepair, facilities were often over crowded and the conditions were wholly unsanitary and inhumane. The supervision over the prisoners was minimal and frequently inmates were left to their own resources to manage in this environment. No generally accepted design for prisons was available; however, as a penal philosophy began to develop so, did a design standard for prisons. Norman Johnston, in his subsequent work, details many of the traits that became common in the design of prisons. [15]

The evolution of specific prison architecture from the 1830's was one developed out of necessity. Efforts to bring humaneness to imprisonment originated largely in Europe and specifically in England. [15] The buildings were constructed on a semicircular or radial layout. These "modern" prisons were designed of centrally connected wings or runs spread out to discourage the contacts between prisoners. These changes provided housing units that could be segregated in the event of emergencies yet provided for a traffic flow of prisoners and staff in a very controlled yet convenient layout.

By the mid 19th century, prison reform was in full swing in North America and the prison designs were modified again. The earlier designs were not as successful as anticipated and the need for more prisons, to address overcrowding, presented opportunities to further develop a standard prison design.[15]

Around the world in the early part of the 20th century, countries began once again to review the buildings meant to keep prisoners. Modifications and improvements of the radial design were built and a new footprint for the prison appeared. Called the "telephone/telegraph pole," these buildings were designed with long core halls with intercalated "crash gates" to divide the hall for security and control. The housing units were positioned laterally off the central run. Cells were arranged either down one or both sides of an alleyway. In these types of facilities, inmates had access to fresh air and sunlight equally distributed along the cellblock. This design persisted until once again the demands for prison space outstripped its availability. One example of this substantial growth is the federal prison system that doubled in size from 1980 to 1987 to a population of 41,000. (16)

Throughout the evolution of the prison architecture, one thing did seem to remain constant and that was the construction materials chosen. Prisons were typically built of stone, brick and later, concrete regardless of the layout or location of the facility. These prison facilities, so constructed, took time to plan and build, requiring one to two years to construct, verify the complex systems incorporated into the building and to finally commission the building to service.

Unfortunately, the demand for prison space was growing with every change of the penal system and every new criminal law legislatures placed on the books. This expansive growth in the prisoner population was not just an American problem and the overcrowding of prisons in general had become intolerable by the 1970's.(17) However, as society has moved into a high demand for prisons, (over 1000 newly constructed since 1970 (17)), the use of faster construction systems was sought to reduce completion times while maintaining a sufficient level of the security. One building technique chosen to deal with the problem was all metal buildings or buildings that were a combination of concrete block and metal construction.

THE TEXAS PRISON SYSTEM

Over the course of its long history, the Texas Prison system, formerly the Texas Department of Corrections (TDC) and now the Texas Department of Criminal Justice (TDCJ), has undergone a tremendous change. Established in 1848, Indian chiefs, civil war prisoners and outlaws were its first residents. Prior to 1970, the system had grown to 16 farm units with approximately 18,000 inmates and had facilities to five Texas counties. [(18)] These facilities were constructed primarily of brick and concrete for reasons of security and because at the time of their construction, prison architects were expected to use these building materials.[(13)]

Beginning in the early 1970’s, the Texas prison population growth rate exploded. Consequently, many organizational changes occurred in the Texas Prison system. The management style practices as a result of the reform in administration and operation were only a portion of the changes with which TDCJ would have to deal.[(19)] During the next twenty-five years, its inmate population would increase to greater than 150,000. Forcing TDCJ to expand the number of its facilities to over 100 locations in 61 Texas counties.[(20)]

The inmate population represents 70% to 80% of the occupants of these facilities. Each facility also has correctional officers comprising 10% to 20% of the occupants and a non-correctional staff (administration, support services personnel) of 5% to 15 % [(20)] a total of 44,991 individuals.

The overcrowded conditions, constitutional violations and some of the environmental controls of the prison system were addressed by the Federal Courts in cases *Ruiz v. Estelle and Ruiz v. Lynaugh*[20-25] In order to accommodate this need for prison space and to address both physical and legal[22] demands, the Texas Department of Criminal Justice had to look to alternative construction methods to rapidly build prisons. The concrete masonry constructed facility was not abandoned, and in fact, several were built in the twenty-five year period, from 1973 to 1998. Additionally, the use of fabricated metal buildings became a way to quickly build the needed prison bed space. The designs are typically of a single span rigid frame support structure with rolled sheet metal as the exterior skin of the building.[26] The walls and ceiling spaces are insulated with fiberglass mats and interior partitions are made of security panels either prefabricated or assembled on-site. The first facility constructed using metal as the primary material was completed in 1982. By 2003, almost half of the TDCJ facilities throughout the State relied on an outer wall construction either partially or completely of metal.

CHAPTER II

LITERATURE REVIEW

HEAT STRESS AND THE ENVIRONMENT

When the human body is accumulating thermal energy faster than it can dispose of it, the overall effect is referred to as heat stress[27]. When the body's thermoregulatory mechanisms begin to shut down, the body physically enters into heat stroke. These two conditions along with prickly heat and heat exhaustion make up the continuum of heat related illnesses. When weather related mortality statistics are reviewed, heat related illness (heat stroke) is the second most frequent cause of death in the United States after cold related mortality[28,29]. In general, the effects of heat and humidity on human health are well documented.[29-32] Some of these include relevant discussions of meteorological factors.[33] In Driscoll's study, the heat stress hazard of the southwestern United States was examined in relationship to a criminological and demographical model. In his analysis, Driscoll found that there were certain factors associated with the increased risk among his study group. These factors included age, economic factors, and cultural practices. The results of his analysis noted that for this region of the United States, which includes Texas, the most intense heat was experienced in the months of July and August.

Other studies of heat stress tested human physiological response. These include circulatory adjustments during exercise and extreme heat exposure[34,35], the stability of the human physiology under heat stress conditions[36], and the effect of accumulated stressors on the human body because of heat exposure[37,38].

HEAT TRANSFER

Although the purpose of this study is not specifically on heat transfer, a basic understanding of heat transfer mechanisms is important to understand the effects of ambient conditions on the performance of the buildings in the study. The flow of heat is present in all physical relationships and heat is defined as the energy transfer due to temperature gradients or differentials. In this research, the transfer of heat from the ambient environment (outdoor or external to the built environment) is dependent on the materials and systems used to construct the facility.

The fundamental law describing the movement of heat were introduced in a publication in 1822, by Joseph Fourier(39). The basic modes of heat transfer are conduction, convection and radiation. Additionally the consideration of other thermal quantities such as sensible heat and insensible heat are necessary to fully understand the system of heat transfer. Conduction heat transfer is energy transported due to molecular motion.(40) Conduction heat transfer through solids is due to molecular vibration. Fourier's law stated that the heat movement (flux) or heat transfer per unit area is proportional to the temperature gradient. The constant of proportionality, in Fourier's equation is termed the "material thermal conductivity" and its magnitude depends on the material. The thermal conductivity also depends somewhat on the temperature of the material. The type of material chosen for a particular application governs the transfer of heat by this mode. The thermal conductivity of materials varies widely from a low example of air at 0.026 W/m°K to 1.4 W/m°K for concrete or 204 W/m°K for aluminum.

The second mode of heat transfer is convection as is energy transport due to bulk fluid motion.[41] Convection heat transfer through gases and liquids from a surface results from the fluid motion along that surface. This type of heat transfer equally applies to a liquid gaining heat from the surface of a pipe as it does to air inside of a building gaining heat from the walls. It too has a heat transfer coefficient, which depends on the type of fluid and the fluid velocity is defined depending on the type of flow. Natural convection or free convection is a result of the motion of a fluid due to differences in density. In most cases, the free convection may be neglected when there is fluid flow; however, in still naturally ventilated spaces the free convection heat transfer mechanism could be substantial.[41,42] Forced convection is the transfer of heat between a moving fluid and a solid surface. There are several examples of forced convection that depend on the physical arrangement and configurations of the fluid flow and the solid surface (tube, plate, perforated sheet) but in general there are no mathematical solutions for all types of forced convection and this heat transfer is usually analyzed by equations based on empirical values and generalized dimensional analysis.

The third mode of heat transfer is radiation. Radiation heat transfer is energy transport due to the emission of electromagnetic waves or photons from a surface or volume. Radiation heat transfer does not require a transfer medium and therefore can occur in a vacuum. The heat transfer by radiation is proportional to the fourth power of the absolute material temperature and is present in all matter.[42,43] The movement of radiant heat and its effectiveness in heating an object depends on the surface accepting the heat. A black surface is defined as a surface that absorbs all incident radiation, reflecting none into the surrounding environment. This form of heat transfers is evaluated using the Globe Temperature of a heat stress apparatus.

Other terms used to describe the movement of heat through a system are sensible heat and insensible (latent) heat.[42] Sensible heat is the heat energy stored in a substance as a result of an increase in its temperature. The sensible heat of a construction material is that heat stored in the material over the day warming cycle. Insensible (latent) heat is the heat that flows to or from a material without changing the temperature of the material. This addition of heat only changes the structure or phase of the material. Examples of insensible heat are the amounts of heat required to either heat a material to boiling or the addition of heat to melt a solid.

In this dissertation, the heat transfer across the boundary of an enclosure is presented to be one-dimensional, for ease of understanding. The conductive heat flux is in the direction perpendicular to the enclosed surface across the entire area of the surface.[44] Each surface material will have an intrinsic thermal resistance to heat movement and this material property is quantified by its insulation capacity or R-factor (thermal resistance). The nominal thermal resistance of selected building materials in Table I is a function of the material thickness and density.

TABLE I. Building Materials and Thermal Resistance

Building Material	Material thickness (m)	Thermal Resistance (m^2 °C hr/kcal)
2 Bricks	0.51	0.73
2.5 Bricks	.064	0.91
3 Bricks	0.77	1.10
Lightweight concrete	0.25	0.83
	0.30	1.00
	0.35	1.17
	0.40	1.34
Reinforced concrete panel	0.22	1.07

From the table it is clear that the materials traditionally used for prison construction, as discussed earlier, have significant thermal resistances and are therefore significant barriers to heat loss and gain. In the text by Anapol'skaya (44)a calculation for averaging the thermal flows between interior and exterior surfaces is presented. However, this study did not include the measurement of surface temperatures for reasons of convenience and reliability. This was in part to the practicality of that data collection in the penitentiary environment.

THE APPARENT TEMPERATURE EXPRESSED AS HEAT INDEX

The Wet-Bulb Globe Temperature (WBGT) is a measurement of environmental conditions and is the standard used by the United States military. WBGT is the preferred model from which the environmental potential for physiologic heat stress is quantified and is the heat index used for most measurements of occupational environments. The WBGT combines the effect of air velocity, relative humidity, ambient air temperature and radiant energy into a single index.(30)The WBGT effectively addresses each of the heat transfer mechanisms and relates their combined effect on the human body. The

WBGT is very useful in assessing the environmental conditions; however, proper measurement of all three temperatures (wet-bulb, dry-bulb and globe) requires the deployment of three thermometers.

In order to simplify the communication of the need to modify activity due to environmental conditions, several attempts to quantify the effects of weather elements on humans have resulted in a variety of indices and equivalencies. [2] Some of these indices have been based on work in the climatologic sciences and attempts to measure human discomfort. [45,46] Each of these heat stress indices has limitations but are not lacking in very creative names such as humiture (after Hevener, 1937), the temperature-humidity index (THI) [47] and the humidex [48].

One of those methods has emerged in the last few years from a reanalysis of work done from the aspect of textile and clothing science. Clearly stated in his manuscripts of 1979, R. G. Steadman [49,50] focuses on the physiological extent that humidity has on increasing the effects of temperature and an individual's perception of that temperature. In his works, Steadman refers to "sultriness" as the term for hot weather's combined effects just as "wind-chill" refers to the winter weather consequence. Steadman goes on to describe other proposed single indices. One of these is an index based on the calculation of heat exchange, first described by Macpherson [31]. Designed as a multifactor index, Macpherson found a satisfactory approach and set the standard for future work on heat estimation that was, with the further work of Steadman and others, to become known as apparent temperature (AT). AT is the temperature that produces the same thermal effect as the current ambient temperature and relative humidity when considered with reference humidity at a dew point of 57°F. Although he later included the effects of wind, radiation and barometric pressure [50] his initial calculations were built on the sole relationship of temperature and relative humidity. He simply stated that [sultriness] "is intuitively clear and no qualitative definition"[49] need be presented. Therefore, as main components to apparent temperature, Steadman identified temperature and water vapor pressure. Other considerations were also presented in the development of his sultriness index:

1) *Sultriness should be capable of expression as an equivalent or apparent temperature.*
2) *As in windchill, this apparent temperature should have a one-to-one correspondence with the thickness of clothing needed to maintain thermal equilibrium in 'mild' sultriness.*
3) *If, however, sultriness is such that no clothing is called for, the apparent temperature should correspond to the thermal resistance of the sweating skin.*
4) *If humidity is higher (lower) than 'average,' the apparent temperature should be higher (lower) than the dry-bulb temperature.*
5) *The index should be amenable to allowing for the effects of changing wind speed, air pressure and extra radiation, particularly sunshine.*
6) *The index should cover the range of sultriness conditions likely to be encountered on the earth's surface.*

Steadman interpreted previous work through thermodynamic equations in the field of heat transfer and human biometeorology to develop tables and nomograms to describe all aspects of modeling the apparent temperature.[51]

Eleven years after Steadman's initial work the National Weather Service (NWS) of the National Oceanographic and Atmospheric Administration (NOAA) took a simplified approach to the heat index equation and ability to report apparent temperature. Lans P. Rothfusz, meteorologist, in an attempt to address requests for "the equation" did this work for the NWS office in Fort Worth, Texas. His Technical paper, SR 90-23[52], was written for forecasters. In the paper, he clearly admits that there is no first principle derivation of the equation for “Heat Index” and that he arrived at the simplified form through regression analysis. In order to simplify the task and address all the possible parameters of Steadman’s work, Rothfusz assigned magnitudes to each of the equation parameters in order to simplify this new model for heat index. The parameters included assumed values for vapor pressure, several external human body characteristics, physical characteristics of the body, properties of human skin, wind speed, activity level, and clothing characteristics. In recognizing the limitations of the model Rothfusz clearly reminds, “these assumptions are important for the forecaster to keep in mind.”[52] In the derivation of the heat index, Rothfusz describes Steadman’s use of five variables: ventilation rate, skin resistance to heat transfer, skin resistance to moisture transfer, surface resistance to heat transfer and surface resistance to moisture transfer. Through an iterative process, one that strictly adheres to the assumptions previously stated, his model related dry bulb temperature (over humidity ranges) and the skin’s resistance to heat and moisture transfer. The skin’s resistance is a function of the skin temperature; therefore, a relationship between temperature, relative humidity and skin (apparent) temperature exists. An equation using more conventional variables, those readily available in weather forecasting, was developed from a multiple regression analysis on the data from Steadman’s AT tables.[49,53,54] The nine-element heat index equation below, Equation 1, is a refinement of the results obtained by the multiple regression analysis performed by Rothfusz on the data from Steadman's Tables. The equation derived is a best approximation and is presented as follows:

$$\begin{aligned} HI = &-42.379 + 2.04901523\,T + 10.14333127\,R - 0.22475541\,TR - 6.83783*10^{-3}\,T^2 \\ &- 5.481717*10^{-2}\,R^2 + 1.22874*10^{-3}\,T^2R + 8.5282*10^{-4}\,TR^2 - 1.99*10^{-6}\,T^2R^2 \end{aligned} \quad (1)$$

HI is the resulting heat index (apparent temperature) when T, ambient dry bulb temperature (°F), and R, relative humidity (integer percentage) are used as the input variables. There are also two published adjustments for the HI equation. The first adjustment, Equation 2, addresses conditions where the relative humidity is less than 13% and the temperature is between 80 and 112 degrees Fahrenheit and results in a net subtraction from the calculated value from Equation 1

$$\text{Adj.}1 = [(13 - R)/4] * \sqrt{[17 - |T - 95|]/17} \quad (2)$$

and

$$\text{Adj.}\,2 = [(R - 85)/10] * [(87 - T)/5] \quad (3)$$

The second adjustment, Equation 2, is an additive adjustment used when the relative humidity is greater than 85% and the temperature is between 80 and 87 degrees Fahrenheit. Table II is constructed by calculations of heat index over a range of temperatures and relative humidities using Equation 1 and in a manner similar to the table published by Steadman and the NWS.

TABLE II. Apparent Temperature from Dry-bulb Temperatures and Relative Humidities

Temperature (°F)	60% RH	70% RH	80% RH	90% RH
70	75.9	73.9	70.9	66.9
75	77.4	76.7	75.6	74.1
80	81.8	82.0	84.2	85.6
85	89.3	92.7	96.8	101.6
90	99.7	105.9	113.3	121.9
95	113.1	122.6	133.8	146.6
100	129.5	142.8	158.1	175.7

A second equation for Heat Index is available although less frequently used or cited in the literature.[19,55] This 16-term heat index equation and a comparison to the nine-term equation are presented in Appendix A.

The nine-term form of the equation was selected for calculations and environmental condition comparisons in this study because it is the most widely used in reporting and relied upon when studying trends in climatology and apparent heat by researchers and meteorologists. Steadman's apparent temperature and therefore Rothfusz's heat index is a reasonable compromise and thus widely used by reporting agencies, researchers and the NWS. Steadman published [49]a table for finding the apparent temperature using combinations of either dry-bulb and dew-point temperatures or dry-bulb and wet-bulb temperatures. The NWS uses a similar table to assist weather personnel in reporting seasonal heat indices using the nine-term, Equation 1 to calculate the table values.

VIOLENCE AND HEAT INDEX

There are also studies that link ambient temperature and environmental conditions to acts of aggression. Schwartz as a study in behavioral science conducted one of the first of these studies. [56] The study looked at political violence on a global scale and goes on to cite what appears to be a causal relationship between the ambient temperature, humidity and precipitation and the apparent level of violence. Researchers have noted that climactic variables are significant considerations when examining violent behavior. The data was important for establishing some basic logic in the “discomfort-irritability-aggression” hypothesis used in further studies, but ultimately the relationship proved inadequate to test the hypothesis. In further studies by Baron and his associates, a curvilinear relationship of ambient temperature exists between ambient temperature and collective violence.[3-5] Robert Baron from Purdue University completed his first investigation on high ambient temperature and aggression in 1972. The purpose of the study was to study the “long hot summer” hypothesis initially fostered in the studies conducted by David Schwartz.

In their 1978 study Baron and Ransberger[7] noted that as the ambient temperature increases, a direct correlation to the increase in collective violence could be predicted as the temperature reached the upper 80’s. Another useful observation made during the study was that increased violence frequency lagged behind the increase in temperature by about 7 days, but as the temperature began to decrease, a return to pre-heat conditions would occur more rapidly in a three-day period.

As this type of relationship research continued, several additional studies in laboratory settings demonstrated aggression increases as the temperature increases to a certain point (usually the mid 80’s) but then as the temperature rose into the 90’s the aggression drops off. [6,8,9,57,58] This was attributed to a negative effect produced by high temperatures; however, the effects could be temporarily reversed if the discomfort was reduced (consumption of cool water or other refreshing activity) and the level of aggression would resume.

In contrast to these studies, a study conducted by Carlsmith and Anderson [59] asserted that the 1978 study by Baron and Ransberger and its findings are in error. Carlsmith and Anderson argue that the greater incidence of riots in the 80 to 85 degree Fahrenheit range are an artifact of the methodology since days with these temperatures occur more frequently in the study period. In another study conducted as a series of three smaller experiments, a team of researchers lead by E. O. Boyanowsky found that there was heightened interpersonal aggression measured as temperature increased over the testing period. However, the aggression response took longer to elicit from the subject during the heat cycle of testing as compared to a similar test with the reduction of temperature to a colder climate. [11]

In a Canadian study[57] the objective of the researcher was to investigate the impact of high ambient temperatures on the motivation of the subjects to engage in an aggressive interaction. The interpretation of the results of the study lead to a different conclusion than that proposed by the work of Baron and Bell: when exposed to high heat conditions the subjects chose the non aggressive tasks. The difficulty with comparing this study to other heat and aggression studies is that the participant teams were divided into pairs. One member of the study pair was exposed to the heat environment and the other was exposed to a tempered (non-heat) environment. The choice offered the subject exposed to the heat was to escape the heat after a tedious task or to administer white noise to their partners. The subjects were permitted to leave the heat after completion of either task, but the tedious task was completed in the shorter amount of time. They desired to escape the heat rather than become aggressive towards their study partner. This study, although providing some good insight to behavioral actions, does not substantially change the premise of Baron, Bell or others in that when the environment is uniformly hot for all the test subjects the level of aggression is increased with the increase in temperature.

In a pair of studies on the issue of environmental determinants of crime and aggression, Harries and Stadler(60,61) evaluated the aggravated assault rate in Dallas, Texas, 1980 to 1981. They conducted pair wise month-by-month analysis on the frequency of assault in neighborhoods according to socioeconomic status in addition to the thermal stress experienced by the neighborhood. In the reexamination of the data from 1980-1981, Harries and Stadler(61) compared the curvilinear model suggested in the combined works of Baron, Bell, and Ransberger(3,6,7) to the linear model suggested by Carlsmith and Anderson.(59) Harries and Stadler noted that the relationship of violence and temperature appeared more linear and that, with their data, the curvilinear hypothesis was not confirmed. They however, did suggest a soft threshold of about 104° F beyond which the extreme positive correlation between heat and assault frequency was not found.

Models of police service demand against rising temperature are also valid references for this study of the TDCJ prison units. In 1969, a study conducted by the St. Louis Police Department(62) clearly established a model with the ability to predict the need for police demand based on the weather in the three metropolitan cities of Chicago, Detroit and St. Louis. Heller concluded that the seasonal variation of police calls should motivate police administrators to schedule vacations and staffing levels prior to the peak demands forecasted by the model. The demand for police services and the changing environmental climate was also the subject of a study by criminal scientists James LeBeau and Robert Langworthy.(63) They concluded that in addition to the thermal environment as a factor for police staffing, police managers must also consider the change in day of the week and the temperature difference from day to day.

A 1987, a paper by J.D. Perry and M. E. Simpson(64) summarizes a longitudinal examination of the relationship between violent crimes (rape, murder, aggravated assault) and environmental factors including seasonal cycles, weather, population and unemployment in the city of Raleigh, NC from 1972 through 1981. Designed as a traditional epidemiological study, the investigators found that the environmental variables showed a significant relationship to the rate of rape and aggravated assault but showed less effect on murder.

In a more recent study(65) conducted to look at the pattern of police calls to respond to domestic disputes, LeBeau notes that domestic disputes are a function of time allocation in society and that these types of offences are committed during periods of discretionary rather than obligatory activities. In simplified terms, domestic violence is more pervasive during leisure time activities. However, that increase of violence can be delayed by the thermal stressors present in the environment. The investigator uses the calculation of THI (47) and evaluates a correlation between mean disputes and the THI lag for each individual season. The study concludes that an increase in the THI may produce a delay or time lag in the reporting of domestic violence.

This concern over environmental influences and crime (aggression) is not limited to North America, but also occurs across the Pacific. The crime data for Korea was examined in a study by Dae H. Chang[(66)] with a primary objective of the study to determine the correlation between environmental variables and the frequency of crime. The study considered as its independent variables: hour of the day, climate conditions, day of the week and seasonal cycle; and although the investigator did not report temperatures or humidities in his analysis it was clearly demonstrated by the data that all crimes, except gambling, peaked in occurrence during the summer months.

BUILDING RESPONSE

Although a detailed evaluation of building response is not present in the public health literature, there are studies in which the investigators looked at fresh air distribution and convective heat transfer and their effects on the indoor environment. In one study Awbi,[(67)] compared values for convective heat transfer in a laboratory setting using two test chambers. The results of his study showed that accurate predictions of heat transfer from room surfaces could be obtained. This work accounted for heat that the wall, ceiling and floor surfaces contribute to the ambient heat in a room and those models have been used to predict heating contribution.

In their literature review Brager and deDear[(68)] identified several studies of thermal comfort and adaptive changes that occur among occupants of naturally ventilated buildings versus reliance on controlled environments. They also concluded from their review that the slow physiological process of acclimatization was not as relevant to thermal adaptation but that behavioral adjustment and expectation had greater influences. Additionally, a sense of control over the indoor environment expedited the thermal adaptation. Each of these is appropriate for the investigation of the prison housing facilities, as their natural ventilation is typically supplemented by some forced ambient air supply. This supplied fresh air is tempered in the winter months but remains otherwise unconditioned throughout the rest of the year. Obviously, the inmates of the TDCJ have very little control over temperature and their environment.

THERMAL COMFORT

Thermal comfort describes a personal satisfaction with the environment whether that comfort is a function of temperature, relative humidity or air movement. Several studies of thermal comfort are present in the literature. One such study published in a thermal biology journal concludes that thermal comfort is determined largely by the skin-surface temperature rather than the body's core temperature.[(69)] Two additional studies address the issue of thermal comfort and its disruption of sleep and the subsequent daily effects. The first of these papers reviewed was written by a group of Japanese researches looking at the effects of humid heat exposure on the human sleep stages and body temperature.[(37)] In this study the researchers exposed seven volunteers to two thermal conditions: 29°C (84.2°F) and 35°C (95°F) and 50% relative humidities and 75%. They observed that the condition 4 (35°C /75%RH) heat index, using Table II, is greater than 123°F. Under the described, conditions 1 (29°C /50%RH) the heat index is less than 82°F. The condition 4 environment caused more wakefulness and lower sleep efficiency than in those experiencing the lower temperature environments. Also when compared to the lower temperature conditions (1 and 2) the rapid eye movement (REM) portion of the sleeping cycle was significantly decreased in the higher temperature conditions (3 and 4). They concluded that humid heat exposure during the sleep period increased the bodies thermal load and reduced the effect of the sleep-induced hypothermia. This resulted in test subjects that were tired and weak following a night of these environmental exposures.

Thermal control and the design of the thermal environment inside a building is typically designed into the structure and mechanical systems incorporated into the buildings. However, in most instances of thermal comfort the occupants are seldom limited to relying on the designer's thermal control alone to attain the desired environmental conditions. The occupants can, as described in thermal comfort criteria, modify their surroundings with additional cooling, warming or circulation to either raise or lower the ambient temperature to a perceived comfort level.[70] Unfortunately, this personal control of the environment is not available to those confined to prison or other institutions for that matter. Typically, these individuals do not have the ability or resources to modify their local environment at will. In these cases, the environmental control and therefore thermal comfort for the occupants must be fully considered and incorporated into the facility by the designers.

CHAPTER III

PROBLEM

CONSTRUCTION PACE

One of the issues that the Texas Department of Criminal Justice had to deal with as a result of Ruiz[22] was to reduce overcrowding because of what the Federal courts found to be an unacceptable level of inmate population in the prison units across the state. In response to the Federal supervision of the prison system, the Texas legislature authorized and TDCJ began an unprecedented building effort to increase in the number of prison units in the state.[18,19,22,71] This decision increased the need for quickly built prison facilities. Between 1980 and 1998 facilities constructed of metal were by far the most prevalent construction type added to the inventory of Texas prison units. Additionally, as previously mentioned, the units were historically centralized in a corridor of ten to twelve counties all within the same climatological zone within the State. The expansion of the prison system and the perception by communities across the state that prisons were good business[71] resulted in a distribution of new facilities into five of the climactic zones found in Texas.

INMATE COMPLAINTS AND THE ENVIRONMENT OF INCARCERATION

Beginning in the summer of 1995 the Office of Environmental Affairs (later Office of EHS) of the Texas Department of Criminal Justice-Facilities Division received complaints of indoor environment issues in the newly constructed metal buildings. Unit grievance personnel were contacting the TDCJ-EHS office with requests for investigation and intervention for the heat complaints in inmate living area. The units were reporting approximately 15 to 20 grievances per month directly related to the temperatures in the living areas. This level of complaints continued throughout 1996 and into the two years (1997, 1998) of this environmental study. In 1997, the EHS office was receiving unprecedented complaints and grievances from unit security personnel. Most complaints came from those required to monitor inmates in the living areas of the newly constructed facilities. There was also a rise in the reporting of heat related employee illnesses through the medical departments on various TDCJ units

The issue of temperature extremes had been addressed by the TDCJ in an Administrative Directive (AD10.64) originally written in 1986 to replace earlier versions from 1978. The directive was to be used by unit personnel in the determination of safe and healthful work conditions. The directive clearly acknowledges TDCJ responsibility to provide a healthful workplace for employees and inmates. The directive addresses that large proportion of inmates who work in field activities, and it only applied to outdoor work or recreation. The directive made unit administrators responsible for the decision to work or not work and advised to shorten work times or modify the work shift to take advantage of the cooler times of the day, in order to prevent heat related illnesses or injuries. The directive also guided the unit personnel in the selection of appropriate clothing for the environment (heat or cold), enforced water intake and rest regimes and provided guidance to reassign inmates currently on medical therapies that predisposed them to poorly tolerate extreme heat conditions.

If elevated temperature is a stressor to which the inmates are exposed, increased aggression is a stress that the prison administration must deal with on a daily basis. A common record of aggression in the Texas Prison system is the incidence of a “Use of Force.” This is recorded every time prison administration is required to quell a disturbance or subdue an inmate for a variety of aggressive actions. These instances would include inmate refusal of a direct order, endangerment of life or facility security, inmate on inmate violence, or inmate on correctional officer violence. These “instances of aggression” are recorded by each of the prison units and summarized in monthly reports to prison administration. These statistics are tracked by the Emergency Action Center (EAC), which is part of the Executive Services office of the TDCJ. The EAC was established in 1984 as a central repository for all unit statistics to include but not be limited to assaults, deaths, suicides, escapes and employee arrests. The Use of Force (UOF) statistic is uniformly reported by each of the TDCJ units. As the prison system has grown, so has the number of assaults reported to the EAC. The EAC reports that in 1988 the prison population was 39, 245 with 6,709 major UOF and grew to a population of 144,119 with 8,317 UOF by 1998.[72] In Table III below the comparison of population and uses of force over the ten year period between 1988 and 1998 is presented.

TABLE III. Population and Uses of Force 1988 to 1998, TDCJ

Year	Prison Population	Uses of Force
1988	39,245	6,709
1989	43,027	6,748
1990	49,209	6,531
1991	50,406	5,957
1992	57,069	6,378
1993	6,9186	7,190
1994	95,945	7,069
1995	126,746	10,107
1996	132,715	7,806
1997	139,535	7,140
1998	144,119	8,317

Obviously, incarceration places many stressors on all those involved, inmates, staff and administration. Although Table III shows a steady decline in the uses of force throughout the TDCJ, there are instances where the uses of force are greater on a unit-by-unit basis than is suggested by the agency average. These units are typically the maximum custody level units that seem to hold a constant level of UOF throughout the year. However, when looking at the newer, lower custody units, predominantly metal construction, the uses of force appear to increase during the warmer seasons.

STUDY HYPOTHESES

In consideration of these problems and the need for additional inmate housing, the increasing inmate population and the possibility of aggression four hypothesis are proposed for this study and center around the different construction materials chosen for the prison (concrete or metal) affect the temperature in the occupied space. The first is that the daily temperatures, during the warm seasons, inside of the metal facilities is higher than the temperatures in the ambient environment and in the concrete facilities.

Second, that the resulting heat index from the daily conditions (temperature and relative humidity) result in higher heat indices in the metal buildings when compared to the concrete facility. Another hypothesis related to the performance of the differing units construction materials is that the concrete facility provides a thermal lag during the heating of the day. Finally, the relationship between occupant and building response is tested. The aggression increases during the season changes measured, as incidents of Use of Force, are greater among the inmates confined to the metal building facilities when compared to the inmates in the concrete facilities.

CHAPTER IV

MATERIALS AND METHODS

SELECTION OF DATA LOGGER

The data collection requirements for this study demanded the placement of a full-time event-logging monitor in each of the study sites. As previously mentioned, the scope of the monitoring program included twenty TDCJ institutional facilities so the geographic locations and distances to each facility required that the instruments selected for monitoring the environments be capable of extended periods of unattended data collection. The monitor chosen for the task was the Smartreader4, manufactured by ACR Systems, Incorporated (Surrey, B.C.). The Smartreader4 logger was selected because it was a compact unit, with a magnetic mounting surface. This allowed the placement of the unit within the occupied space of the housing units while securing the unit from tampering or removal. The Smartreader4 monitor is equipped with a lithium battery rated for a 10 year operating life. The logging unit, designed for monitoring heating, ventilation and air conditioning (HVAC) systems, has an internal clock capable of logging external events in time increments ranging from 8 seconds to once every 5 days and with a clock accuracy of +/-2 seconds. The memory of the unit will hold 32,768 readings and can operate using one of two sampling modes, a fixed capacity (fill-then-stop) or a continuous (first-in, first-out) configuration. For this study, the units were set to sample at 30-minute intervals and in the continuous mode. This necessitated at least two trips during the study to each of the sampling locations for monitor downloading using the proprietary software ACR Trend Reader©[73], supplied with the logger units. This software package also provided the interface with the loggers for programming the parameters for data collection. The software also allows for notation and manipulation of the data and allows for the export out of the application by converting the data into an ASCII format.

The parameters logged by the Smartreader4 in each of the sampling locations were date and time, temperature, relative humidity and local barometric pressure. Temperature data is collected by the monitor using an internal thermistor temperature sensor. The sensor is mounted within the case of the Smartreader4 and has an operating range of -40°F to 158°F with a resolution of 1.8°F over that range. The relative humidity sensor was also internal to the monitor but accessible for replacement. Relative humidity (RH) was logged by the unit using a non-condensing capacitive polymer film. The range of the sensor was from 0 to 100% RH with an accuracy of +/- 4% of the range over 10 to 85% RH. The plug-in barometric pressure sensor recorded pressures in the range zero to thirty pounds per square inch, absolute (psia), with a resolution of 0.15 psia. The manufacturer also encrypts each monitor unit with a unique serial number that is used to identify the monitor and track its location within the facility.

SELECTION OF PRISON UNITS

A monitoring program in twenty-one of the TDCJ facilities was initiated in July 1997. Monitors were initially placed in prison facilities in each of the construction type categories (brick/concrete, metal or metal/block composite). The monitoring program was designed to cover a variety of the institutional facilities of differing security levels spread across the state of Texas in nearly all of the climactic zones. The State lies in both the cool and warm portions of the Temperate Zone of the Northern Hemisphere.

Texas has three major climactic types that are classified as Continental, Mountain and Modified Marine.[(74)] The prison units of the TDCJ lie predominantly within two of these three types of climate, Continental and Modified Marine. The Modified Marine climate type is further divided into classifications across the state. These sub-classes are Subtropical Arid in the western portions of the state, Subtropical Steppe along the southwestern border with Mexico, Subtropical Sub-humid through the heart of central Texas and the Subtropical Humid bordering Louisiana. This eastern most climate sub-area of the state includes the majority of the Gulf coastal area and contains all of the units of the TDCJ prior to the expansion in 1982. Additionally, of the 114 units (prisons) currently used by the TDCJ, 60 (52%) are located in this climate zone.

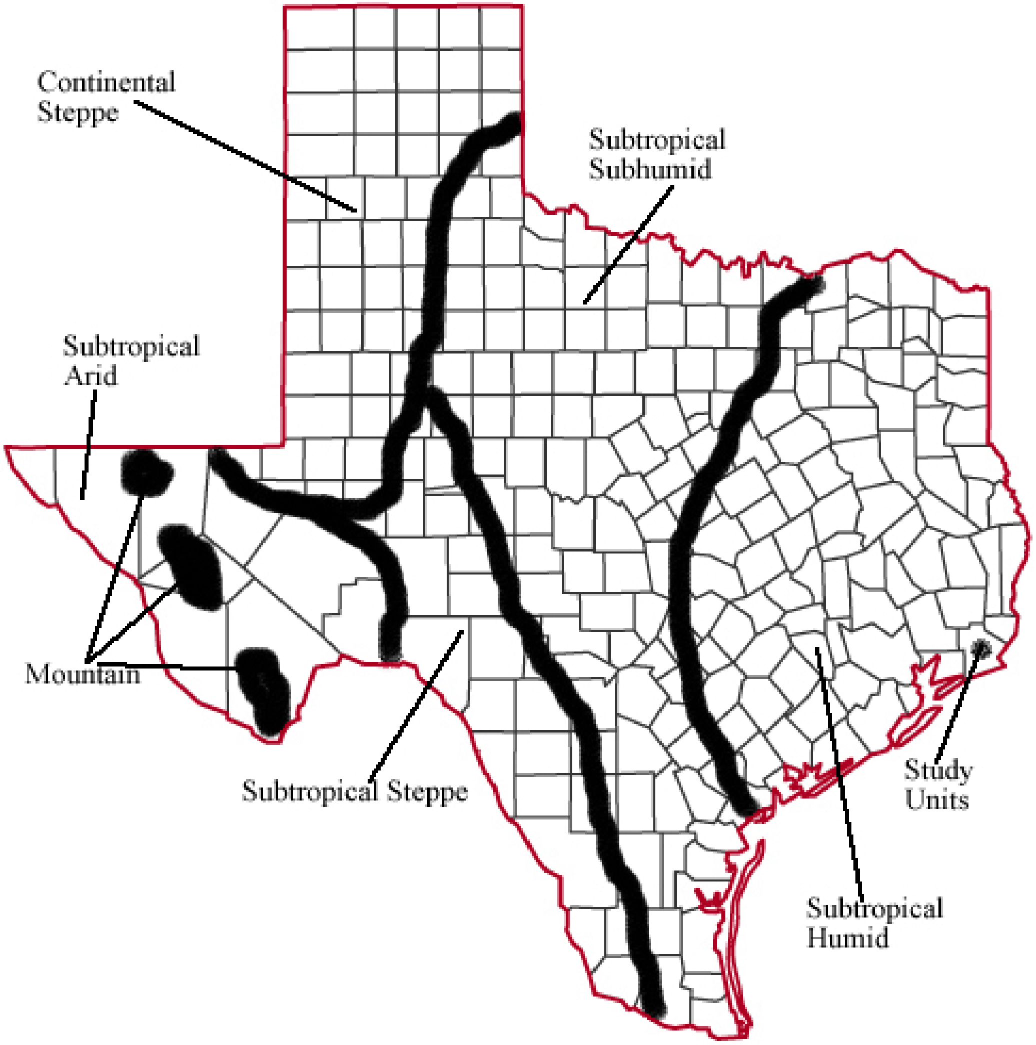

FIGURE 1. Climate of Texas and location of study site

It was for this reason that this zone was chosen for this study. Figure 1 shows the climates of Texas and the location of the study units. Further, in order to have all subject construction types in the closest proximity to each other, the units located in Jefferson county were chosen as indicated in Figure 1. The Stiles Unit, Gist State Jail Facility and the LeBlanc Substance Abuse Felony Punishment Facility are co-located on 776 acres and lie within one half mile of each other, just outside of the city of Beaumont, in Jefferson County. A State of Texas Juvenile facility and a Federal Prison facility are also located within 2 miles of these units. The choice of these three units was also influenced by the fact that they were completed within two years of each other, and began accepting offenders into their housing facilities in that twenty-four month period.

The Mark Stiles unit of the TDCJ Institutional Division is located in Jefferson County, on Farm to Market Road 3514 off Texas State Highway 69 (29° 59’ 34”N, 94° 02’ 31”W). Stiles is a high security reinforced-concrete facility constructed in a distributed campus footprint with a modified radial floor plan for the inmates housing buildings. Majorities of the unit’s buildings were constructed with on-site fabricated tilt-wall construction. The unit was placed on line in June of 1993 and has a maximum offender capacity of 2, 897.[(20)] The custody levels housed on the facility include all general populations G1-G5, administrative segregation and safekeeping. There are four general population-housing units and each is designed with three wings. In each of these wings, three housing areas are located. The arrangement of the housing units are one and two man cells located along the exterior wall of the building and facing into a three story central core used as a common area or “day room”. The Stiles unit also has two housing units for inmate segregation. The first is a pre-hearing detention facility and the second provides administrative segregation housing. These housing units were not included in the study because the occupants are not considered members of the general population, because they represent a minority of the unit’s prisoners and because routine access to any monitors placed in these facilities would be difficult. A primary consideration in excluding these two housing units from the study is that the inmates here are not free to move about the building. Their time in confinement is different from that present in the general population buildings because they typically spend from 15 to 23 hours in their cells every day.

The LeBlanc Unit of the TDCJ Institutional Division is also located along FM 3514 and State Highway 69 (29° 59’ 38”N, 94° 02’ 09”W). The facility came on line in June 1995, has a maximum offender capacity of 1,008, and is composed of state custody levels for general population G1 and G2.[20] Designed as a Substance Abuse Felony Punishment Facility (SAFPF), the housing buildings are configured around a central court area. All the buildings on the facility are constructed of sheet metal outer wall around an erected steel frame. The interior walls are security panel construction, a sheet metal panel with fiberglass insulation contained within the panel. Each building has two sections and each section is comprised of two dormitory type-housing areas. The inmates in the LeBlanc type unit have more privileges than either the Stiles population or that of the Gist unit described below. The LeBlanc unit also has an offender segregation area in a building on the facility that was not included in the study.

The final TDCJ facility in this geographic area and included in the study is the Gist Unit, a state operated, state jail facility of the TDCJ State Jail Division is also located along FM 3514 and State Highway 69 (29° 59’ 38”N, 94° 02’ 20”W). The Gist unit was placed on line November 1994, has a maximum offender capacity of 2,276 and its population is composed of the following custody levels: State Jail Offender, Low Risk, Medium Risk I&II, High Risk and Segregation.[20] Offenders in this facility meet the classification guidelines for State Jail incarceration. This means that they have been sentenced under the state jail felony portion of the penal code. The facility is constructed along a central walkway and the buildings used for housing are on parallel lines either side of the central walk. Each building is divided into two sections and each section is again subdivided into four smaller dormitory style housing areas or pods. These buildings are constructed of insulated metal panels with an exterior surface of sheet metal. The roof is constructed of sheet metal similar in design to the Leblanc unit. One unique feature of the Gist unit is that one housing unit (C7) had an air conditioning unit installed and was monitored as an internal control reference for the study. The segregation housing on the Gist unit was not included in the study.

The unit populations and work force varied slightly over the period of the study. Table IV shows the average population and workforce used in the reporting of the data for the units. The inmate population was used to normalize the data used to describe aggression

TABLE IV. Unit Demographics Averaged Over Study Period

TDCJ Unit	Total Employees	Security Employees	Inmate Population
Stiles	837	592	2863
LeBlanc	280	158	979
Gist	408	280	2074

In each of these units selected for inclusion in the study, two locations were identified for the placement of the Smartreader4 environmental loggers. Considerations for site selection included: security of the logging device against tampering or removal, visibility of the monitor unit by security personnel so that visual confirmation could be made on an ongoing basis during the study, and access of the unit by survey personnel for downloading data. The locations chosen were locations on Stiles unit in Building 3, Section A and Building 7, Section A. In the LeBlanc unit, Dorm 1C and Dorm 5N were selected for monitoring and on the Gist facility; one housing unit (C1) was chosen in addition to the air-conditioned housing unit (C7) already identified.

REVIEW OF CONSTRUCTION DOCUMENTS

A broad selection of construction documents for each of the study sites were reviewed. The selections included mechanical drawings, floor plans, materials schedules and fan schedules. Each of the three units has buildings constructed on reinforced concrete slabs, on grade. Prior to construction, the sites were cut and graded using select fill as a base for the concrete slab foundations.

The Stiles unit is constructed of reinforced concrete tilt wall. The nominal thickness of the concrete in the housing buildings was eight inches. The roof on the housing units is composite over concrete slab also about eight inches thick. The other two facilities selected (Gist and LeBlanc) were constructed as single-span metal buildings with insulated panel walls and exterior sheet metal wall. The roof on these buildings was also constructed of sheet metal with rolled fiberglass and a moisture barrier included along the roof membrane.

The other documents reviewed were the ventilation system, fans and ducts, found in each of the housing units. Each housing unit on the three test sites is provided with fresh air from a forced air system. The occupants receive 100% fresh air twenty-four hours per day. During the winter months, the air is tempered with supplemental natural gas fired heating to a range of 74 to 78°F. However, as previously noted, the indoor environment was not conditioned (heated or cooled) during the summer and early fall months. The fresh air provided to the ventilation system, was only ambient air supplied through forced air distribution systems and removed continuously through fans.

COLLECTION OF DATA

The six monitors were located in the housing units in a secure location to reduce the possibility of tampering and to increase the monitor recover rate. The monitors were installed in their sampling locations on July 9, 1997 and remained in place until November 11, 1998. One download cycle was completed with each of the loggers on February 2, 1998. The monitors were placed in the selected prison units and programmed to collect all data (temperature, relative humidity and barometric pressure) at thirty-minute intervals in the continuous mode. This represents 192 data readings per day, or a collection period of 170.67 days, storing 32,768 readings. This data storage limit and sampling method resulted in the loss of first-in data during the survey period from February 2, 1998 to March 30, 1998. However, this loss of data from the sites was not detrimental to the study and the volume of data was substantial and sufficient. Another loss of data occurred when the monitor placed on the Stiles Unit Building 3 section A was not recovered during the study. The data set for the study contains the daily temperature, relative humidity and barometric pressure measures taken at 30-minute intervals from July 1997 to November 1998. There are 20,353 time intervals logged in each of the testing locations resulting in 305,295 separate data points of temperature, relative humidity or barometric pressure. Barometric pressure was stripped from the working data set because of inaccuracies identified because of logging monitor placement.

In addition to the unit environmental data, ambient data (weather conditions) reported by the closest meteorological station were downloaded from the National Climatological Data Center (NCDC) and the Surface Weather Observation (METAR) system[75]. The data reported by the Beaumont/Port Arthur, TX (call sign -BPT) station was selected as the closest location and appropriate for unit temperature comparisons. The data from BPT is also identified by its Weather Bureau Army Navy identification number of WBAN12917. The station, also identified by its NWS number 417174, is located 16 feet above sea level at Latitude 29°57' N, Longitude 94°01'W. The distance from the weather reporting station to the prison units is three miles. The data is maintained on hourly intervals beginning with 0053 hours each day and contains temperature, dew point, wet-bulb and relative humidity data. The data stream also contains visibility, barometric pressure, ceiling, wind speed, direction, and an overall atmospheric stability rating. The data used for this study from the BPT data included only the temperature and relative humidity for the period coinciding with the presence of the logging monitors in the prison buildings. The data set includes 17,536 time intervals and 35,072 data points for temperature and relative humidity. The unit internal environmental data from the five locations and the meteorological data from the weather service facility are included in Appendix B.

METHODS OF DATA ANALYSIS

A variety of statistical and graphical techniques are employed in this study to describe the data sets and infer relationships between the ambient conditions (temperature, relative humidity, heat index), internal unit conditions (temperature, Relative humidity, heat index) and the relation of temperature or heat index and its effect on the inmate occupants of the prison units. The unit logger data (ACR SmartReaders) and the NCDC data were imported into Microsoft Excel(76) as comma delimited files, formatted into Excel cells and chronologically arranged over the sampling period from July 1997 to November 1998. Then the nine-element heat index equation (Equation 1) was entered into the spreadsheet and Excel was used to calculate daily heat indices for each day in 30-minute intervals. The values from the NCDC data set are recorded by the weather stations in 1-hour increments. This interval did not match the time interval of the unit data. In order to allow for direct comparison of the ambient and internal conditions, the prison facility data was selected at the full hour and then compared to the NCDC hourly values for each time increment for temperature and relative humidity. Statistical analysis of the data set was accomplished using the Data Analysis plug-in available within the Excel program. This included descriptive statistics and regression analysis and correlation of the temperature and heat index data for each of the units for comparisons to each other and to the ambient data.

One parametric technique selected for analysis of the data set was autocorrelation. If two random variables are defined as have originated from a random process at two different times, then one can expect that their value, relative to each other, would be a function of how rapidly the time increment passes. The autocorrelation functions play important roles when representing random processes and is a tool used to check randomness in a data set.[77] This analysis is accomplished by testing the data values at varying time lags. If the data are random, then the autocorrelation should be near zero for any time-lag separations. If, however, the data are periodic, then one or more of the autocorrelations will be significantly non-zero. Auto correlation plots are formed by a calculation of the autocorrelation coefficient plotted against the time lag within a single set of variables. The autocorrelation coefficient is calculated using Equation 4.

$$R_h = C_h / C_o \tag{4}$$

Where C_h is the autocovariance function and calculated using Equation 5

$$C_h = (1/N)\sum_{t=1}^{N-h}\left(Y_t - \overline{Y}\right)\left(Y_{t+h} - \overline{Y}\right) \tag{5}$$

and C_0 is the variance function defined by Equation 6.

$$C_0 = \frac{\sum_{t=1}^{N}\left(Yt - \overline{Y}\right)^2}{N} \tag{6}$$

The horizontal axis in the plot of autocorrelation (correlogram) is the lag time interval and the vertical axis of the plot represents the correlation coefficient for that lag. For this study the autocorrelations were calculated using a proprietary software package StatTools©[78,79] which is an add-in application for Microsoft Excel. The autocorrelation analysis of the time series data sets (temperatures and heat indices) provides an identification of a data set as either moderately or strongly auto correlated and then allows for the further analysis of the data using a least squares linear regression.

The second parametric analysis of the data performed was the cross correlation.[77] Although similar to autocorrelation, crosscorrelation functions are quite different. Crosscorrelation plots are formed by a calculation of the crosscorrelation coefficient plotted against a time lag. This time lag though is derived from the offset of two variable sets with respect to each other. This analysis differs from the autocorrelation in that the results provide an analysis of two variables, which are random, yet responding to the same set of external forces. The correlation coefficient for the crosscorrelation is calculated using Equation 7.

$$\rho_{xy} = \frac{C_{xy}}{\sigma_x * \sigma_y} \qquad (7)$$

Where C_{xy} is the covariance of the data sets x and y, calculated using Equation 8

$$C_{xy} = \left(\frac{1}{n}\right)\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) \qquad (8)$$

and σ_x and σ_y is the standard deviation for each variable, x and y and defined by Equations 9 and 10.

$$\sigma_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (9)$$

$$\sigma_y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2} \qquad (10)$$

The crosscorrelation can be used to identify the location and duration of the lag between two data sets. This analysis is important in determining the amount of time the internal heat index increase lags behind the external increase.

One of the most important analyses of the data comes from inspection of the graphical representations of variations in temperature, heat index, uses of force and the trend lines found in those data sets. In one of his many texts on the subject, Edward Tuft points out that graphics can be more precise and revealing than conventional statistical computations.[80] In the analysis phase of this project, the data provides for the examination of several trends and characteristics that are not easily analyzed by statistical methods. Therefore, however important statistical validation is to this or any project, a good representation of the graphical analysis is also appropriate.

CHAPTER V

RESULTS AND DISCUSSION

BUILDING RESPONSE AS A FUNCTION OF CONSTRUCTION TYPE

A building's ability to shelter its occupants from extreme temperatures should be a major design concern. As buildings are designed, there are sets of environmental criteria and building codes considered by architects and engineers. The placement of the building and the prevailing wind, temperature and seasonal variability are some of those factors that will inevitably impact the building and its occupants. Internal monitoring of environment (temperature and humidity) and of the external conditions allows comparison of the building's internal environment as it responds to those stressors.

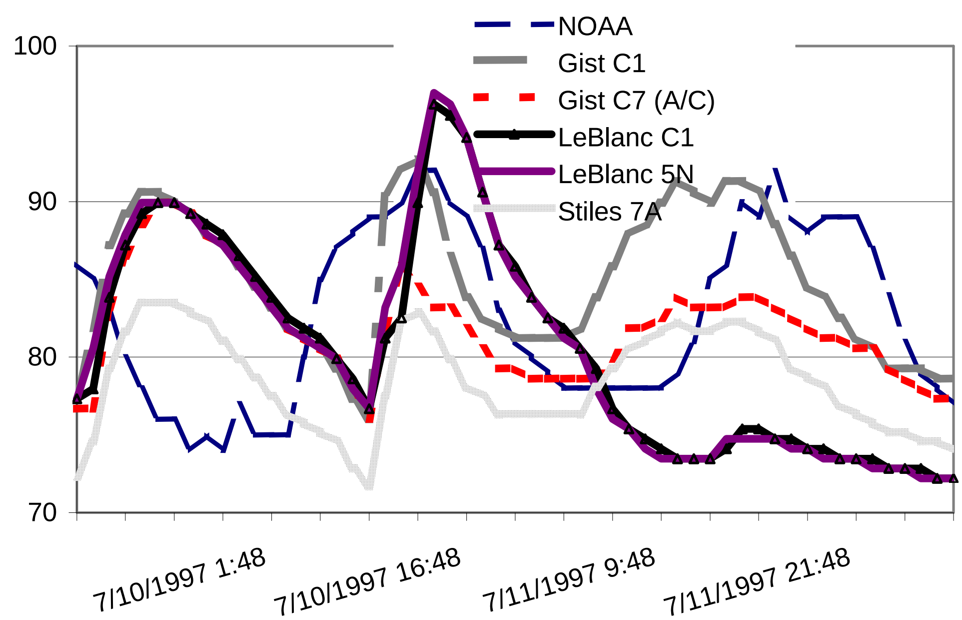

FIGURE 2. Temperature fluctuations in study sites, July 9 to July 12, 1997

In Figure 2 a general comparison of all the subject units is shown for a three day period at the beginning of the study, July 1997. Clearly shown by the figure is the lower internal temperature experienced in the internal environment of the Stiles unit. Figure 2 demonstrates the higher temperatures when compared to the NOAA meteorological data. It also indicates that during this time increment the Stiles unit performed as well as the air-conditioned section (C7) of the Gist unit.

The response of each of the construction types is presented in figures below. In Figure 3 the response of the Gist C1 housing unit to temperature in the Fall of 1997 as a scatter plot of the seasonal data. The same comparison is made in Figure 4 and 5 for the Stiles 7 housing unit and the LeBlanc N5 housing unit respectively. Clearly, the reinforced concrete Stiles unit maintains a lower temperature relative to the outside, even if it is not highly significant.

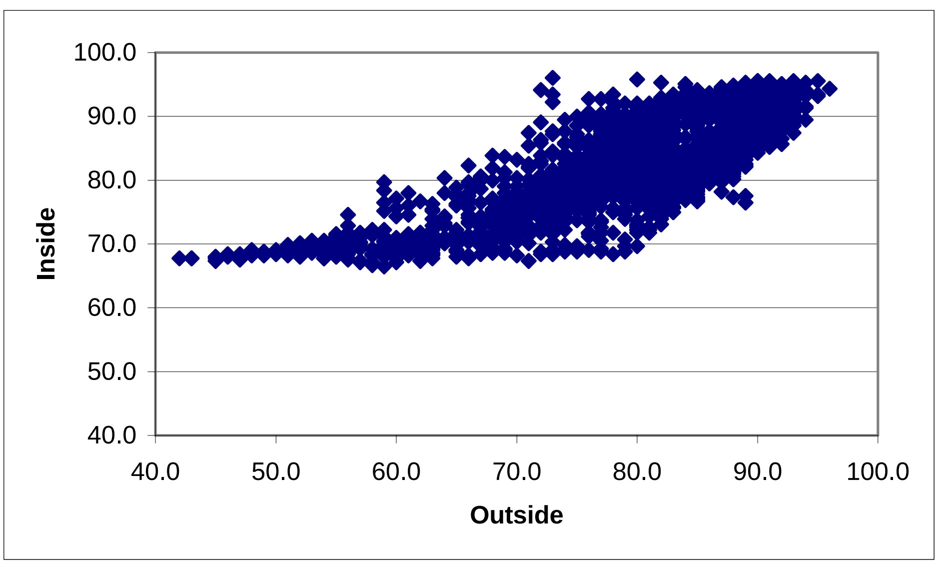

FIGURE 3. Comparison of hourly temperatures between the ambient and Gist C1, Fall 1997

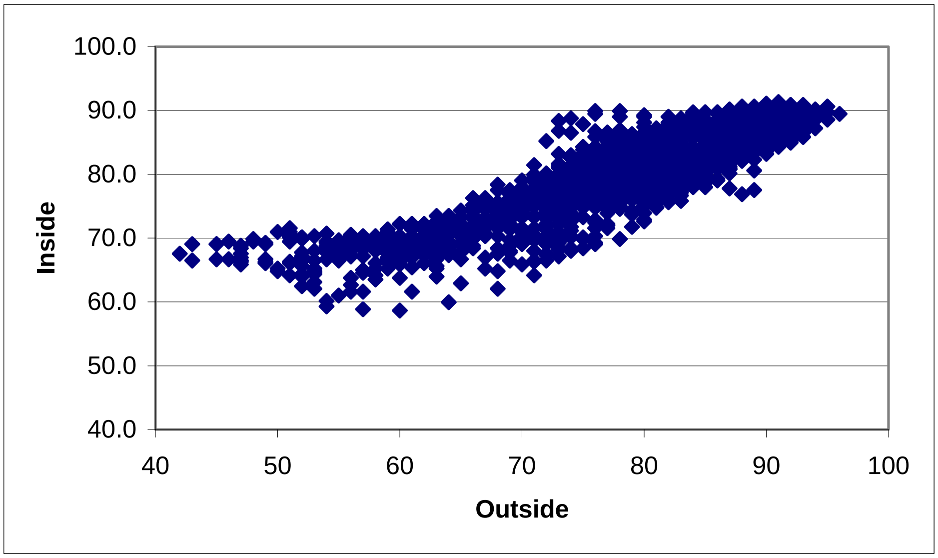

FIGURE 4. Comparison of hourly temperatures between the ambient and Stiles, Fall 1997

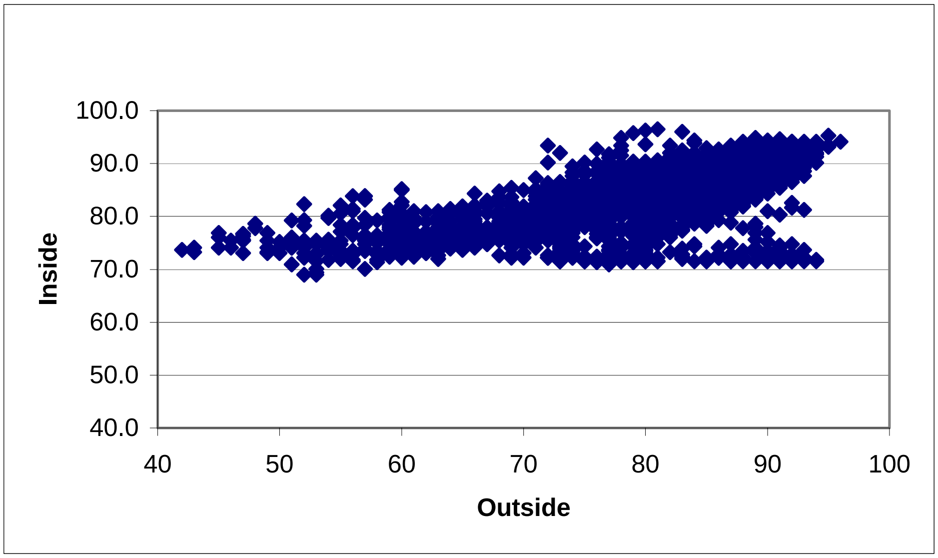

FIGURE 5. Comparison of hourly temperatures between the ambient and LeBlanc, Fall 1997

Another factor in the evaluation the performance of the concrete facility to those constructed of metal is a comparison of daily maximum temperatures between the two construction types. In Figures 6 and 7 demonstrate the differences in daily maximum temperatures between the metal facilities (Gist or LeBlanc) and the concrete Stiles facility. Over the two-month period covered in either Figure 6, for July/August 1997 or Figure 7, for September/October 1997 it is clear that the Stiles unit attains a lower daily maximum temperature in all except a couple of days during these periods.

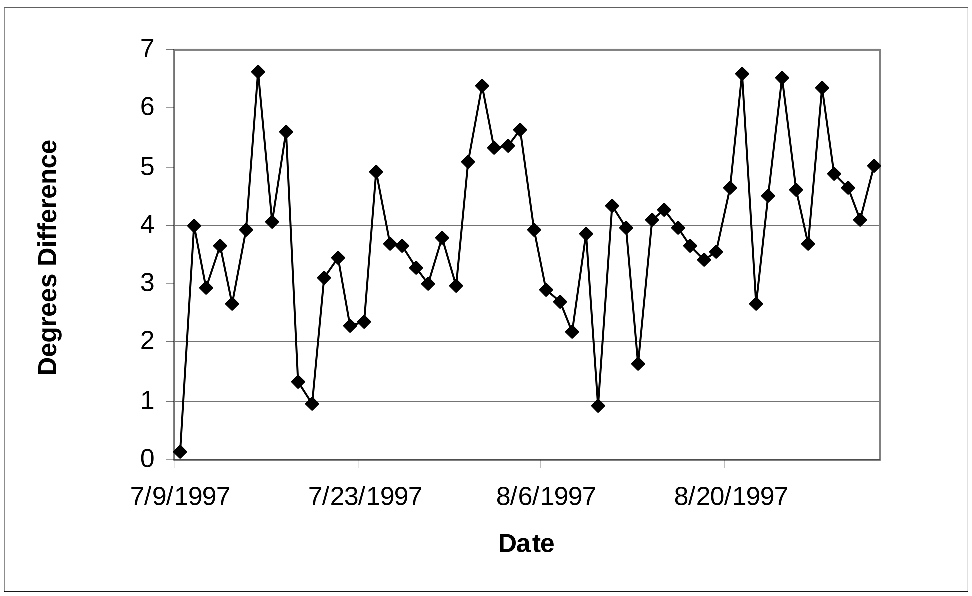

FIGURE 6. Difference in daily maximum heat index temperatures between Gist and Stiles, July and August 1997

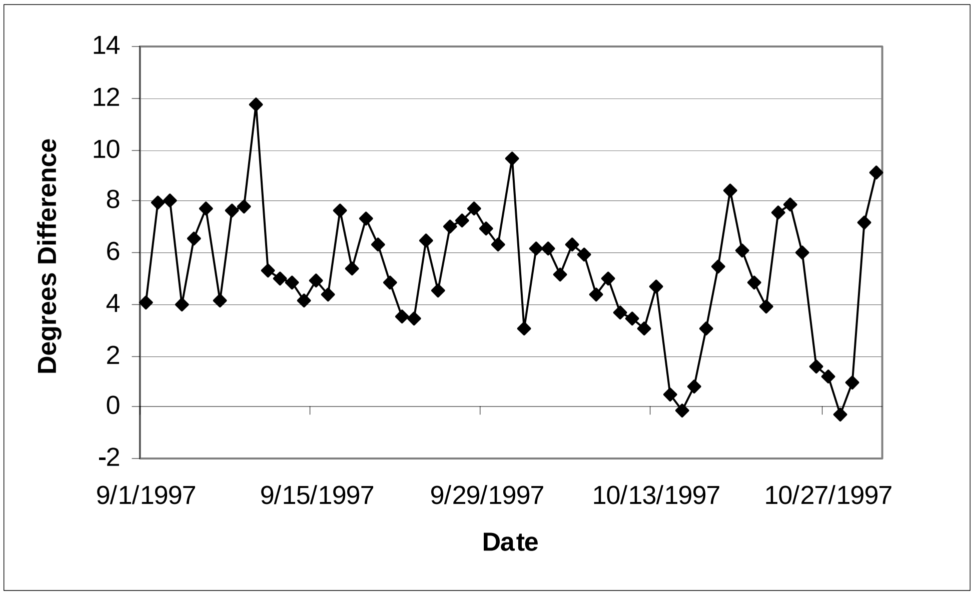

FIGURE 7. Difference in daily maximum heat index temperatures between LeBlanc and Stiles, September and October 1997

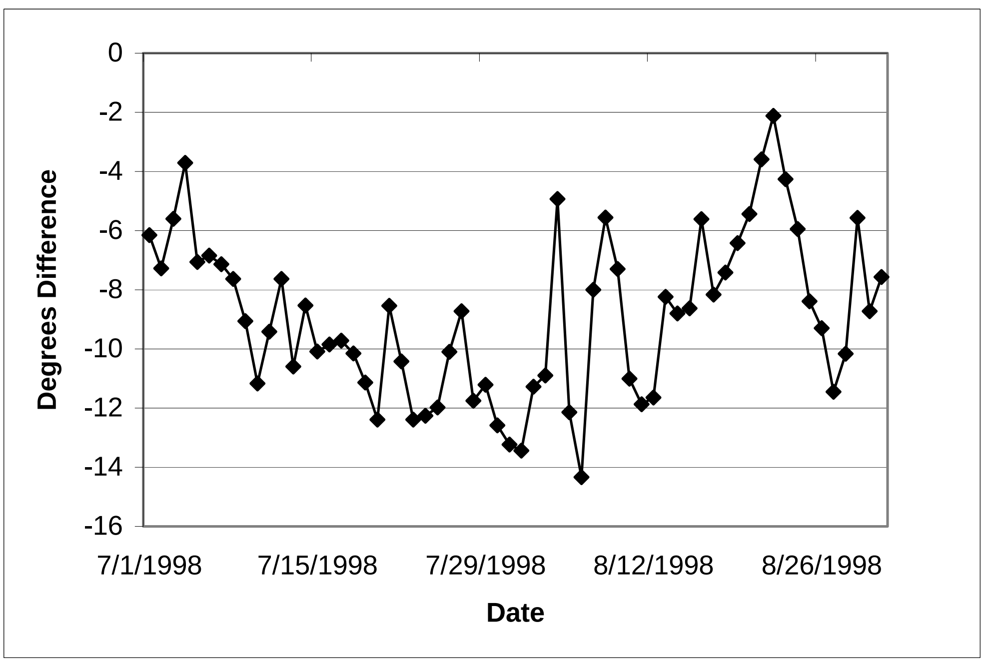

FIGURE 8. Difference in daily minimum heat index temperatures between Gist and Stiles, July and August 1998

Figure 8, above, clearly demonstrates the warming capacity and heat retention of the concrete facility (Stiles). In the comparison of minimum daily temperatures the Stiles unit consistently has higher lows, moderating the temperature fluctuation, and reducing the thermal stress on the occupants.

In the last season of the study the comparison of the outdoor to the indoor temperature is no less significant as shown in Figures 9, 10, and 11. The relative slope of the data indicates that daily heating occurs much more rapidly in the metal buildings and between the metal facilities Gist C1 and Leblanc N5; Gist occupants are experiencing the greatest rate of rise.

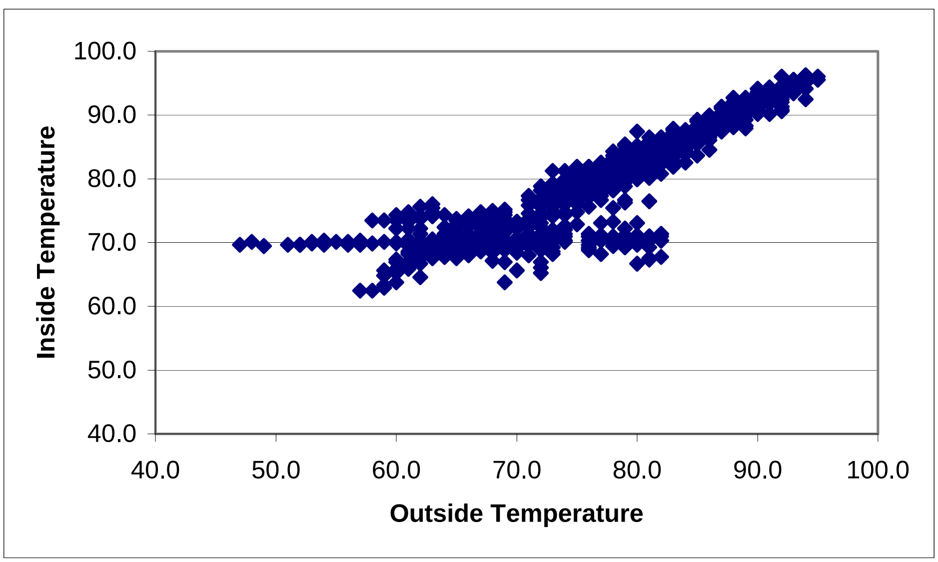

FIGURE 9. Comparison of ambient to Gist C1 temperatures, Fall 1998

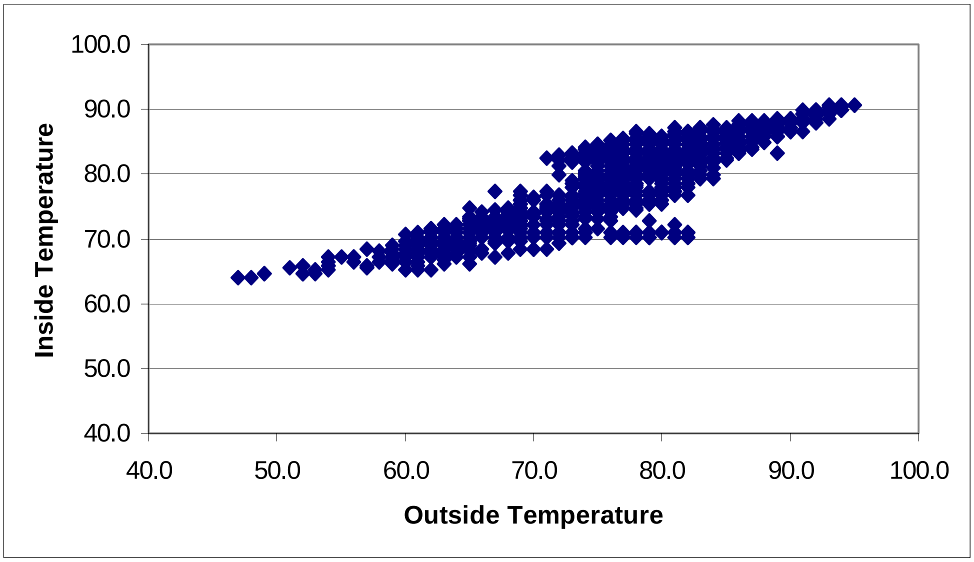

FIGURE 10. Comparison of ambient to Stiles temperatures, Fall 1998

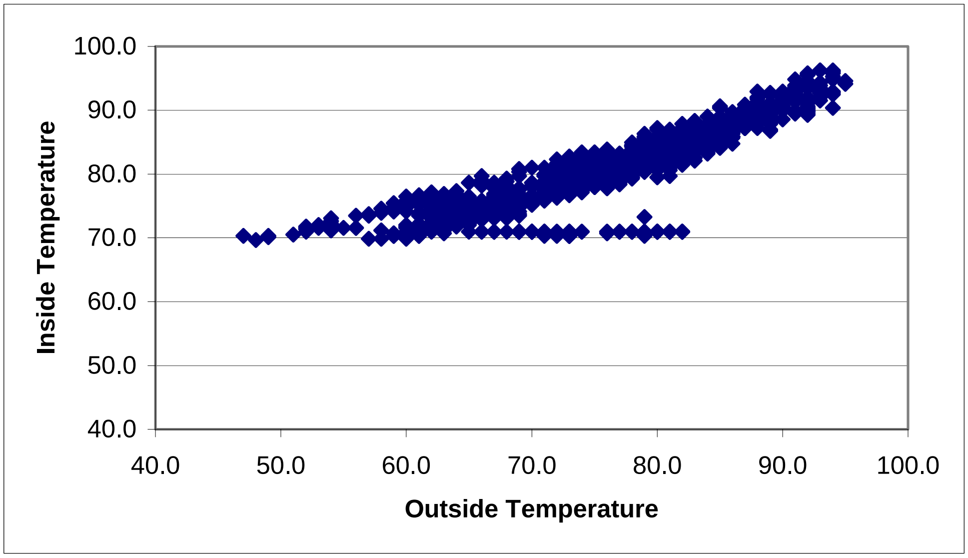

FIGURE 11. Comparison of ambient to LeBlanc N5 temperatures, Fall 1998

A greater difference, or protective effect, between the concrete unit (Stiles) and the metal units (Gist and LeBlanc) can be observed in the heat index plots of the Summer of 1998. In Figures 12, 13 and 14 the heat index of the internal environment is compared to the external environment. As described previously, the heat index is calculated using the 9-term heat index equation (Equation 1).

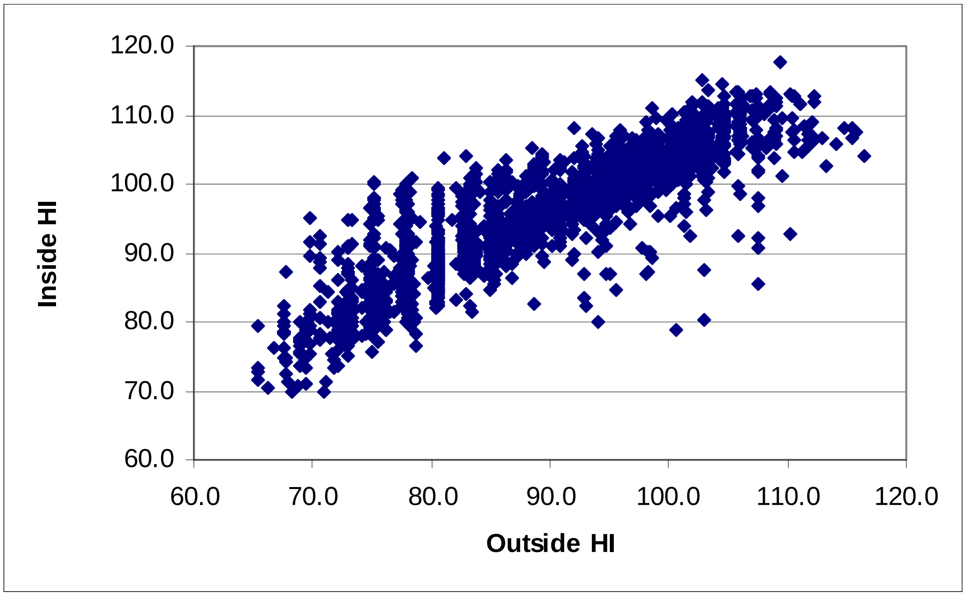

FIGURE 12. Heat index comparison of ambient to Gist C1, Summer 1998

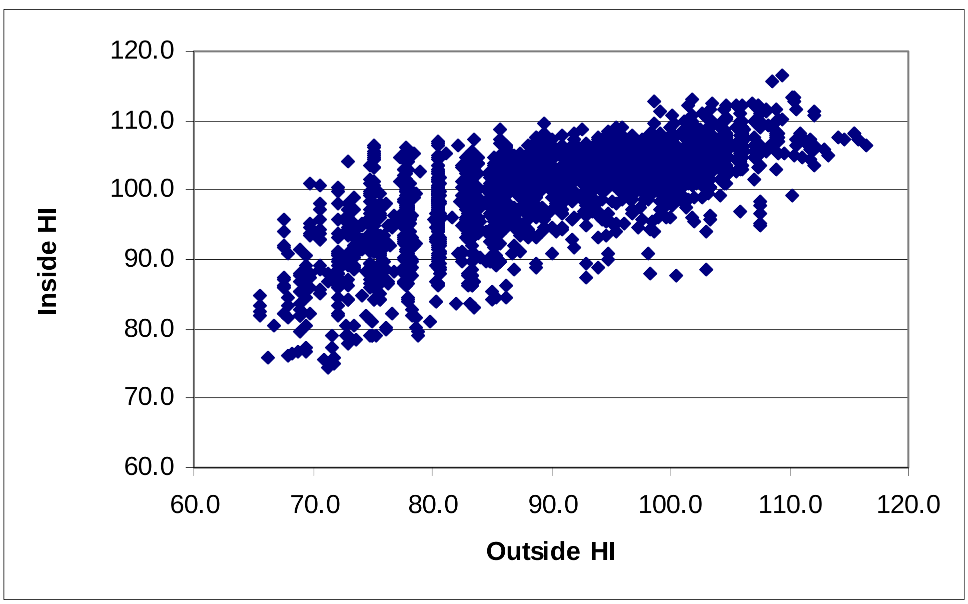

FIGURE 13. Heat index comparison of ambient to Stiles, Summer 1998

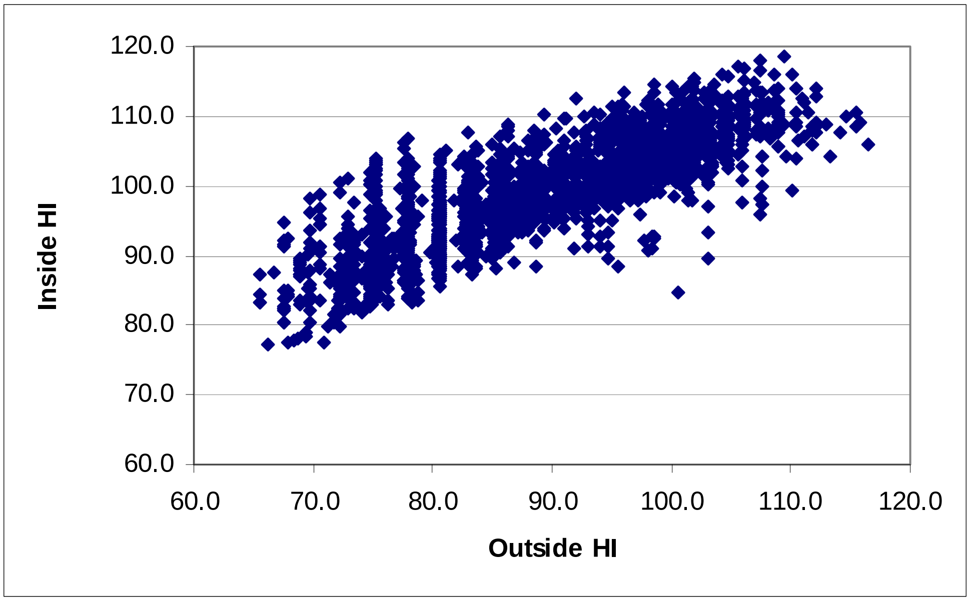

FIGURE 14. Heat index comparison of ambient to LeBlanc N5, Summer 1998

From the summer of 1998 heating rate data (degree rise per hour) was calculated for three high temperature days for the Gist and Stiles facilities and the ambient rise in temperature. The heating rate for the ambient environment for the summer 1998 averaged 0.2313°F/hr. The heating rate for air inside the Gist(metal) and Stiles(concrete) units for the same period were 0.10135°F/hr and 0.0845°F/hr, respectively. This clearly demonstrates the building response of the metal building: although somewhat protective, it responds to the external thermal load more rapidly than the concrete building.

The cooling rate must also be considered, as indicated by the differences in daily minimum temperatures (Figure 8), the cooling rate of the buildings has a significant effect on the internal environment. This rate assessment is an important consideration when designing a facility and in the evaluation of these construction types. In Figures 15 and 16 the cooling rate is compared for the ambient conditions and in each of the prison units in the study group. The ambient air losses its heat quickly and each of the buildings moderates the loss of heat, but the concrete building does the most to reduce the overnight heat loss. The upper axis in each of the Figures 15 and 16 is a scale for mean solar time. Solar time is defined by the position of the sun. The solar day is the time it takes for the sun to return to the same meridian in the sky. Local solar time can be measured with a sundial. When the center of the sun is on the observer's meridian, the observer's local solar time is zero hours (noon). Because of the earth's variation in speed of rotation throughout the year and because the earth's equator is inclined, the length of the solar day is different depending on the time of the year. Mean solar time, for convenience, is measured relative to an imaginary sun that lies in the earth's equatorial plane. Every mean solar day is of the same length. The indication of solar time provides a reference to the point in time that the sun is directly overhead and providing the maximum heating influence on the ambient temperature.

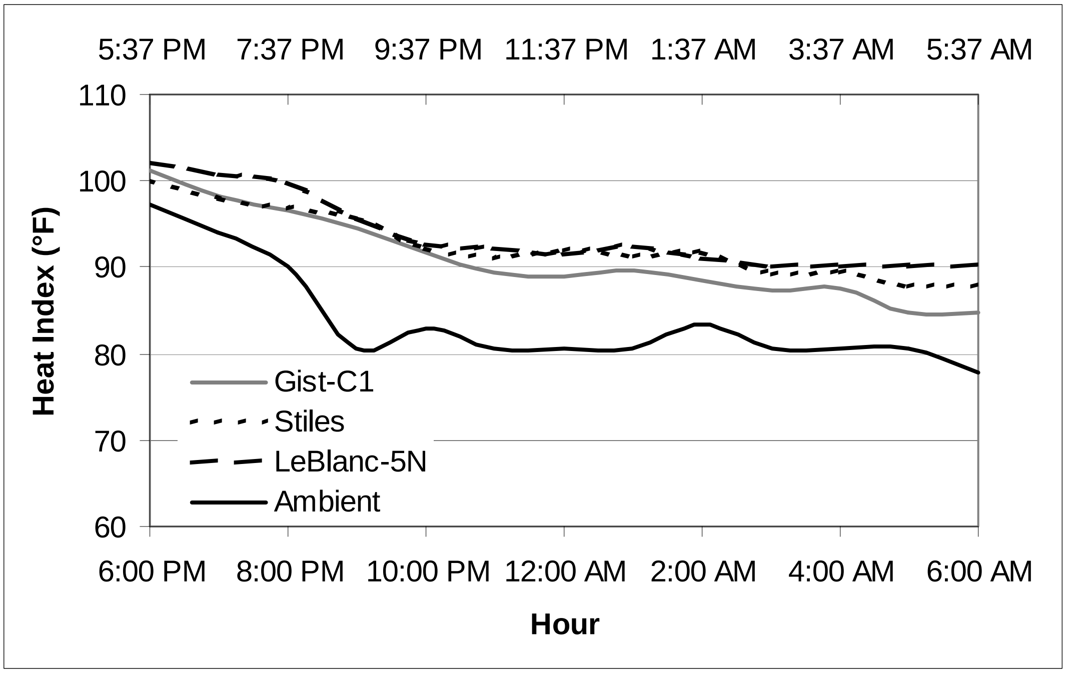

FIGURE 15. Comparison of heat index decrease under ambient conditions and in buildings, July 20, 1997

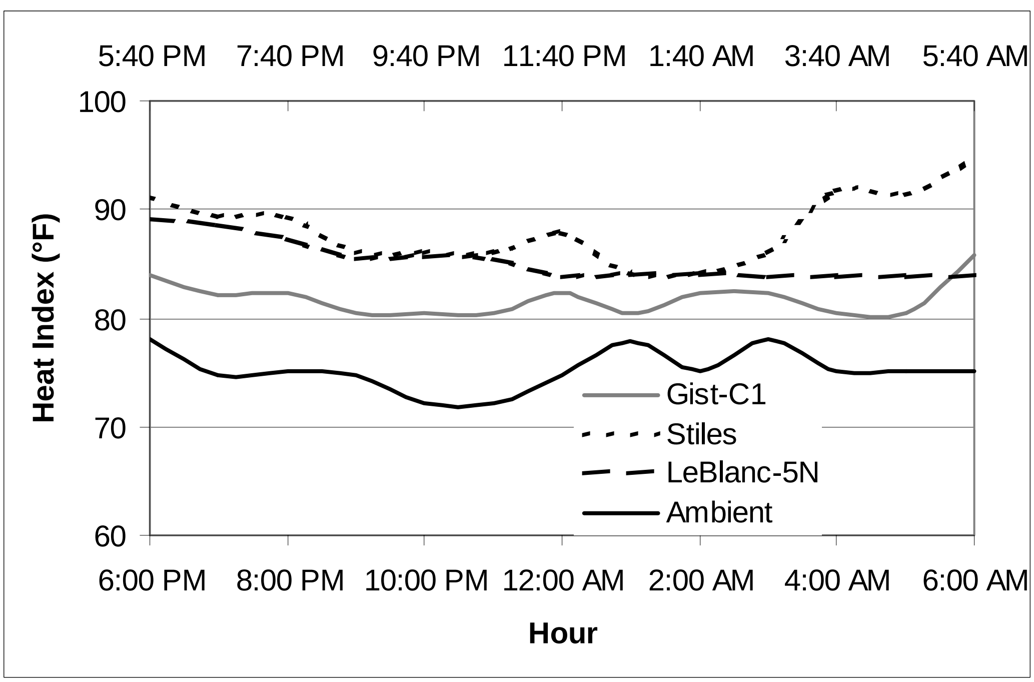

FIGURE 16. Comparison of heat index decrease under ambient conditions and in buildings, August 20, 1998

An analysis of variance (ANOVA) one-way was performed on a comparison of means of ambient temperatures and each of the units. The sample size was 16,441 in each of the six units and an overall mean of 85.645. The comparison of the ambient heat index conditions to the Gist unit resulted in a mean difference of - 3.275 (CI –3.94 to -2.60, $p<0.01$), the Stiles unit had a mean difference - 2.187 (CI –2.86 to –1.51, $p<0.01$) and the LeBlancN5 facility a mean difference of - 4.884 (CI –5.55 to –4.21, $p<0.01$). Each of the metal units were also compared to the concrete unit and the mean difference between Gist and Stiles was calculated to be 1.088 (CI 0.42 to 1.75, $p<0.01$). This meant that the Stiles unit was typically cooler as compared to the Gist unit. When the the mean difference between Stiles and LeBlanc was calculated for this data set it was found to be –2.697 (CI –3.36 to –2.02, $p<0.01$).

The comparisons of heat indices over the 16 months of the study are presented in Figures 17, 18, and 19 by year. The heat indices calculated for the warm months of 1998, for the Gist Unit shows a small increase over the heat index for the same period in the previous year (Figure 17). However, the other two prison units in the study exhibit a slight reduction in the calculated heat index over a majority of the heating months.

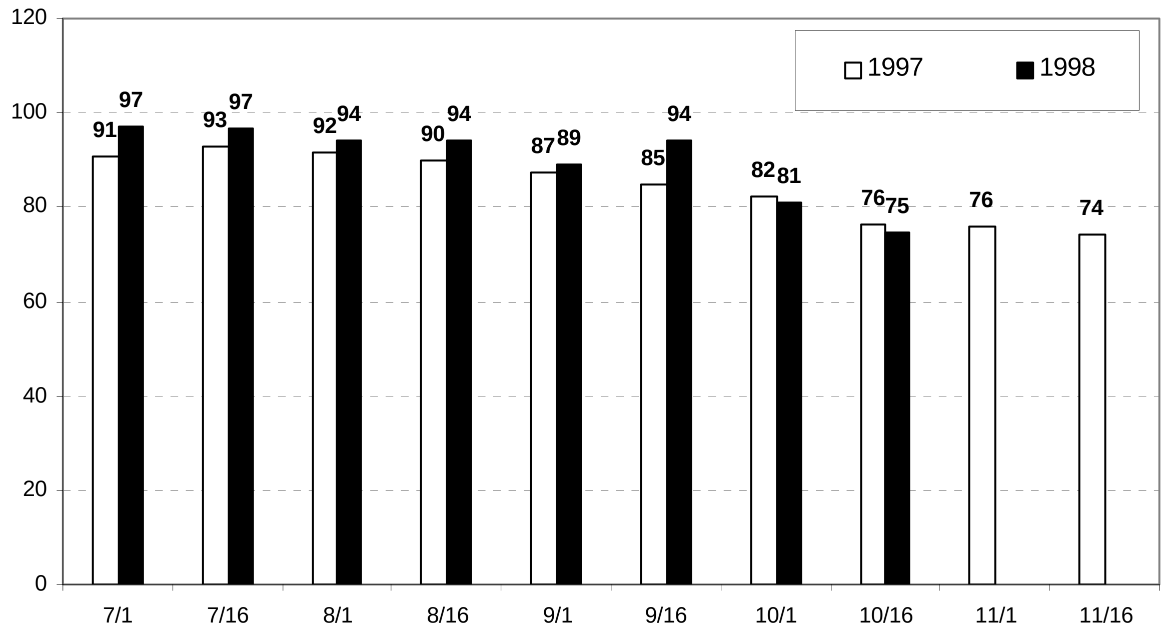

FIGURE 17. Heat indices for Gist unit on comparable dates 1997 and 1998 (°F)

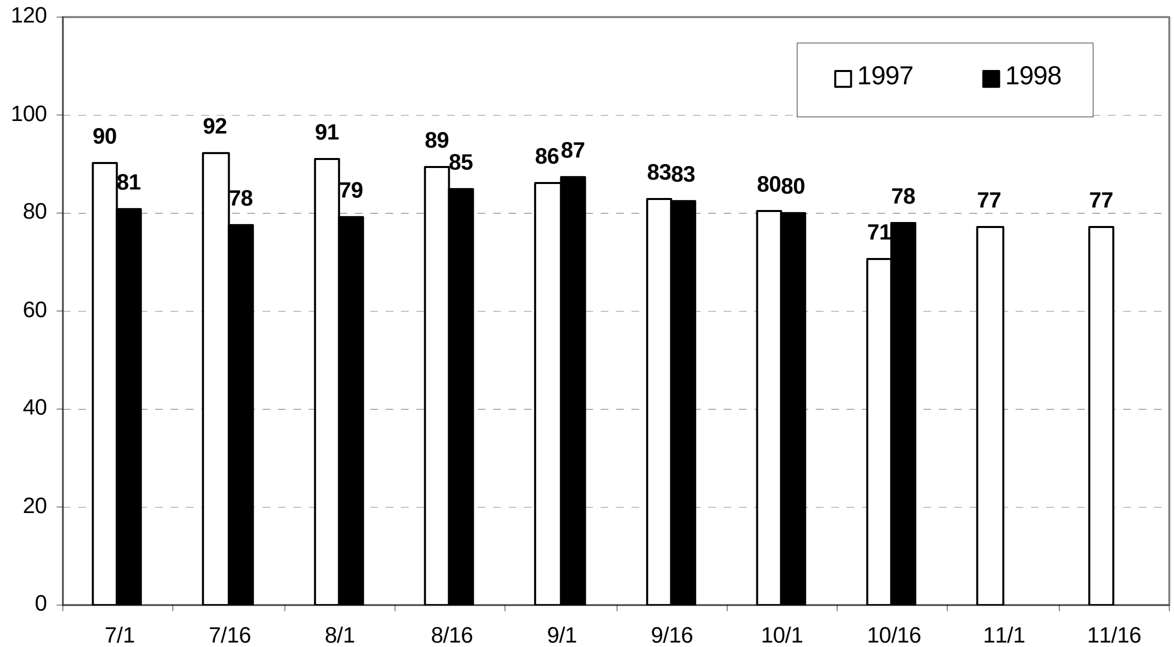

FIGURE 18. Heat indices for Stiles unit on comparable dates 1997 and 1998 (°F)

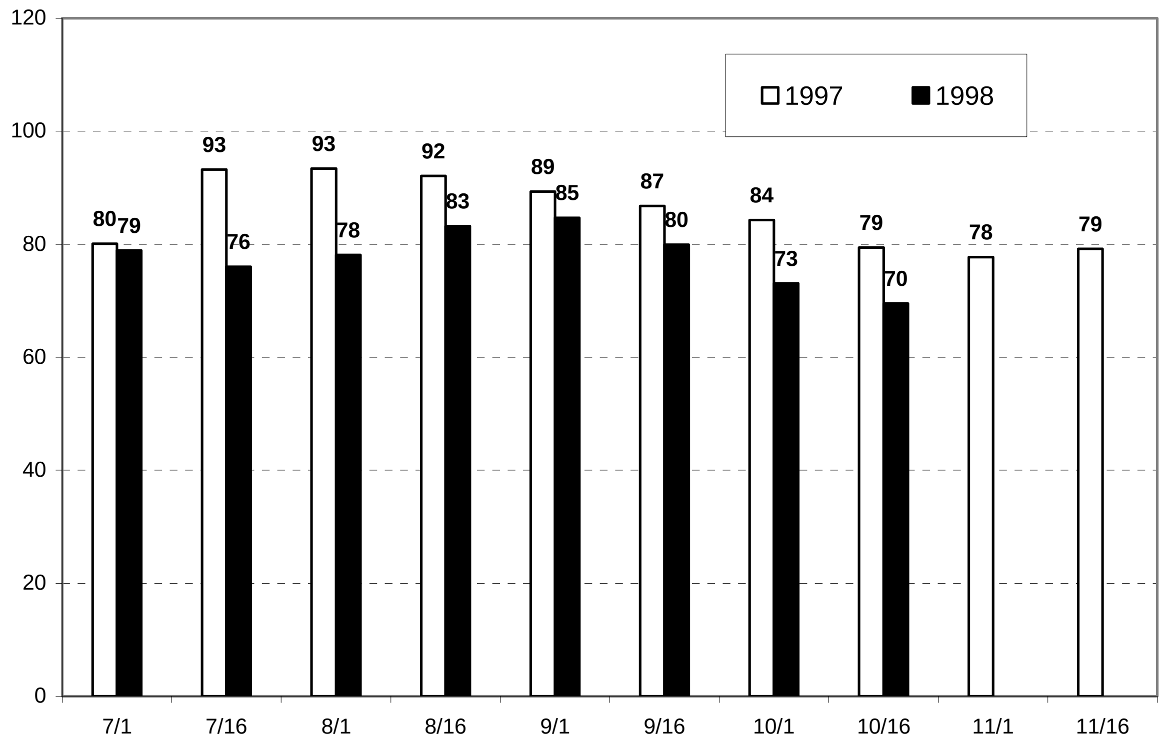

FIGURE 19. Heat indices for LeBlanc unit on comparable dates 1997 and 1998 (°F)

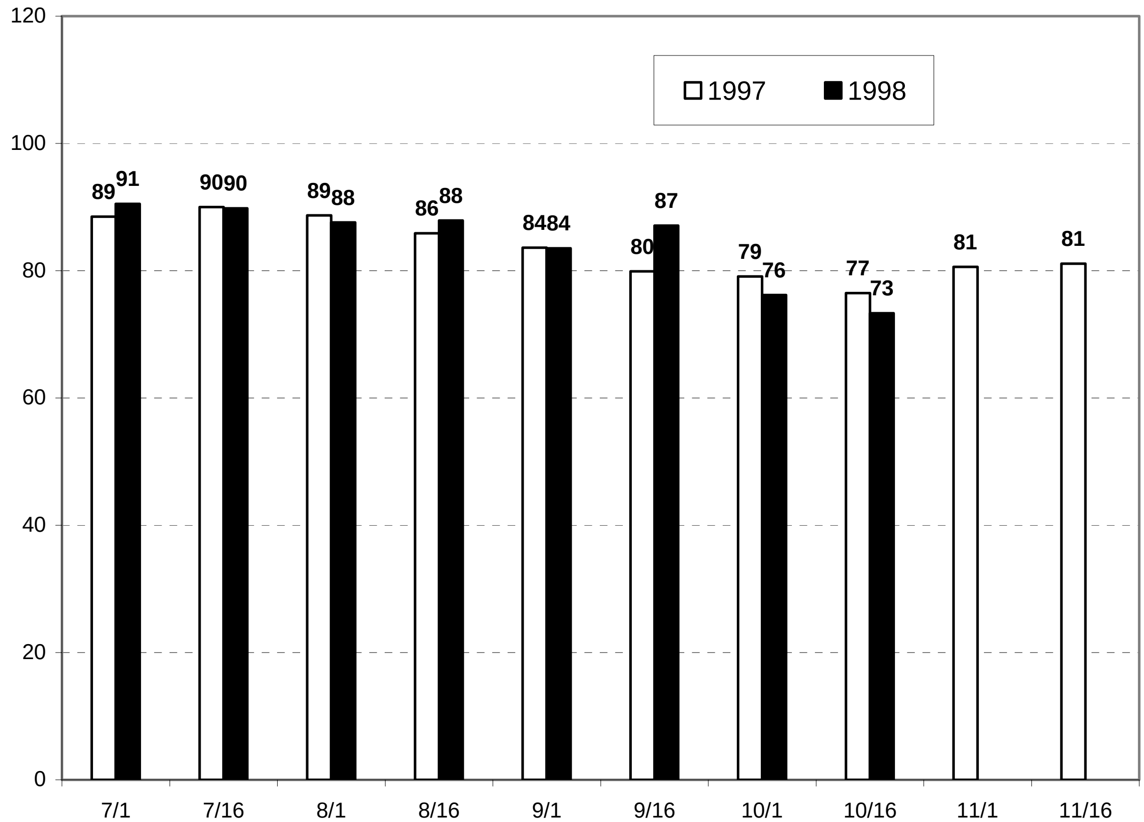

FIGURE 20. Heat indices for ambient conditions on comparable dates 1997 and 1998 (°F)

Figure 20, is the comparison of ambient heat index, calculated form the ambient dry-bulb temperature and relative humidity. The yearly variation between heat indexes for any given day is low from year to year. By comparing Figure 20 to any of the other Figures 17, 18 or 19 the protective barrier offered by the building envelope can be realized. The building material chosen moderates the temperature in the internal environment and without the presence of some other means of either reducing temperature or relative humidity the internal environment of the prison buildings will fluctuate with the ambient conditions. The extent of that fluctuation is clearly a function of the selected building material.

EVALUATION OF THERMAL LAG

In the examination of the response of the buildings to the external temperature and relative humidity, the rate of rise was viewed as a coincident to the occurrences outdoors. However, the rise in the heat index for the buildings was not only slower but also was displaced in time. This delay in heating (cooling) is the intrinsic thermal lag of the construction materials. The thermal lag was estimated by examining the temperature, relative humidity and heat index data for each of the facilities on the data spread sheets. The lag was evaluated for three seasons Fall 1997, Summer 1998 and Fall 1998 using the crosscorrelation function as described earlier in this paper. The lag times as determined by the crosscorrelation calculations are presented in Table V, by season. Since supplemental natural gas heat is used during the winter months to maintain an interior temperature of 68 to 75°F the lag between outdoor temperature and indoor conditions cannot be estimated.

TABLE V. Temperature Lags by Season and Unit

	Fall 1997	Summer 1998	Fall 1998	Average lag
Gist C1	3 hours	1 hour	1 hours	1.67 hours
LeBlanc N5	3 hours	2 hours	2 hours	2.33hours
Stiles 7	9 hours	4 hours	8 hours	7.0 hours

Table V shows that the Stiles unit, regardless of season, provided a greater refuge from the ambient temperature and if combined with the lower rate of temperature rise, the concrete building provides the best occupant environment. The data for the units were tested for autocorrelation and correlation before and after the adjustment for thermal lag. Both temperature and heat index was determined to be highly autocorrelated in each of the seasonal periods.

In Figures 21, 22 and 23 the heating trend for each of the units is compared to the ambient conditions. In Figure 21, the heating during a 12-hour (6 AM to 6PM) period is used as an example of the seasonal heating pattern. The ambient heat index rises gradually over the course of the morning to an afternoon high temperature. Each of these figures also indicates the corresponding solar time. In Figures 22 the concrete unit (Stiles) trails behind the rest of the units. This lower heat index profile emphasizes the capabilities of the concrete walls to shelter the occupants from the more dynamic changes in heat index.

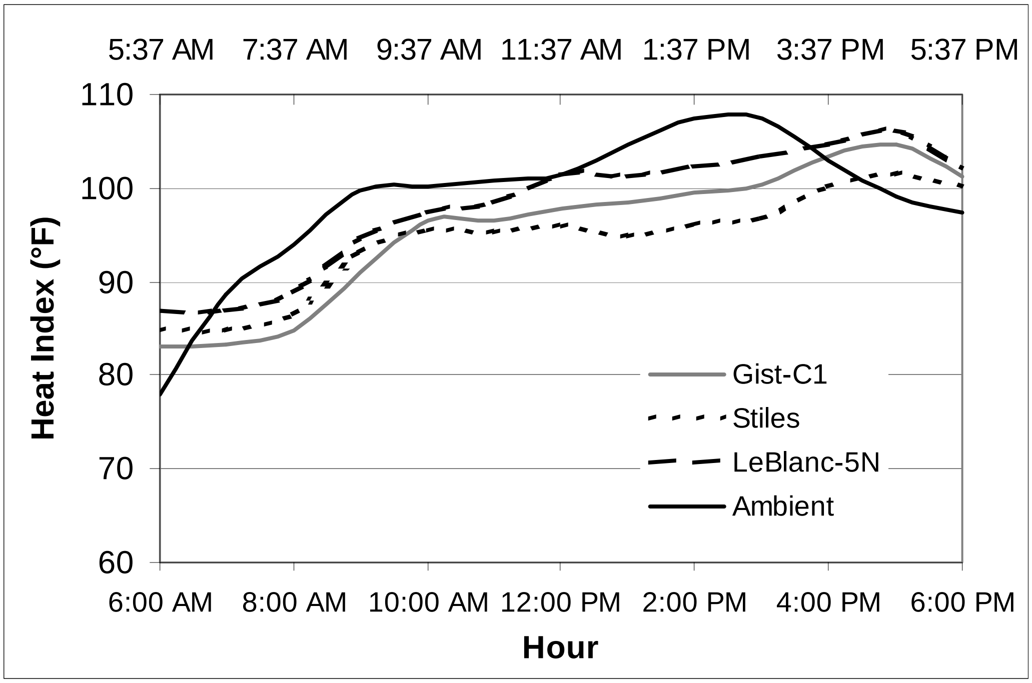

FIGURE 21. Comparison of heat index rise under ambient conditions and in buildings, July 20, 1997

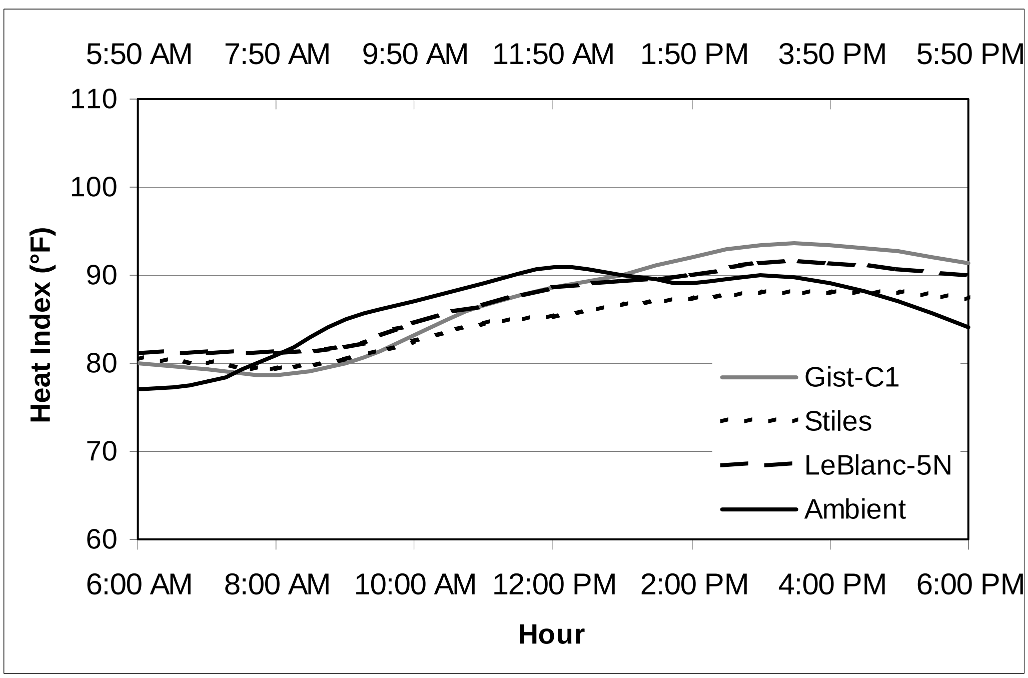

FIGURE 22. Comparison of heat index rise under ambient conditions and in buildings, September 20, 1997

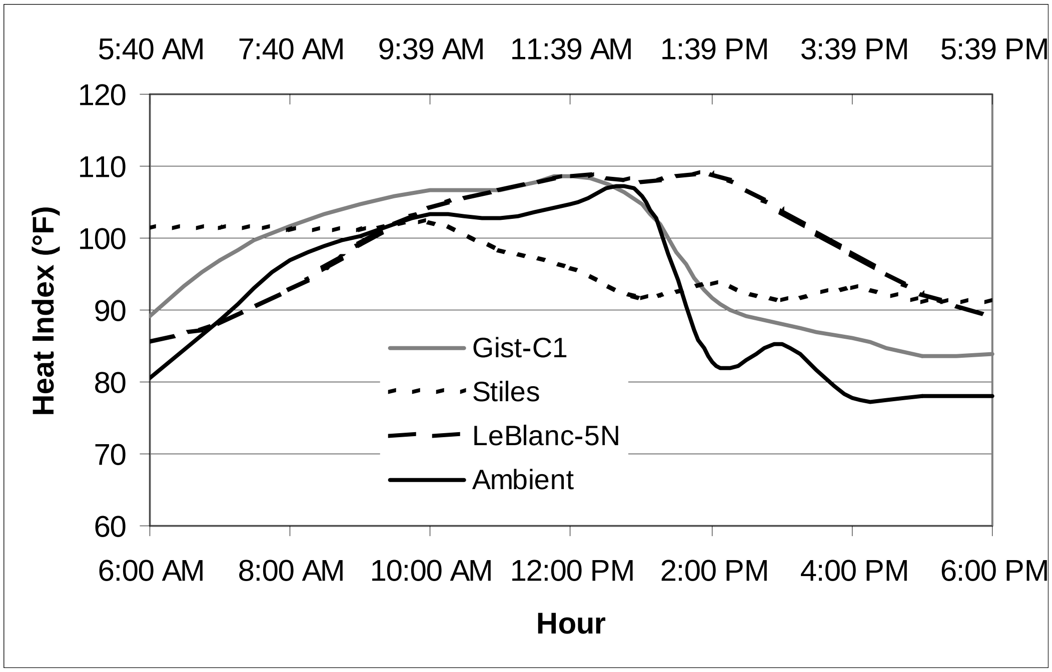

FIGURE 23. Comparison of heat index rise under ambient conditions and in buildings, August 20, 1998

Figure 23 is slightly different than the other two figures, previous, in that on this particular day the ambient conditions changed rapidly and each of the buildings responded to that change based on its capacity to store or release heat into the internal and the external environment. In this case the concrete facility seems to have responded more quickly to the change, if not only because it had not reached its maximum internal temperature on that day.

Finally, a correlation of the temperatures in each of the seasons was evaluated aligned with the ambient temperature before and after lag time adjusted as determined above. The results were that prior to the lag adjustment Stiles had a correlation with the ambient temperature of 0.470 but after the lag adjustment that correlation increased to

0.764. Similar increases in correlation were calculated for each of the other sites Gist-C1 0.598/0.722 and for LeBlanc-N5 0.243/0.591. The overall effect of the lag on the occupants is that the heating or cooling of the indoor environment is delayed. This provides a little cooling effect during the hot portions of the day and a warming effect as the ambient temperatures begin to fall. There is also less fluctuation from daily high to daily low in the concrete buildings and the stability of the indoor environment can be attributed to the thermal storage of the concrete construction.

OCCUPANT RESPONSE TO HEAT

The final objective of this study was to investigate the increase in violence rate and to determine if the construction type provided some leveling effect here too. One confounder in the establishment and comparison of the Use of Force incidents between the three selected prison units is the type and classification of inmate found in each facility. In the year prior to the study the Uses of Force pattern was reviewed and that data is presented in Figure 24. From this graph, the incidents in Use of Force steadily increase, beginning in the spring months and reaching a peak in July.

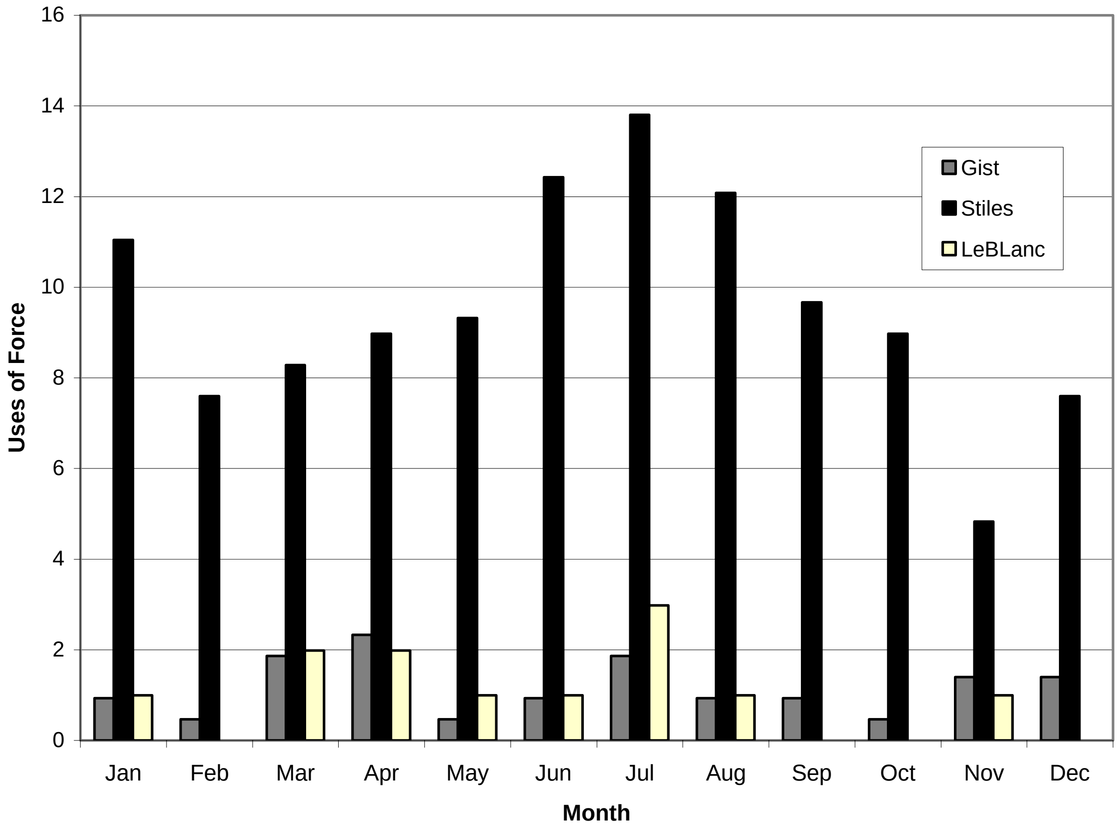

FIGURE 24. Use of force incidents per thousand inmates for 1996 by month of occurrence

Another problem with analyzing the UOF data with respect to temperature variation is that a daily record of the UOF does not exist and the records are only compiled and accessible on a monthly basis. This presented a little of an analysis problem because of the lack of statistical power in the data set. Consequently, the UOF data was combined by season rather than on a month-by-month basis. In Table VI the average seasonal temperature inside each of the testing units is compared to the UOF numbers for that season. Although Stiles with the more aggressive inmate population maintains a high incidence of UOF, the proportional increase is not as great as is observed in the Gist unit. The table also highlights one of the confounders of the type of population in each of the units. LeBlanc appears to have a very low UOF incidence; however, the characteristic of this population is that they are predominantly substance abuse felons. These inmates are typically not violent. Their incarceration is usually because of drug related offenses and they are not considered violent at the time of sentencing. The inmates also desire to remain in the substance abuse program. By avoiding confrontation with other inmates and security staff, they reduce the likelihood that they will be transferred to a higher custody level facility, such as Stiles.

TABLE VI. Temperature Averages for Season and Uses of Force (per thousand inmates) by Unit

Unit	Fall 1997 (74.5)	Uses of Force	Winter 1997 (55.1)	Uses of Force	Spring 1998 (67.8)	Uses of Force	Summer 1998 (82.8)	Uses of Force	Fall 1998 (68.2)	Uses of Force
Stiles	80.5	8.9	75.3	5.9	76.2	7.5	85.9	8.4	76.1	7.4
Gist	80.7	3.3	69.6	1.6	74.4	3.0	85.5	3.0	76.3	1.8
LeBlanc	62.3	0.3	76.9	0.3	76.9	0.3	86.1	0.7	77.7	0.3

In the Gist unit the increase in the UOF incident is almost twice that observed in the cooler months. The cooler season is considered the baseline rate of UOF for comparison purposes in this study. Meanwhile the Stiles facility, the highest level of risk facility among the test cohort, experiences only a slight increase in the UOF incidents during the hot season.

One other analysis of the data is to look at seasonal temperature variations (max-min) and the relative UOF risk. The relative UOF risk value is calculated by separating the monthly statistics into either warming or cooling months. The cooling months were defined as those with average ambient temperatures below 73°F and the warming months as those with averages temperatures above 73°F. The months combined into the cooling category were November 1997 through April 1998 and November of 1998. The warming months were July 1997 through October 1997 and May 1998 through October 1998. The seasonal difference between cool and warm were calculated and the UOF statistics for the cooler months were taken as the expected rate of UOF. The relative UOF risk is then calculated as a rate of observed (warm month UOF) to the expected (cool month UOF). In Table VII each of the units in the study is compared against the differentials of seasonal temperature, relative humidity and heat index.

TABLE VII. Comparison of Warm Seasons to Cold Seasons

Unit	Temperature Difference	Heat Index Difference	Relative Use of Force Risk
LeBlanc N5, C1 (avg)	7.5	11.3	1.037
Stiles 7	7.7	4.6	1.126
Gist C1	11.3	14.4	1.179
Gist C7(A/C)	10.4	13.2	
Ambient	20.4	3.1	

The comparison clearly shows that although the Heat Index variation in the LeBlanc unit is considerable there is not a large increase in UOF risk. Where as in the Gist unit the relative UOF rate is slightly higher at when there is only 3 degrees difference in the heat index. What is the most remarkable about the comparison provided in Table VII is that the Stiles unit has a very low heat index variation, but that there is a significant amount of moisture (relative humidity) variation in the concrete unit. In fact, all the units have rather large relative humidity variations.

PREDICTING AND PLANNING FOR INMATE AGGRESSION

Based on the findings of this study the prison administration could use seasonal variations to adjust the level of staff on a prison unit. The adjustment would be a consistent result with other studies of aggression and environmental conditions as reported in this dissertation. The rise in temperature during the Spring and Summer months would lead to the decision of increasing the staff level to address the increased risk of aggression. Additionally, if the extreme heat directive is followed for outdoor work (81) more inmates will be inside of the housing units and have more discretionary time as described in the study of domestic disputes.(65) The TDCJ administration can also choose to modify the internal environmental condition; however, except for a couple of exceptions, the majority of the units were not designed to allow for cooling or dehumidifying of the environment, so increased circulation of the air within the facility is the only feasible solution.

CHAPTER VI

CONCLUSIONS AND IMPLICATIONS

CONSIDERATIONS FOR PRISON CONSTRUCTION

This dissertation reports an evaluation of three facilities of the Texas Department of Criminal Justice. This was conducted to evaluate the effect of construction type on the occupant environment. The study also examined the relationship between the occupant environment and its effects on the aggression of the occupants measured as the convenient indicator, the Use of Force. This study adds to the science in understanding some key components of occupancy and environmental control of the built environment. Building response to temperature changes is accepted but the studies demonstrating the response are not well documented in the public health literature. The information that is available deals primarily with modifications to the indoor environment such as ventilation and heat transfer from surfaces rather than an overall building response, measured as temperature and humidity changes, to the outdoor stressors. Secondly, the literature does document the relationship between aggression (violence) and temperature increase but the application of those relationships has not been used to predict aggression in prisons nor has the data been used to justify modifications in building designs in order to reduce the incidence of violence in the prisons. The comparison of uses of force between the metal buildings and their concrete counterparts indicates the effects of temperature rise in the metal facilities. Although the difference is not statistically significant, there is a suggestion in the data that aggression reduces as temperatures decline. This trend is repeated in the seasonal nature of the UOF reported by TDCJ facilities. Additionally, the examination of the temperature moderating effect of the concrete buildings when compared to the metal buildings demonstrates the environmental mediating effect that the old style of prison construction had on the occupied spaces.

Finally, from this study the control of the internal environment by mechanical means would have a significant effect on the population within the prison system. The temperatures found in the Gist C7 unit with air conditioning showed that even with a thermostat set to a relatively high temperature the occupant environment could be controlled. The temperatures and heat indices were found to be lower in the concrete building as compared to the metal construction. The concrete building also controlled the variability of the internal environment resulting in much narrower heat index swings from hot to cold. The data also supports the conclusion that the concrete building allowed for heat that is more gradual over the course of a day and that this gradual heating resulted in a temperature lag. This lag afforded the occupants a refuge from the heat during the day and allowed them to take advantage of heat release from the structure during the night hours. The study only looked at stress outcomes of the inmate population but the security personnel in the prison facilities are exposed to the same environmental conditions as the inmates. Another outcome of this study is to encourage the TDCJ to look at alternative methods for reducing the heat and relative humidity in the prison facilities. Although the taxpayers of Texas would probably never accept air-conditioned prisons, yet the relative costs of air conditioning and the response to increased aggression should be considered.

RECOMMENDATIONS FOR FUTURE RESEARCH

The TDCJ designs a single proto-type of their facilities and then has historically placed that proto-type of facility across the state regardless of local climate. This study focused on one geographical location and three prison facilities within the State of Texas. The expansion of the TDCJ into all areas of the state indicates that these construction types, heat load, and aggression tendencies should be addressed in each of the climates in Texas where TDCJ facilities are located.

This study has raised additional questions relevant to future research. Additional studies of thermal response in the other climactic zones for the same construction types (concrete and metal) should be conducted and the building responses evaluated. This will remove any ambiguity as to selection of construction type for a particular climate. Future studies should also examine mechanisms to create an occupant environment that is not so stressful. This will then address and reduce the fluctuations in violent acts. The studies should include the effects of the heat on the security forces with in TDCJ. With a prison system as large as TDCJ, several factors influence the quality of life for the workers in the system. Changes over the last quarter century (19) have placed a great burden on the security personnel who are charged with keeping the public safe from the criminals within their fences.

There are many opportunities for others to learn from the design issues of the Texas prison system. Historically the very best design for a prison facility had entwined in it both a rehabilitative mission and the needs of the community for security. Now is the time to recognize that environmental conditions within the correctional facility can be managed and made a key component in the design process. Several states have begun looking at tempering the occupant environment within the prisons and jails. There are even attempts at making these cooling systems cost efficient and practical for use.[82] Public health and emergency service planners have for years considered the need to consider the thermal environment. Changes need to be proposed in order to facilitate that same level of responsiveness inside the penitentiary environment.

REFERENCES

1. **Rose, S. R.:** *Evaluation of Heat Stress in an Aluminum Smelter*. M.S. thesis, Department of Safety Engineering, Texas A&M University: College Station, 1999.

2. **Dixon, R. W.:** *Heat Stress Hazard in the Southern United States: An Evaluation Using a Climatological and Demographic Model*. Ph.D. dissertation, Department of Geography, Texas A&M University: College Station, 1996.

3. **Baron, R. A.:** Aggression as a function of ambient temperature and prior anger arousal. *Journal of Personality and Social Psychology 21*: 183-189 (1972).

4. **Baron, R. A.:** Aggression and heat: The "long hot summer" revisited. In *Advances in Environmental Psychology*, A. Baum , S. Valins and J. Singer, (eds.). Mahwah, NJ: Lawrence Erlbaum Associates, 1978. pp. 57-84.

5. **Baron, R. A. and P. A. Bell:** Aggression and heat: Mediating effects of prior provocation and exposure to an aggressive model. *Journal of Personality and Social Psychology 31*: 825-832 (1975).

6. **Baron, R. A. and P. A. Bell:** Aggression and heat: The influence of ambient temperature, negative affect, and a cooling drink on physical aggression. *Journal of Personality and Social Psychology 33*: 245-255 (1976).

7. **Baron, R. A. and V. M. Ransberger:** Ambient temperature and the occurrence of collective violence: The "long hot summer" revisited. *Journal of Personality and Social Psychology 36*: 351-360 (1978).

8. **Bell, P. A. and R. A. Baron:** Aggression and heat: The mediating role of negative effect. *Journal of Applied Social Psychology 6*: 18-30 (1976).

9. **Bell, P. A. and R. A. Baron:** Aggression and ambient temperature: The facilitating and inhibiting effects of hot and cold environments. *Bulletin of the Psychonomic Society 9*: 443-445 (1977).

10. **Bell, P. A. and M. E. Fusco:** Heat and violence in the Dallas field data: Linearity, curvilinearity, and heteroscedasticity. *Journal of Applied Social Psychology 19*: 1479-1482 (1989).

11. **Boyanowsky, E. O., J. Calvert, J. Young and L. Brideau:** Toward a thermoregulatory model of violence. *Journal of Environmental Systems 11*: 81-87 (1981).

12. **Spens, I.**, ed.**:** *Architecture of Incarceration*, 1st ed. London: Academy Editions, 1994.

13. **Johnston, N.:** *The Human Cage: A Brief History of Prison Architecture.* Philadelphia: Walker & Company, 1973.

14. **Raffaelli, L. and F. Jubien:** Saint Mark's Square. In *Knopf Guides, Venice*, 4th ed. New York: Alfred A Knopf, 1996. pp. 252-253.

15. **Johnston, N.:** *Forms of Constraint: A History of Prison Architecture.* 1st ed. Chicago: University of Illinois Press, 2000.

16. **Sevick, J. R. and W. I. Cikins**, eds.**:** *Constructing Correctional Facilities*, 1st ed. Washington, D.C.: The Brookings Institute, 1987.

17. **Fairweather, L. and S. McConville**, eds.**:** *Prison Architecture: Policy, Design and Experience*, 1st ed. Woburn, MA: Architectural Press, 2000.

18. **Glenn, L. B.:** *Texas Prisons - The Largest Hotel Chain in Texas.* 1st ed. Austin, TX: Eakin Press, 2001.

19. **Gorton, R. J.:** *Organizational Change and Managerial Control During the Contemporary Post Reform Period of the Texas Prison System.* Ph. D. dissertation, Department of Sociology, Texas A&M University: College Station, 1997.

20. **Texas Department of Criminal Justice:** *Unit Profiles.* Huntsville, TX: TDCJ, 2000. pp. 35, 59, and 92.

21. **Ruiz v. Lynaugh**; 5th Circuit, 1987; F. 2d,856.

22. **Ruiz v. Estelle**; S.D. Tex, 1980; F. Supp.,1265.

23. **Ruiz v. Estelle**; 5th Circuit, 1982; F. 2d.,266.

24. **Ruiz v. Estelle**; U.S. Supreme Court, 1983; S. Ct.,1438.

25. **Ruiz v. Estelle**; 5th Circuit, 1992; F. 2d,1115.

26. **Watson, D. A.:** Division 5 (Metals). In *Construction Materials and Processes,* 2nd ed. New York: McGraw Hill, 1978. pp. 100-141.

27. **National Oceanographic Atmospheric Administration (NOAA):** *Heat Stress.* Asheville, NC: NOAA, 1980.

28. **National Oceanographic Atmospheric Administration (NOAA):** *Heat Wave: A Major Summer Killer.* Asheville, NC: NOAA, 1985.

29. **Huynen, M. M. T. E., P. Martens, D. Schram, M. P. Weijenberg and A. E. Kunst:** The impact of heat waves and cold spells on mortality rates in the Dutch population. *Environmental Health Perspectives 109*: 463-470 (2001).

30. **Fulton, D. R.:** Heat Stress. Quest Technologies: Oconomowoc, WI, 1989, pp. 1-4.

31. **Macpherson, R. K.:** The assessment of the thermal environment: A review. *British Journal of Industrial Medicine 19*: 151-164 (1962).

32. **United States Senate:** *Heat stress and older Americans: Problems and solutions*. Washington, D.C.: Special Committee on Aging, 1983, pp. 1-14.

33. **Driscoll, D. M.:** Human health. In *Handbook of Applied Meteorology,* D. D. Houghton, (ed.). New York: Wiley-Interscience, 1985. pp. 778-814.

34. **Brengelmann, G. L.:** Circulatory adjustments to exercise and heat stress. *Annual Review of Physiology 45*: 191-212 (1983).

35. **Havenith, G., J. M. L. Coenen, L. Kistemaker and W. L. Kenney:** Relevance of individual characteristics for human heat stress response is dependent on exercise intensity and climate type. *European Journal of Applied Physiology and Occupational Physiology 77*: 231-241 (1998).

36. **Kandjov, I. M.:** Thermal stability of the human body under environmental air conditions. *Journal of Thermal Biology 23*: 117-212 (1998).

37. **Okamoto-Mizuno, K., K. Mizuno, S. Michie, A. Maeda and S. Iizuka:** Effects of humid heat exposure on human sleep stages and body temperature. *SLEEP 22*: 767-773 (1999).

38. **Bynum, G. D., K. B. Pandolf, W. H. Schuette, R. F. Goldman, D. E. Lees, J. Whang-Peng, E. R. Atkinson and J. M. Bull:** Induced hyperthermia in sedated humans and the concept of critical thermal maximum. *American Journal of Physiology 235*: R228-R236 (1978).

39. **Lienhard, J. H.:** *A Heat Transfer Textbook.* Englewood Cliffs, NJ: Prentice-Hall, 1981.

40. **Holman, J. P.:** Steady-state conduction - One dimension. In *Heat Transfer,* 8th ed. New York: McGraw-Hill, 1997. pp. 26-75.

41. **Holman, J. P.:** Principles of convection. In *Heat Transfer,* 8th ed. New York: McGraw-Hill, 1997. pp. 218-281.

42. **Mills, A. F.:** *Heat Transfer*. Homewood, IL: Richard D. Irwin, Inc., 1992.

43. **Holman, J. P.:** Radiation heat transfer. In *Heat Transfer,* 8th ed. New York: McGraw-Hill, 1997. pp. 394-515.

44. **Anapol'skaya, L. E. and L. S. Gandin:** *Meteorologicheskie Faktory Teplovogo Rezhima Zdanii.* 1st ed. Jerusalem: Keter Publishing House Jerusalem, Ltd., 1975.

45. **Quayle, R. and F. Doehring:** Heat stress: A comparison of indicies. *Weatherwise 34*: 120-124 (1981).

46. **Kalkstein, L. S. and K. M. Valimont:** An evaluation of summer discomfort in the United States using a relative climatological index. *Bulletin of the American Meteorology Society 67*: 842-848 (1986).

47. **Thom, E. C.:** The Discomfort Index. *Weatherwise 12*: 57-60 (1959).

48. **Masterson, J. and F. A. Richardson:** *Humidex, A Method of Quantifying Human Discomfort Due to Excessive Heat and Humidity*. Downsview, ON: Environment Canada, 1979.

49. **Steadman, R. G.:** The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. *Journal of Applied Meteorology 18*: 861-873 (1979).

50. **Steadman, R. G.:** The assessment of sultriness. Part II: Effects of wind, extra radiation and barometric pressure on apparent temperature. *Journal of Applied Meteorology 18*: 874-885 (1979).

51. **Steadman, R. G.:** A universal scale of apparent temperature. *Journal of Climate and Applied Meteorology 23*: 1674-1687 (1984).

52. **Rothfusz, L. P.:** *The heat index "equation" (or, more than you ever wanted to know about heat index)* Fort Worth, TX: National Weather Service - Southern Region, 1990.

53. **Ahrens, C. D.:** *Meteorology Today*. 3rd. ed. St. Paul, MN: West Publishing, 1988.

54. **Henderson-Sellers, A. and P. Robinson:** *Contemporary Climatology*. New York: John Wiley & Sons, 1986.

55. "Heat Index + Sports @ Zunis.org." [Online] Available at http://www.zunis.org/ (accessed July 28, 2004).

56. **Schwartz, D. C.:** On the ecology of political violence: "The long hot summer" as a hypothesis. *The American Behavioral Scientist 8*: 24-28 (1968).

57. **Palamarek, D. I. and B. G. Rule:** The effects of ambient temperature and insult on the motivation to retaliate or escape. *Motivation and Emotion 3*: 83-92 (1979).

58. **Bell, P. A.:** Physiological, comfort and performance, and social effects of heat stress. *Journal of Social Issues 37*: 71-94 (1981).

59. **Carlsmith, M. M. and C. A. Anderson:** Ambient temperature and the occurrence of collective violence: A new analysis. *Journal of Personality and Social Psychology 37*: 337-344 (1979).

60. **Harries, K. D. and S. J. Stadler:** Aggravated assault and the urban system: Dallas, 1980-81. *Journal of Environmental Systems 15*: 243-253 (1986).

61. **Harries, K. D. and S. J. Stadler:** Heat and violence: New findings from Dallas field data, 1980-1981. *Journal of Applied Social Psychology 18*: 129-138 (1988).

62. **Heller, N. B. and R. E. Markland:** A climatological model for forecasting the demand for police service. *The Journal of Research in Crime & Delinquency 7*: 167-176 (1970).

63. **LeBeau, J. L. and R. H. Langworthy:** The linkages between routine activities, weather, and calls for police services. *Journal of Police Science and Administration 14*: 137-145 (1986).

64. **Perry, J. D. and M. E. Simpson:** Violent crimes in a city: Environmental determinants. *Environment and Behavior 19*: 77-90 (1987).

65. **LeBeau, J. L.:** The oscillation of police calls to domestic disputes with time and the temperature humidity index. *Journal of Crime and Justice XVII*: 149-161 (1994).

66. **Chang, D. H.:** Environmental influences on criminal activity in Korea. *Criminology 10*: 338-352 (1972).

67. **Awbi, H. B.:** Calculation of convective heat transfer coefficients of room surfaces for natural convection. *Energy and Buildings 28*: 219-227 (1998).

68. **Brager, G. S. and R. J. de Dear:** Thermal adaptation in the built environment: a literature review. *Energy and Buildings 27*: 83-96 (1998).

69. **Bulcao, C. F., S. M. Frank, S. N. Raja, K. M. Tran and D. S. Goldstein:** Relative contribution of core and skin temperature to thermal comfort of humans. *Journal of Thermal Biology 25*: 147-150 (2000).

70. **Fisk, D. J.:** *Thermal Control of Buildings.* 1st. ed. Englewood Cliffs, NJ: Applied Science Publishers, 1981.

71. **Parrish, J. R.:** *The Two-Headed Monster: Crime and Texas Prisons.* 1st ed. Austin, TX: Eakin Press, 1989.

72. **Texas Department of Criminal Justice:** *Select Statistics.* Huntsville, TX: TDCJ, 1998.

73. **ACR Systems, Inc.:** *TrendReader* [Computer Software], 1.56 ed. Surrey, BC: ACR Systems, Inc., 1995.

74. "Texas Climactic Bulletin." [Online] Available at http://www.met.tamu.edu/osc/TXclimat.htm (accessed February 20, 2002).

75. "Local Climatological Data, NCDC." [Online] Available at http://ols.ncdc.noaa.gov (accessed February 20, 2000).

76. **Microsoft Corporation:** *Microsoft Excel 2000®* [Computer Software], Seattle, WA: Microsoft Corporation, 1999.

77. **Cooper, G. R. and C. D. McGillem:** Correlation Functions. In *Probabilistic Methods of Signal and System Analysis,* 2nd ed. New York: Holt, Rinehart and Winston, 1986. pp. 189-229.

78. **Palisade Corporation:** *Stat Tools Statistics Add-in for Microsoft Excel®* [Computer Software], 1.0.1 ed. Newfield, NY: Palisade Corporation, 2003.

79. **Albright, S. C.:** *Learning Statistics with StatTools.* 2nd. ed. Newfield, NY: Palisade Corporation, 2003.

80. **Tufte, E.:** *The Visual Display of Quantitative Information.* Cheshire, CT: Graphics Press, 1988.

81. **Texas Department of Criminal Justice:** Temperature Extremes in the TDCJ Workplace. In *Administrative Directive AD-10.64* 3rd. ed. Texas Department of Criminal Justice - Executive Services: Huntsville, 1999, pp. 1-10.

82. **Wright, F. W.:** Keeping cool for a lot less. *Corrections Forum 7*: 41 (1998).

APPENDIX A

16 Element Heat Index Equation

The equation presented here for completeness is not used in this study and the exact derivation of the sixteen element equation for Heat Index is not known, but was found published on the website of the Chicago office of the National Weather Service by John Coyle, M.D., . (Personal communication: John Coyle, M.D., University of Oklahoma, Tulsa Medical College, August 2004)

$$\begin{aligned}
HI_{16} =\ & 16.923 + 1.85212*10^{-1}T + 5.37941R - 1.00254*10^{-1}TR + 9.41695*10^{-3}T^{2} \\
& + 7.28898*10^{-3}R^{2} + 3.45372*10^{-4}T^{2}R - 8.14971*10^{-4}TR^{2} + 1.02102*10^{-5}T^{2}R^{2} \\
& - 3.8646*10^{-5}T^{3} + 2.91583*10^{-5}R^{3} + 1.42721*10^{-6}T^{3}R + 1.97483*10^{-7}TR^{3} \\
& - 2.18429*10^{-8}T^{3}R^{2} + 8.43296*10^{-10}T^{2}R^{3} - 4.81975*10^{-11}T^{3}R^{3}
\end{aligned} \qquad (10)$$

Both equations (1) and (10) have limitations in their evaluation of heat index (apparent temperature) and since the multiple regression analysis leaves some error in the calculation the fitness of one equation over another must be evaluated from the sensibility of the output. The calculation results of the two equations (1) and (10) are presented in Table A1 for a range of temperatures (70°F to 100°F) and relative humidity ranges of (60% to 90%). A graphical comparison of the linearity and slope from the two Heat Index equations (HI_9 and HI_{16}) are presented in Figures A1 and A2.

.

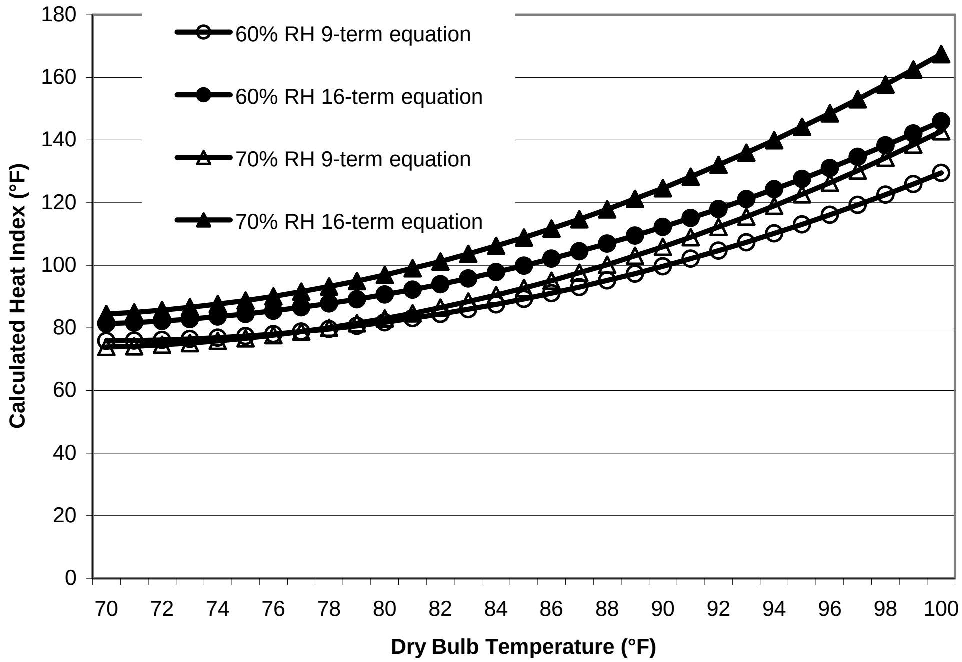

FIGURE A1. Comparison of nine term and 16 term heat index equations at 60 and 70% relative humidity

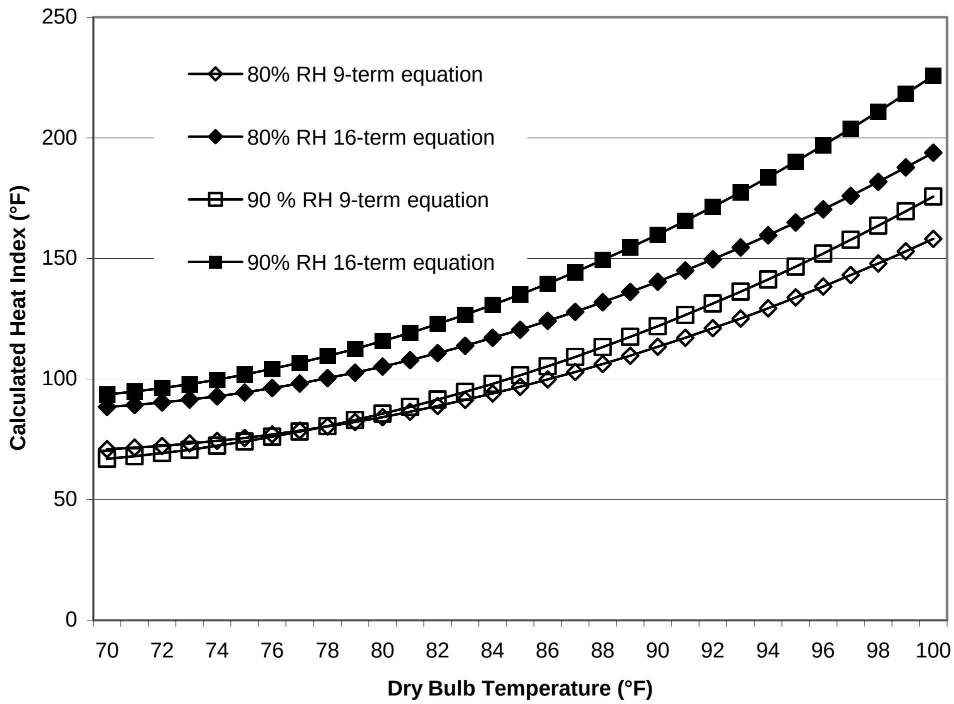

FIGURE A2. Comparison of nine term and 16 term heat index equations at 80 and 90% relative humidity

Table AI is a comparison of the calculations for heat index over a range of temperatures and relative humidities using the 9-element and 16-element heat index equations to calculate apparent temperatures in a manner similar to Steadman and the National Weather Service.

TABLE AI. Comparison of 9-Element to 16-Element Heat Index Equations

Temperature (°F)	60% RH		70% RH		80% RH		90% RH	
	9 term	**16 term**	**9 term**	**16 term**	**9 term**	**16 term**	**9 term**	**16 term**
70	75.9	81.4	73.9	84.4	70.9	88.4	66.9	93.6
75	77.4	84.4	76.7	88.8	75.6	94.4	74.1	101.9
80	81.8	90.6	82.0	96.9	84.2	105.1	85.6	115.7
85	89.3	99.9	92.7	108.9	96.8	120.5	101.6	135.1
90	99.7	112.2	105.9	124.6	113.3	140.4	121.9	159.9
95	113.1	127.6	122.6	144.2	133.8	170.3	146.6	190.1
100	129.5	146.0	142.8	167.5	158.1	193.9	175.7	225.8

The use of the 16-element equation for calculating heat index does result in an expression of apparent temperature that does not fit in normal weather forecasting. This error is a function of the derivation of the equation. Note in Table AI that under certain conditions of dry-bulb temperature (100F) and relative humidity (80% and 90%) that the 16-element predicts heat index conditions that are not logically accepted.

APPENDIX B

RAW DATA FILES

These files contain the logger downloads of date/time stamp, temperature, and relative humidity data from each of the Texas Department of Criminal Justice (TDCJ) units identified in this study and the hourly weather data from the National Climactic Data Center (NCDC) for the Beaumont/Port Arthur station (WBAN12917). The files are Microsoft EXCEL files and labeled "Prison Study Site DataUnits only" for the prison unit values and "Prison Study NWS Data" for the data obtained from the NCDC. Both files are rather large, 13.7MB and 9.6MB respectively, and require space accommodation for access. The files are available through the Texas A&M library or contact the author directly at the address provided or at torey.nalbone@uthct.edu.

VITA

Joseph Torey Nalbone
3234 Fry Ave
Tyler, Texas 75701

Education: Ph.D. Interdisciplinary Engineering; Texas A&M University, December 2004

Master of Science, Environmental Science (Engineering); University of Texas at Dallas, December 1993.

Bachelor of Science, Biology; Baylor University, May 1981.

Employment: Assistant Professor; Department of Occupational Health Sciences; University of Texas Health Center at Tyler, August 1999 to present.

Associate Director of Graduate Program – Environmental Science, University of Texas Health Center at Tyler, March 2000 to present.

Deputy Director; Southwest Center for Agricultural Health, Injury Prevention and Education; University of Texas Health Center at Tyler, July 2000 to present