THE IMPACT OF HUMIDITY ON INDOOR THERMAL COMFORT OF BUILDINGS IN WARM HUMID CLIMATE OF ABIA STATE, NIGERIA.

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Abstract: The paper discussed major discoveries of the impact indoor humidity has on inmates' thermal comfort in warm humid climate of Abia State. A detailed field study was undertaken in the major urban areas in the state. A total of one thousand five hundred individuals were requested to complete questionnaire based on ASHRAE seven point's thermal sensation of +3 (hot) to -3 (cold). Indoor thermal comfort parameters of temperature, relative humidity and air velocity were measured. Particular measurements of indoor relative humidity were noted. The analysis showed that residents expressed thermal comfort at wide range of relative humidity. A relative humidity of 78% mean value was optimal. The effect of relative humidity on occupant's thermal perceptions could not be established by regression models. The study applied a quadratic regression model for predicting mean indoor relative humidity based on indoor temperature and got the same result as in Djamilia (2014). The a model which could be applied to predict an approximate indoor relative humidity value when needed, was developed and applied by Djamiliai in Djamilia (2014)

Keywords: Humidity, Thermal Comfort, Warm Humid Climate, Abia State.

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INTRODUCTION

The three major environmental components that determine the thermal comfort of homemakers in warm humid climate zones remain air temperature, relative humidity and air velocity. Relative humidity however could provide a great difference in occupants thermal experience at all times. Djamila, Chu and Umaresan (2014) and Adebamowo (2010) both observed that most of the thermal studies on these thermal comfort parameters of air temperature, relative humidity and air velocity have always been conducted in climate chambers or air conditioned environments, and that only scanty experimental studies that expressed special interest on how these affect indoor thermal comfort of homemakers or buildings where productivity is a function of thermal comfort exist.

Djamila (2014) believed that the lack of major interest in observational research on these three environmental components of thermal comfort may rather be attributed to the major concern of researchers in validating the PMV in air-conditioned spaces and the adaptive model in naturally conditioned spaces. The trending issues of global warming and climate change have in recent times heightened the need for improved indoor thermal conditions in buildings, and it has in turn sparked off further interest in the investigation of environmental and thermal comfort factors of air temperature, air velocity, air quality and relative humidity.

According to Alozie (2014), it remains a widely accepted fact that evaporative cooling is one of the more acceptable methods of improving indoor thermal comfort during summer days, in warm humid environments. In like manner air movement is also a preferred technique that improves indoor thermal comfort in warm humid climates (Alozie, 2015). The heat lost through evaporation, which comes as sweating is the major heat loss the body exhibits, therefore when humidity is higher and air movement is slower, heat is lost effectively from the body (Alozie, 2014).

Despite the establishment that thermal comfort may at times hold under higher indoor air temperature and humidity levels, in most tropical climate environments, it is yet to be established how one who is used to a particular climate environment of high relative humidity will respond in an environment of yet higher humidity value (Djamila, 2014).

This paper therefore, studied how different levels of humidity affects the thermal comfort of homemakers, in naturally ventilated buildings in warm humid climate of Abia State.

2. HUMIDITY AND THERMAL COMFORT STUDIES

ASHRAE (2010) and ISO (2005) defined thermal comfort as state of mind which describes the satisfaction towards the thermal environment. While ASHRAE (2004) provided that 80% of the slightly active members of that environment under study must be thermally satisfied. The most influential environmental factors in the study of thermal comfort have remained air dry temperature, mean radiant temperature, air velocity and humidity (Ogunsote 1990, Odim 2008, Alozie 2014).

Humidity is the quantity of water vapor a unit volume of air (moisture content) holds at any given time. (Ogunsote 1990, Heeragun, 2004). This could be classified in varying expressions like the dew point temperature, humidity ratio and relative humidity (Djamila, 2014). Holm and Engelbrecht (2005) finds it a widely accepted fact that at higher humidity and air temperature, thermal sensation is intensified and reduces the body's perspiration and evaporation capacity, consequently not allowing the body to be cooled, this Arens, Gonzalez and Baerglund (1996) did not observe in air conditioned spaces.

Djamila (2014) noted that thermal comfort studies have not placed any upper or lower humidity limits, but that limits suggested for the still air comfort zone, based on the practical considerations of vapor above 1.86Kpa (14mmHg) are likely to cause respiratory discomfort.

Olesen and Parsons (2002), noted that recommendations on different humidity levels for thermal comfort influenced the revision of thermal standards by ASHRAE. According to Sreshthaputra's 2013, history of thermal comfort reviews by ASHRAE dates back 1967 and subsequent revisions of the ASHRAE standards with its maximum allowed humidity levels, are found in literature reviewed by accomplished scholars, in (Sreshthaputra 2003), (Fountain, Arens, Xu, Bouman and Massayaki 1999). The maximum air relative humidity in ASHRAE 1992 was set at 60% because beyond this limit, mildew and mold begins to grow. According to Djimila (2014). ASHRAE 1994 tolerated slightly higher relative humidity to include evaporative air conditions, whereas no lower humidity level was recommended in ASHRAE 55 - 2004, because the humidity for thermal comfort is negligible but might have secondary health implication as stated in the same standard, this is further illustrated in Ibrahim and Hazrin (2009) to reveal that at low relative humidity, there is increase in evaporation.

ASHRAE (55 - 2004) sets an upper humidity ratio of 0.012, a limit that was postulated for instruments designed to manage humidity, a design that agrees with an upper relative air humidity level of 80% with 20^{o}C low dry bulb temperature.

Djamila (2014) in a comprehensive literature review of ASHRAE standards pointed out that ASHRAE 55 - 2010 kept the limit of humidity ratio at 0.012, and again that the standard did not specify a minimum humidity level. He however revealed that the standard clearly stated other factors that may place limit on the minimum humidity value, to include dryness of the skin, and the eyes. The literature also revealed the non-inclusion of any limits for humidity or air speed in the use of adaptive model chart.

It is of note that all comfort charts of (ASHRAE 1981), slopped vertically from lower right limits to upper left, indicating that thermal comfort became noticeable when operative temperatures are above 27^{0}C whereas at lower operative temperature below 21^{0}C, the relative humidity seem to improve comfort. This is example is shown in ASHRAE 2010 chart, the charts however are known to be more relevant in air-conditioned spaces and may not be the case in naturally ventilated buildings (Djamila 2014).

The literature review exposes the fact that the effect of humidity on thermal comfort in air condition spaces may not be the most determinant factor in thermal comfort appreciation, due to the strict hindrances placed on health, indoor air quality, and other factors. (Olesen and Parson 2006, Berglund, 1998, Fang, Glausen and Fanger 1996).

The result of this survey is expected therefore to enhance studies on the effect of humidity on the thermal comfort perception of homemakers naturally ventilated buildings at an increased humidity level in warm humid environments of Abia State.

3. Materials and Methods

A field study took place in three major urban cities of Aba, Umuahia and Ohafia of Abia State, in South Eastern geopolitical region of Nigeria, Fig 1. The state has on Lat. $5^0$25N and Loug $7^0$30E of a tropical warm-humid environment. The survey was carried out in eighty one building locations. The surveyed buildings have a spectrum of architectural features, styles, and building materials. The objective of the experimental design was that the field survey should be conducted under various indoor climate conditions and spanned to cover a minimum period of one full year, January 1st to December 31st 2015. The table 1 shows a summary of the surveyed buildings sites.

The field survey was designed in such a way to ensure monthly and hourly day time recordings. This was done to provide accurate and more representative evaluation of the population under survey the three major urban sites were considered major centers for the study, as the study buildings were regularly visited and monitored by the researchers and their assistants. A total of 1500 respondents which were downsized to 1200 when filtered against the criteria established before analysis were considered, and only respondents who have lived at least one year in their environment were included in the final analysis. The survey was designed as cross sectional data collection with the highest percentages of the surveyed occupants under the category "Normal Weight". The average clothing insulation level worn by the subjects was about 0.3 CLO. The estimated average surface area for a typical Nigerian body proportion was 1.68 m^2 and the metabolic rate of the surveyed subjects in the range of 0.96 and 1.30met the age of the occupant was set to be not less than 18 years. Other requirements set in the present survey include the occupant's being free from any major health problems, not having fever, flu or any disease that may affect the prediction of the neutral temperature. This method was adopted from Djamila (2014), since both have similar aims and objectives.

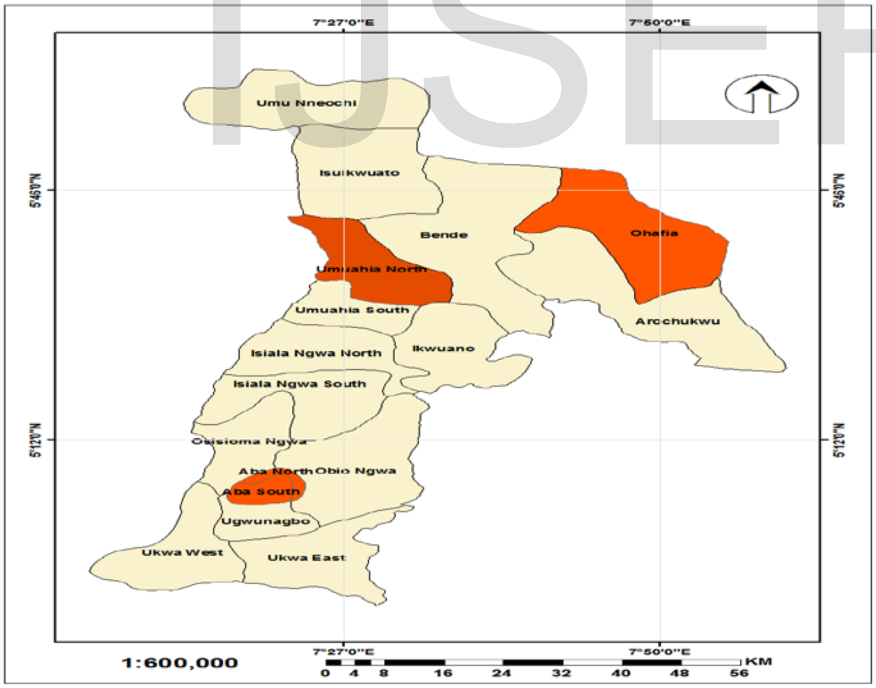

Figure 1. Map of Abia State Nigeria, showing the three major urban areas, Aba, Umuahia and Ohafia.

4. ANALYSIS AND DISCUSSIONS

The study examined, the relationship between indoor air temperature and relative humidity. While the indoor air temperature remained independent, the humidity was varied in the study. This relationship was achieved by finding the linear, quadratic cubic and other available values in the SPSS17. The scatter graph of the indoor air temperature against indoor relative humidity. Fig 2 further illustrates the quadratic model. The quadratic model given by (n = 1200, r = 0.279, f = 407.382, p value = 0.000 best described the relationship between indoor air temperature (*Ta*) and relative humidity (*RH (kk-in)*) during the field survey. $RH\ (kk\text{-}in) = 0.020T^2a - 15.365Ta + 352.293^{(1)}$ quadratic regression was also used to examine the relationship between mean indoor air temperature in the bin *(Ta (mean)* and mean relative humidity per temperature bin (1^0C) $(RH_{\ (means)})$.

Table 1 shows the equation variables and standard deviation of the estimated mean relative humidity values. Assessment rightly revealed that the generated (equation (2) presents a more factual.

Figure 2 shows the plotted values with their corresponding confidence and predicted intervals. The coefficient of the determination of the quadratic regression was close to one corresponding to a perfect quadratic relationship between the two variables. (r^2= 0.993, Adjusted r^2= 0.99i, F = 430.9, P value = 0.00, n = a) the regressed model is expressed by Equation (2)

$RH_{(Mean\text{-}kk\text{-}in)} = 0.140T^2a_{(mean)} - 11.679Ta_{(mean)} + 297.188^{(2)}$. Both methods are also remarked in Djamila (2014). Shanmugavelu’s investigation in Davis, Ghazali and Nordin (2006) also reached near similar results. $RH_{(out\ KL)=}\ 0.0598T^aa - 7.106Ta + 213.04$ (3).

This study makes it possible to compare results reached between two models within the range of the field survey associated with the indoor air temperature. Figure 3

A look at the multiple bar shows that the maximum difference in the relative humidity between the two studies is no more than 4% when using mean values. The highest difference of 6% was when all the responses were considered. The entire present model is consistent with Shanmugavelu's prediction within the indoor temperature range of 27^{o}C to 35^{o}C. Therefore the results might be used for an approximate prediction of indoor relative humidity from indoor temperature when needed in essence the generated quadrated (equation (2)) appears to be more precise for predicting the mean relative humidity values. This is because of the high variability of the recorded relative humidity which is reflected by the wide predicted interval and the variability of the standard deviation at each mean temperature bin. Concluding from the analysis results, isolating the individual contributions of air temperature and relative humidity to an occupant thermal sensation vote of the seven point ASHRAE scale is not feasible. The high correlation coefficient between mean air temperature and mean relative humidity suggests that the combination of these two parameters for the use of multiple regression analysis for indoor thermal comfort prediction may not be valid.

The comfort temperature in further analysis of the impact of relative humidity on inmates of buildings was predetermined on the seven-point ASHRAE comfort scale of +3 for (hot) sensation to -3 for (cold). In the study the estimated comfort temperature value was (30^{0}C). The acceptable comfort zone corresponding to the optimum percentages of vote within the central three categories of (-1, 0 and 1) and ASHRAE thermal sensation scale varies from 27.5^{0}C to 33.5^{0}C, while Fountain et al (1999) kept the estimated comfort band at 6^{0}C. Also, investigations showed that the determination of the mean relative humidity at the optimum neutral temperature is possible, by placing the neutral comfort temperature in equation 1 or 2.

The mean relative humidity corresponding to neutral temperature of 30^0C is about 73%. Olese and Parson (2002) noted the indoor thermal comfort range of 27.5^0C and 33.5^0C to have a corresponding mean relative humidity values with the range of 82% and 63% respectively. This happens when equation 2 is applied, and shows occupants tolerance to higher humidity levels. Therefore, according to Tanabe and Kimera (1994), higher humidity values may not affect occupants thermal comfort. Mclntyre (1980) did not also notice any increase in thermal sensation in her study, however Fountain (1999) found few differences in human response to air relative humidity exposure between 60% and 90% of the temperature 20^0C-26^0C while sedentary (new effective temperature).

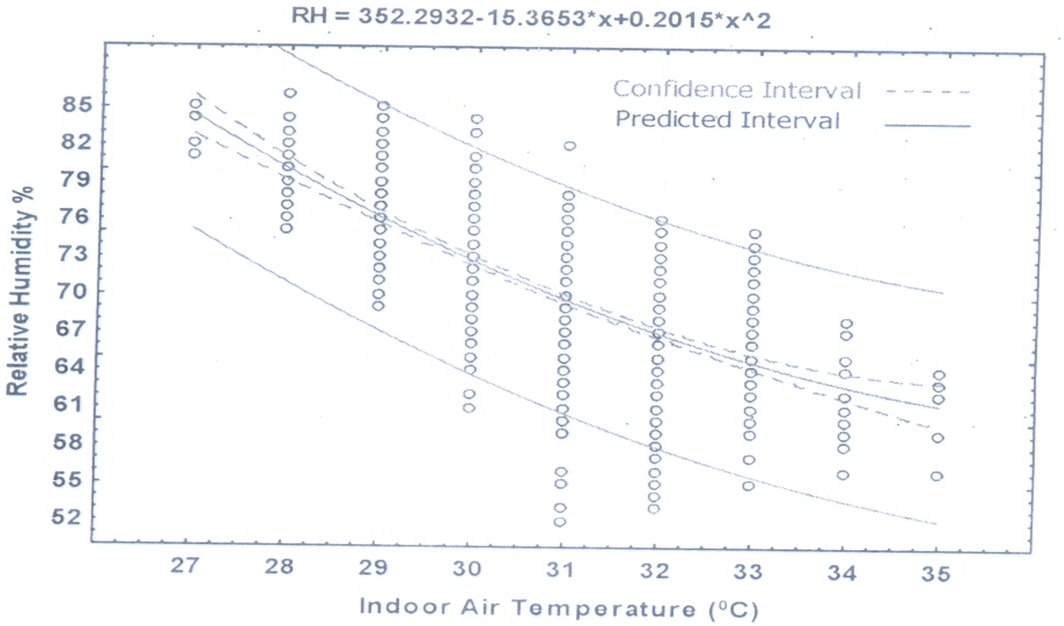

Figure 2. Indoor air temperature versus relative humidity with the corresponding confidence and predicted interval.

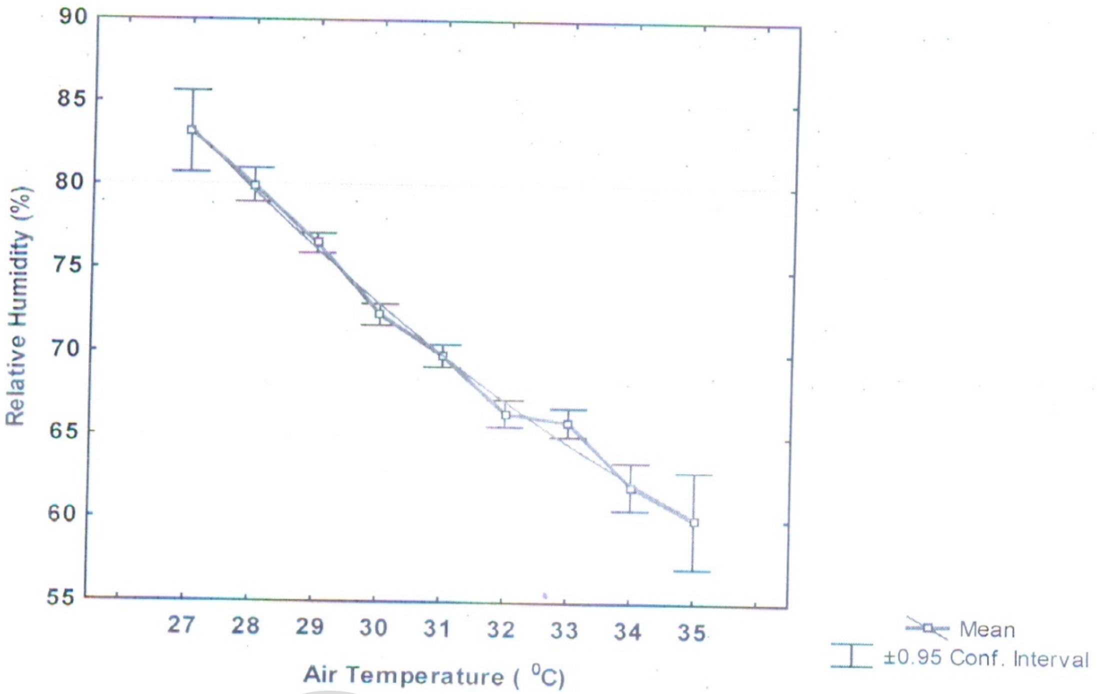

Figure 3. Mean air temperature in the bin vs. mean relative humidity per temperature bin.

URBAN SITES STUDIED	NUMBER OF BUILDINGS STUDIED
UMUAHIA	27
ABA	27
OHAFIA	27
TOTAL NUMBER OF BUILDINGS	81

Table 1. Showing the number of buildings studied in each urban area

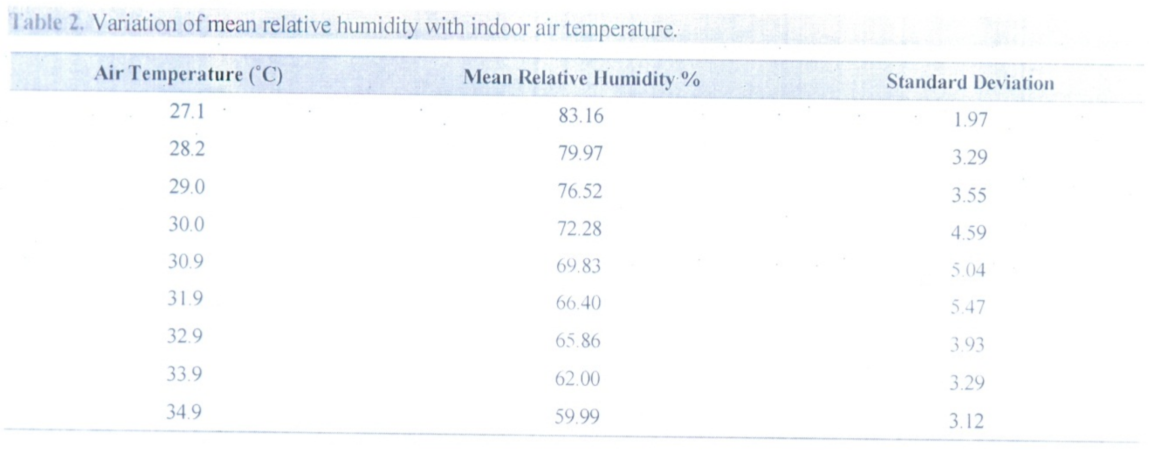

Table 2. Variation of mean relative humidity with indoor air temperature.

Air Temperature (°C)	Mean Relative Humidity %	Standard Deviation
27.1	83.16	1.97
28.2	79.97	3.29
29.0	76.52	3.55
30.0	72.28	4.59
30.9	69.83	5.04
31.9	66.40	5.47
32.9	65.86	3.93
33.9	62.00	3.29
34.9	59.99	3.12

5. Conclusions

Analysis and the data from this study offer useful information on people's thermal comfort towards indoor humidity. The analysis of relative humidity dataset revealed that, the suggested quadratic regression models from the present work were in close agreement with that developed model by Shanmugavelu in Davis, Ghazali, and Nordin, (2006). Therefore a regression model was suggested which may help in estimating relative humidity from air temperature and also very useful when there is no hygrometer. It also helps in studies that need approximate prediction of the indoor relative humidity. It also revealed that the thermal feeling of people in the warm humid climate might not be affected by variations in relative humidity thus, higher relative humidity in air-conditioned spaces might be acceptable.

In non-air conditioned spaces in the warm humid climate of Abia State, the separation between both air temperature and relative humidity parameters was neither possible nor necessary, because the two parameters are highly correlated. It is therefore strongly recommended then that in future field research studies, that the direct humidity effects on subjects' thermal perceptions due to sweating, is investigated because the subjects in the humid tropics are mostly exposed to higher humidity levels all year round. Also of further research interest is the effect of higher humidity levels at higher indoor temperatures on the deterioration of indoor air quality. This study agrees with Djamila (2014) in findings, analysis, comments and in conclusions having reached very similar results under the same investigated conditions and methodology.

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