Statistical Model Evaluation and Calibrations for Outdoor Comfort Assessment in South Florida.

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ABSTRACT: In tropical and subtropical areas, people can spend more time outdoors than in other latitudes. Understanding the sensitivity of outdoor comfort is a fundamental element for architects and urban designers working in these specific climates. This study is part of a research project attempting to relate climatic influences and human thermal sensation. The primary objective of this funded research is to study the influence of climatic parameters in outdoor comfort. This paper analyzes the climatic parameters such as temperature, radiation, humidity, and wind speed in four selected public spaces in the downtown area of the city of Fort Lauderdale, Southeast Florida. The climatic data was correlated with thermal sensation surveys of occupants using selected public spaces. This paper presents data from the surveys, evaluates two existing statistical models, and proposes two calibrated statistical models to predict thermal comfort based on the values of mean radiant temperature, wind velocity, relative humidity, and air temperature. The analysis of this data will establish parameters for architects and urban planners to have a more appropriate design for specific outdoor public spaces in the area of Fort Lauderdale. This research project is funded by Architectural Research Centers Consortium (ARCC) and Florida Atlantic University (FAU)

Keywords: South Florida tropical climate, outdoor comfort, statistical model calibrations, climate surveys.

1. INTRODUCTION

This study is based on survey data compiled in the City of Fort Lauderdale, which is located in a semitropical region. The four sites utilized are open public spaces within an urban fabric. These sites host a combination of variables: natural features vs. man made features, and linear vs. park/plaza space. The study presents data from the survey, evaluates statistical models, and calibrates them using the survey data.

Most people living in South Florida do not walk or use outdoor public spaces as much as the inhabitants of other tropical and sub-tropical areas throughout the world. According to the survey, participants spend about 2.6 hours per day outdoors. Private cars transportation is more dominant than public transportation. Some reasons for less outdoor living are the availability of parking areas, the relative low density and the inadequate public transportation. Outdoor comfort plays an important role in the use of outdoor spaces. The millions of visitors that arrive each year to South Florida beaches and other attractions appreciate the climate of the region. However, temperatures can be very high during the summer months. Relatively high temperature together with high humidity is one of the reasons why many Floridians spend relatively little time outdoors. In the case of Fort Lauderdale, as with many other cities in the South and Central area of the state, one of the main problems is high solar radiation due to lack of shading to protect outdoor spaces. More than 70% of the participants in the sites with less natural features would like more shading trees or structures. In South Florida there is a predominant use of several species of palm trees in the cities landscape. Palm trees are considered exotic for the tourists visiting the state from cold regions; however they do not produce enough shadow to encourage the use of the surrounding areas. Adequate and well-designed outdoor spaces in conjunction with the study of outdoor thermal comfort will help to improve the quality of outdoor public spaces.

2. OUTDOOR THERMAL COMFORT

2.1. Importance of outdoor thermal comfort:

The development of design parameters and a more knowledgeable understanding of outdoor thermal comfort can enhance the quality of outdoor spaces. Well-designed outdoor spaces can improve the economy, natural ecology, social well-being, and lifestyles of the local communities. The development of outdoors spaces with optimal thermal comfort have been shown to increase local real estate values, urban pedestrian and cycling levels, and public transportation usage. Successful spaces that attract a large number of people have been found to attract businesses, workers, and residents (1). Therefore, the local communities can become more economically profitable through outdoor space designs that combine different strategies to respond to summer and winter conditions. The consumption of building energy can be reduced by providing shading from solar radiation in the summer and potentially providing a radiant heat source in the winter through the provision of an exterior thermal mass.

2.2. Metric model for Outdoor thermal comfort:

A standardized metric model for determining optimal thermal comfort for occupants of outdoor spaces has undergone a development. The model development requires localizations responsive to local climates. Psychological adaptation plays an important role in the model development for the outdoor thermal comfort assessment (3). In previous research (4), the psychological adaptation includes effects from: naturalness, expectations, experience (short/long term), time of exposure, perceived control and environmental stimulation, These parameters have a variant percentage of impact, and should be considered in relation to whether these parameters can impact design decisions, and vice versa. The psychological adaptation effects can produce disagreement between model predictions and actual sensation votes. Hence, there are needs for model adjustment to fit the local climatic conditions.

People living outdoors falsely assume that the outdoor thermal microclimate cannot be controlled through architectural design or mechanical control, and thus, they perceive a broader range of conditions as ‘acceptable’ in regards to climate (2). Research has shown that quantifiable, microclimatic physical parameters can account for approximately 50% of the variation between subjective and objective comfort evaluation.

2.3. PMV model

This research focused on modifying the internationally accepted thermal comfort prediction model for building occupants, PMV. Fanger developed this method in the late 1960’s via testing the comfort level of college students in steady air-conditioned interior environments within moderate thermal climate zones (2).

PMV predicts the mean thermal sensation vote on a standard scale for a large group of people in any given combination of thermal environmental variables, such as activity, and clothing levels. PMV has been shown to be inaccurate in predicting occupant thermal comfort in naturally ventilated buildings, as well as in outdoor spaces (3). Regardless of inadequate predictions of outdoor thermal comfort conditions using the PMV, the results of this research project developed substantive correlations between actual thermal comfort votes and predicted thermal comfort votes, through the development of a thermal prediction model based on PMV. Discrepancies still occurred, which can most likely be attributed to the lack of inclusion of psychological adaptation into the model, although further research into this phenomenon is required. Furthermore, this model cannot be applied at a global scale within varying climate zones, and has not been tested for varying seasons.

Utilizing a standard metric system for multiple outdoor sites within a specific thermal climate region provides a basis to compare, quantify, and qualify the thermal qualities, comfort levels, and design characteristics of inherent heterogeneous outdoor environments. As previous research has identified (5), a city’s outdoor spaces cannot be analyzed and evaluated as a whole, but rather evaluated on an individual basis. Therefore each space is unique providing them with different thermal qualities due to the surrounding local environment. This methodology has the potential to identify the design parameters, qualities of outdoor space, and individual physiological and psychological parameters that lead to optimal outdoor thermal environments.

In this paper, a statistical regression model is proposed. Researchers have been working with climatic data such as radiant temperature, wind velocity, and humidity as parameters for a statistical model. (1) and (6). This research is a pilot study to understand the validity of proposed models.

3. DESCRIPTION OF THE EXPERIMENT METHODOLOGY:

3.1. Selected Public sites:

The research is based on interviews with the users of the selected public sites and climatic data collected during the process. The data was recorded in four different public areas located in downtown Fort Lauderdale during 2010 Summer and Fall.

The first site is the Broward County Main Library Plaza/Park
(Figure 1), this is one of the few spaces downtown where local people congregate. The plaza has a generous grass area surrounded by matured trees, the pavement leading to the library entry occupies less than twenty percent of the total area.

Figure 1: Aerial view of the Broward County Main Library Plaza/Park

The second site is Riverwalk (Figure 2), a waterfront touristic pedestrian corridor adjacent to the New River. The proximity to the water is an opportunity to create a favourable microclimate. Nowadays, the discontinuity of shading and the abundance of hardscape pavement make this area uncomfortable to be used as a resting place.

Figure 2: Aerial view of the Riverwalk

The third site is Las Olas Boulevard (Figure 3), a longitudinal corridor with small commercial, retail, restaurants, and some shading trees. The commercial activities and shadows allow the continuous use of this outdoor space throughout the length of the corridor.

Figure 3 : Aerial view of Las Olas Boulevard

The last selected site is the University Plaza (Fig 4). This sector is walled on two sides by University buildings. Due to the proximity of the educational buildings, it is expected to anticipate a significant participation of users within the gathering space. Unfortunately the plaza lacks sufficient shade and appropriate vegetation and it is also exposed to adjacent traffic on both east and west front.
A better design will allow this space to be used by the public more frequently. As detailed in this section, the selected sites for the study have unique characteristics that allow for obtaining a diverse data pool.

Figure 4: Aerial view of the University Plaza

3.2 Survey interviews methodology:

The surveys comprise an interview of almost 100 users at the four selected public spaces. User activities within the selected spaces range from walking, resting, exercising or just passing through. Most of the interviews were realized during the noon and afternoon hours due to higher levels of activities and user volume in the selected public areas.

The survey questions revealed information such as:

-The user's characteristics including city of origin gender, age, height, weight and skin colour.

-Activity that the user has been involved in the last 15 minutes.

-Descriptions of clothing and clothing adaptation (preference to remove or add a clothing item).

-Duration of being outdoors.

-Daily average of time spent in an air-conditioned space and outdoors.

-Sensation votes related to: comfort, humidity, wind, sunlight.

-Opinions on the selected urban spaces and the use of public urban spaces.

-Point measurements of the skin and the clothing temperatures of each interviewer.

A modified version of the questionnaire is presented bellow.

FLORIDA ATLANTIC UNIVERSITY

Outdoor Comfort Study: Interview
Gender: ♂ ♀
Age: ……...........years Height: ....feet
............inches
Weight: ……..........lbs

- Where are you from?

- How long have you been in S. FL.?

2 What type of activity you were involved in the last 15 minutes?

3 Which is the best description of your clothing?

4. Clothing Adaptation

To improve your level of comfort, you would:
a. put on ....
b. remove ....
c. do nothing.

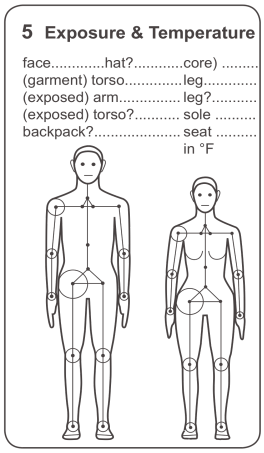
Thermal History

6 How long have you been outdoors?
.... hours
.... mins

7 How many hours per day do you spend in an air-conditioned space? .... hours

How many outdoors?........ hours

8 Comfort: You feel that it is:
a. very hot b. hot
c. slightly hot d. warm
e. comfortable f. cool
g. slightly cold h. cold
i. very cold



9 Humidity: You feel that it is:
a. very humid b. humid
c. slightly humid d. neutral
e. slightly dry f. dry
g. very dry

10 Wind: You feel that it is:
a. very high b. high
c. slightly high d. neutral
e. slightly low f. low
g. very low

11 Sunlight: You feel that it is:
a. very strong b. strong
c. slightly strong d. neutral
e. slightly weak

12 What do you like/dislike about this outdoor public space?
....

13 What do you usually do here?
....

14 How would you modify or change this outdoor public space?
....

15 What would encourage you to use this outdoor public space? (in nice weather)
....

16 What are your reasons for using an urban public space?
....

Figure 5: Modified Survey interview questionnaire.

From all the data collected in the interviews, this paper only uses the results of the actual sensation vote according to a proposed 9-point thermal sensation scale. The scale is similar to the ASHRAE scale, differing by an additional category to incorporate a very hot thermal sensation. The proposed 9-point thermal sensation scale is compared to the ASHRAE scale in Table 1.

Table 1: 9-point thermal sensation scale compared with ASHRAE scale.

9-points	ASHRAE	Value
Very hot		4
Hot	Hot	3
Warm	Warm	2
Slightly warm	Slightly warm	1
Neutral	Neutral	0
Slightly cool	Slightly cool	-1
Cool	Cool	-2

3.3 Climatic data methodology:

Detailed climatic data was measured during each interview using portable mini-weather stations. The data comprises the following measurements:
- Amplified Pyrometers to measure the global and diffuse radiation
- A QuestTemp 36 portable monitor able to measure:
- Mean radiant temperature,
- Relative humidity
- Wind speed
- Dry and wet bulb temperature
- Data loggers type CR200X record the data in intervals of 1 second during each interview, and generate averages every 1 minute to match the same recording resolution of QuestTemp 36.

4. RESULTS

The collected data in the survey is complex and only some parameters are analyzed in this paper. Further surveys in all the seasons and additional user surveys will provide more complete results than in this pilot study.

4.1 Climate data results:

The average values of the most important climatic data collected during the interviews are presented as a reference in Table 2. The data only includes interviews and measurements taken during the day. Early morning and night data is not part of this experiment. In future research, the climatic data will include additional hours and all the seasons of the year.

Table 2: Climate data during the surveys interviews in Fort Lauderdale.

	Mean	St Dev	Min	Max
Avg WBT ©	23.5	2.2	21	27.2
Avg DBT ©	28.6	1.6	26.7	31.4
Avg Globe©	32.4	7.0	26.8	46.4
AvgWBGTout ©	26.1	3.1	22.8	31.2
AvgRH (%)	0.6	0.1	0.4	0.8
Airflow (m/s)	1.7	0.9	0.3	3.2
AvgHea tIndex ©	56.9	25.4	30.5	84.7

4.2 Survey interviews results:

From all the data recollected in the surveys, this paper uses only the actual sensation vote (ASV). Table 3 shows the percentage of each value of the thermal sensation scale in relation to the air temperature at the moment of the interview. The original 9-point thermal sensation scale described in Table 1 was reduced to six points because none of those interviewed voted for any of the last three cold thermal sensation options. The average air temperature or dry bulb temperature was 28.56 °C during the interviews and the standard deviation was 2.2 °C. This small deviation is explained by the fact that the data was gathered during the summer and fall seasons when changes of temperature usually are not pronounced in South Florida.

Table 3: ASV of those interviewed in relation with the air temperature

(ASV)	Air Temperature ©		
	26<28	28<30	30<32
Cool (%)	5.3	0	0
Comfortable (%)	30.6	14.7	2.7
Warm (%)	4	9.3	1.3
Slightly hot (%)	1.3	4	5.3
Hot (%)	0	4	14.7
Very Hot (%)	0	1.3	1.3

5. MODELLING THERMAL COMFORT:

In order to find a correlation between the ASV and the data collected during the interview, two correlation models were developed.

5.1 Statistical Model SV1

The first one uses the following variables:
MRT= Mean Radiant Temperature
V= Wind Velocity
RH Relative humidity
AirTemp: Dry bulb temperature

The original formula was developed by a pilot study in Greece by Nikolopoulou, (7), and its formula is as follow:
SV1 = 0.061*(AirTemp) + 0.091*(MRT-AirTemp) - 0.324*(v) + 0.003*(RH*100) - 1.455

SV1 is the sensation vote of the original formula. Figure 6 present a scattered diagram between the ASV and the original model SV1. Root Mean Square Error (RMSE) is used to evaluate the predictive power of the model. A lower value of the RMSE indicates a small degree of disagreement between model predictions and the ASV. The data has a RMSE of SV1 model is 1.1603.

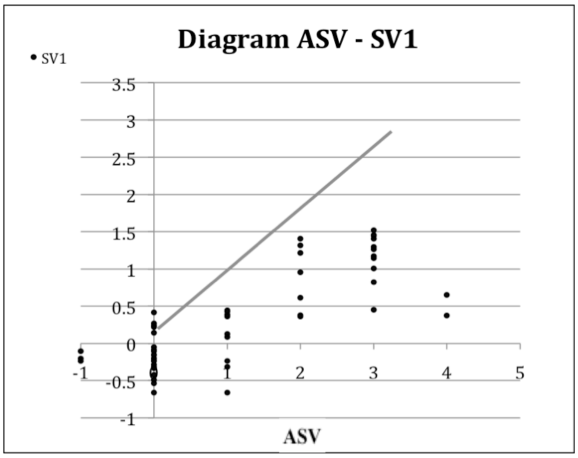


Figure 6: Scattered table of actual sensation vote (ASV) in relation with the sensation vote in the calibrated model (SV1)

5.2 Statistical Model SV2

A second proposal is SV2, a calibrated model of SV1 expressed as follow:
SV2 = 0.2336*(AirTemp) + 0.1886*(MRT-AirTemp) + 0.0252*(v) + 0.0478*(RH*100) - 9.2268
It was found that the formula above yielded a root mean square error (RMSE) of 0.6967, has a very satisfactory performance. (Fig 7)

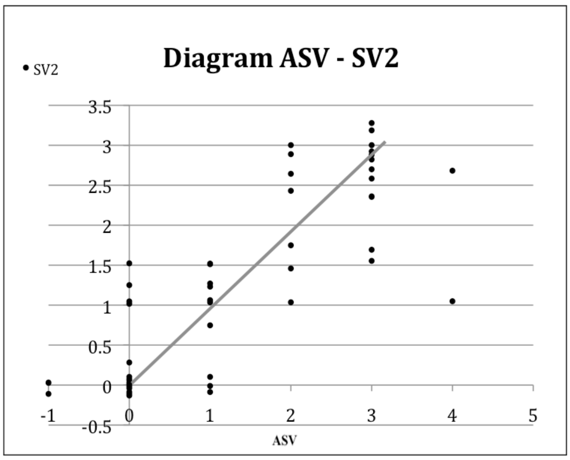


Figure 7: Scattered table of actual sensation vote (ASV) in relation with the sensation vote in the calibrated model (SV2)

Looking at the statistical influence of each parameter, the air temperature is the most important factor in the model. There is a stronger correlation between the standard vote of the model and the Actual sensation vote (ASV) of the public in model SV2 in comparison with model SV1.

5.3 Statistical Model SV3

A third model is proposed for this study. The original values for this model was developed by Marques and Peinado (6) The formula components are the same as the models SV1 and SV2, the equation is as follow:

SV3 = -3.557 + 0.0632 (AirTemp) + 0.0677(MRT) + 0.0105(RH)- 0.304*(v)

SV = sensation vote or thermal sensation perception
MRT = mean radiant temperature
RH = relative humidity
v = wind velocity
The RMSE of this original equation is 1.3999. Figure 3 shows a scattered diagram of the ASV and the model proposed SV3. Even when this model is working in a lineal pattern as expected and there is a strong correlation between the public opinion or ASV, the model SV3 has a RMSE much higher than in the statistical model SV2. The scattered table of the model is presented in Figure 8.
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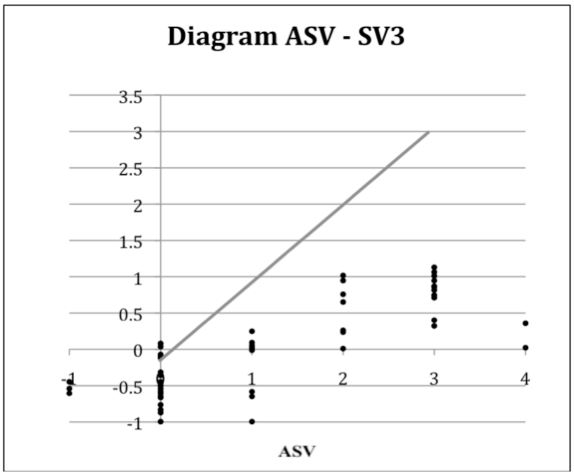

Figure 8: Scattered table of actual sensation vote (ASV) in relation with the sensation vote in the original model (SV3)

5.4 Statistical Model SV4

The final model proposed in this paper is SV4. This model uses the same formula as SV3 and the calibration realized yields:

SV4=9.2268+0.0450*AirTemp+0.1886*MRT+4.7846*RH+0.0252*v

The prediction using SV4 produces a RMSE of 0.6967
This model works much better than the model SV3, Figure 9 represents the same type of scattered

diagram presented for the other models. As in the SV2 calibrated model the ASV has a good correlation. As a conclusion the calibrated models can be used in future research after incorporating some changes. Interestingly, their root mean square errors between the prediction and the ASV are identical in the calibrated models SV3 and SV4. This is due to the fact that they are both linear regression models with similar climatic parameters in the equations.

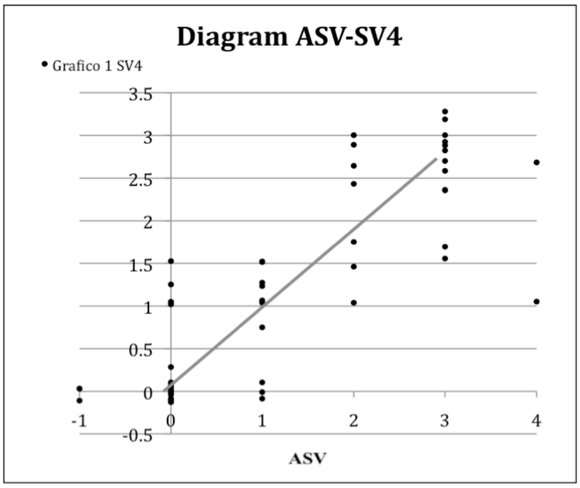

Figure 9: Scattered table of actual sensation vote (ASV) in relation with the sensation vote in the original model (SV4)

6. CONCLUSIONS

This paper is a pilot study of a research project investigating the complex parameters influencing thermal comfort in outdoor spaces. The complexity of the relationship between the different climatic and psychological parameters requires future research and a more complete data pool to include all the seasons of the year. The main problem is not only the thermoregulatory system of the human body responding to climatic conditions, but also the psychological adaptation parameters.

Two previously proposed statistical models are evaluated. Their structures are comparable to each other due to the use of linear regression technique. Prediction results of the models exhibits trends that follow the ASV. One of the models SV3 was proposed for a subtropical area. However, the level of agreement between predictions using the models, and the ASV is not adequate.

Subsequently, the two models were calibrated to develop two new models that yield considerable improvement. In future research the calibration can be improved and other parameters could be included in new model formulas.

7. ACKNOWLEDGEMENTS

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