American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-11, pp-48-52
www.ajer.org
Research Paper Open Access

Influencers Of Residents' Adaptive Actions In Response To Indoor Thermal Discomfort In A Warm-Humid City

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ABSTRACT: *The paper presents an evaluation of residents' adaptive actions influencers in response to thermal discomfort within selected neighborhoods of Ibadan, a warm-humid Nigerian city. It was found that 63.6% of respondents were in the "Discomfort" zone and 59.5% expressed different degrees of dissatisfaction with the indoor thermal condition of their respective living rooms in the afternoon assessment. The adaptive actions utilized most by respondents out of the 14 identified in the study were drawing the curtain, opening the window, putting on the fan, movements to verandah, porch, courtyard or balcony and opening the door. Respondents effected adaptive change in relation to the building components and spaces first before personal change actions to reduce experienced discomfort. The verandah, porch and courtyard offered better alternative of comfort to the respondents compared to other spaces. The correlation of adaptive actions of the respondents to many spatial design elements was significant in the study. This implied a substantive recognition of the impact created by spatial elements on the adaptive comfort of the building users. It was concluded that the spatial design decisions in the residential buildings greatly impacted on the adaptive actions of users.*

KEYWORDS: *adaptive action influencers, adaptive principle, residential building, thermal discomfort, warm-humid city.*

Date Of Submission:02-11-2018 Date Of Acceptance: 16-11-2018

I. INTRODUCTION

Thermal stress is an endemic challenge in the tropical regions. Urban residents need to adjust as much as possible using adaptive actions to assuage their discomfort due to high insolation. Indoor discomfort because of solar heat is of concern. It is only when the residents are comfortable that the buildings can be certified to be satisfactorily fulfilling their requisite function. The adaptive nature of thermal comfort implies the extension of comfort conditions as the occupants utilize available adaptive opportunities. There are a number of factors that affect the comfort of urban residents. The context of a warm-humid tropical urban environment presents intricate possibilities of variability of spatial and environmental features in the urban landscape and the accompanying adaptive opportunities for thermal comfort. Urban residents are certain to make use of the available spaces around them in response to the varying thermal environmental conditions within those diversities of spaces.

Adaptive actions are produced based on the adaptive principle. The adaptive principle states that if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort [1]. This adaptive nature of thermal comfort has been made possible due to the existence of means of control for thermal comfort parameters within building spaces. Additionally, the behavioral tendencies of building users in terms of relocation within a space or from one space to another, as well as adjustments in clothing, activity level and posture, all contribute to the attainment of adaptive thermal comfort [2].

It is of interest to identify the influencers of the adaptive actions being taken in response to thermal discomfort, The variability or diversity of spaces within the context of an urban environment is considered to be of significance. The fact that urban building spaces may present diversified thermal conditions due to the different spatio-structural elements also implies that the thermal conditions experienced by residents within most urban buildings and neighborhoods. This study is directed towards identifying influencers of adaptive actions of residents by focusing on the adaptive thermal responses within the spatial and environmental diversity of the residential neighborhoods in Ibadan - a city in South-Western Nigeria.

II. LITERATURE REVIEW

Building residents make adaptations to their clothing and their thermal environment to secure better comfort experiences. According to [3], people have always attained their desired thermal condition for living in a variety of ways and the diversity of their responses to thermal stimuli could be used to allow a concept of 'free trade' in environments. [4] also submitted that people all through the ages have always used available ranges in their shelters to adapt to local climate. The adaptive thermal comfort approach investigates the dynamic relation between people and their everyday thermal environments. Adaptive comfort is the basis of the thermal experience in an urban spatial environment [5], [6]. As stated by [7], the concept is that thermal comfort is self-regulating whereby people take actions to attain comfort. The adaptive comfort principle reportedly infers a greater comfort range and consequently a higher level of energy savings. The experimental basis of the adaptive approach to thermal comfort is the field study. According to [8], the field studies conducted in tropical climates indicated that the international standard for indoor climate ISO 7730 which was based on Fanger's PMV/PPD equations does not adequately describe comfortable conditions. It was suggested that adaptive thermal standards from local comfort survey results can be used to complement the failing international standards. Air movement and humidity were considered to have implications for adaptive comfort standards in the tropics by the study.
It is necessary to appreciate the spatial diversity abounding in the urban built environment. According to [9], the concept of environmental diversity is intended not only to make environmental design responsive to a richer, and therefore more realistic spectrum of criteria, it also seeks to contribute to a more profound cultural issue. The environmental diversity relates to design in manifesting spatial contrast and distinctions in the thermal environment. This diversity needs to be recognized as an adaptive opportunity for the residents. According to [10], spatial and environmental design can never be separated. The conditions of the indoor thermal environment and the fluctuations therein are dependent on such factors as the spatial components and materiality in relation to climatic elements. [4] also suggested that a predictable behavior is for people to use comfortable spaces as long as possible and to minimize the use of uncomfortable spaces – except for necessary activities and when there is no alternative. [11] stated that it will be of help if there is plenty of usable thermal variety when people are free to choose their location. People can select the most suitable microclimate from the available range of thermal zones in a building. The adaptive thermal comfort concept was engaged in this study.

III. STUDY AREA

Ibadan, the study area, is located on latitude $7^0$23'N and longitude $3^0$55'E in the South-Western part of Nigeria. The city ranges in elevation from 150m above sea level in the valley area to 275m on the major north-south ridge which crosses the central part of the city [12]. The city falls within the warm-humid tropical climatic zone having a seasonally humid classification because of its inland location. According to [13], weather conditions in Ibadan, as well as other places in West Africa during the course of a given year depend on the location of the place in relation to the fluctuating surface position of the Inter-Tropical Discontinuity (ITD) in the region. The warm-humid climatic context in the study area presents challenges for indoor comfort. According to the analysis of the Ibadan climate given by BBC Weather [14], the record highest temperatures of 39^{o}C occurred in February and 38^{o}C in March and April. The mean maximum temperature was highest in February and March (34^{o}C) closely followed by April, January and November (33^{o}C). The months with the lowest mean maximum temperatures were August (27^{o}C) and July (28^{o}C). The record lowest temperature was 10^{o}C in January. The mean minimum temperature was least in January, July, August and December (21^{o}C) and was highest in March and April (23^{o}C). With respect to the sunshine hours, highest value of 198 was in February, November and December followed by 170 in January, April and May. From the analysis the month of April in which the survey was done rightly qualified as one of the expected hot and uncomfortable months in the study area.

IV. METHODOLOGY

A thermal comfort survey was conducted in the study area.. Ten percent (12) of the 119 neighborhoods identified from the metropolitan map as produced by the Ibadan North Local Government Planning Unit were selected by stratified random sampling comprising 2 low, 3 medium and 7 high residential densities. The total number of houses in each of the neighborhoods was estimated to be an average value of 885 based on data from [15]. A sample size of five percent of this gave 44 houses in each neighborhood which were selected using systematic random sampling to give a total of 528 houses for the survey. For each selected building, an adult resident filled a questionnaire indicating the thermal response at different periods of the day using the ASHRAE thermal comfort scale. They specifically indicated any action taken in response to thermal discomfort as well as their clothing ensemble and activity level. The respondents indicated their use of any available adaptive opportunity in the spaces and their movements, either from space to space or within the spaces in the study area. A special afternoon indoor thermal comfort assessment was also done by the respondents indicating their levels of discomfort. Indoor and outdoor measurements of relevant climatic elements were done in representative buildings in the neighborhoods. The survey was done in April, one of the hottest months in the study area.

V. RESEARCH FINDINGS

Relevant data was collected from the study and analyzed and the findings are hereby discussed in this section under the following sub-headings.

Residents' Discomfort Levels

The afternoon period was analyzed as the period of the highest level of discomfort in the day. The analysis of their level of comfort within the living room was given as: 10.8% Very uncomfortable, 22.2% Uncomfortable, 30.7% Slightly uncomfortable, 7.0% Neutral, 12.1% Slightly comfortable, 14.0% Comfortable and 3.2% Very comfortable. This indicated that 63.6% were in the "Discomfort" zone at different uncomfortable levels. The analysis of the respondents' level of satisfaction with the indoor thermal condition was given as: 11.2% Very dissatisfied, 26.7% Dissatisfied, 21.6% Slightly dissatisfied, 10.6% Neutral, 13.8% Slightly satisfied, 11.7% Satisfied and 4.4% Very satisfied. This indicated that a total of 59.5% of respondents expressed different degrees of dissatisfaction with the indoor thermal condition of their respective living rooms in the afternoon. Majority of respondents (79.9%) indicated that they preferred to feel cooler while only 6.1% preferred to feel warmer. 14.0% of respondents wanted no change in their thermal sensation.

Residents' Response to Discomfort

The adaptive actions taken by respondents during the afternoon period were assessed and the results indicated that larger proportion of respondents utilized most of the adaptive opportunities available to them. The results indicated that 70.3% opened the window to make themselves more comfortable while 40.9% opened more portions of the window, 77.8% drew the curtains, 52.8% opened the door, 66.7% put on the fan, 47.5% sat closer to window or fan, 53% moved to either of verandah, porch or courtyard and 43% removed an item of clothing to be more comfortable respectively. The following adaptive actions were also made use of by lower percentages of respondents: use of hand fan -35.4%. taking a cold drink -33%, movement to different position in the room -27.1%, movement to another room space -16.1%, movement to outside of the building -28.6%, adjustment of posture -22.9% while 1.9% took other actions like taking a bath. From this analysis it can be deduced that respondents took adaptive actions to make themselves comfortable in the discomfort of the period considered according to the adaptive principle.

It should be noted that respondents utilized more than one adaptive action due to their need for thermal comfort and the availability of the adaptive opportunity. In all, 14 adaptive actions were recorded in the study. The adaptive action that was utilized most by respondents was drawing the curtain with a 13.51% proportion of use. Next to this was opening the window accounting for 12.20% of the different actions. Putting on the fan represented 11.57% proportion of use. The other significantly utilized adaptive actions were the following: movement to verandah, porch, courtyard or balcony, opening the door, sitting closer to window or fan, removal of clothing item, using a hand-fan and taking a cold drink representing 9.20%, 9.17%, 8.25%, 7.46%, 6.15% and 5.72% of the actions respectively. The other less utilized actions were the following: movement to outside of the building, movement to different position in room, adjustment of posture, movement to another room and taking a bath accounting for 4.96%, 4.70%, 3.98%, 2.8% and 0.33% of use respectively. The use of drawing the curtain, opening the window and putting on fan were related to the indoor spatial configuration and were foremost in use by respondents. In terms of movement actions of respondents, movement to the verandah, porch or courtyard was utilized most by respondents. This inferred that the verandah, porch and courtyard offered better alternative of comfort to the respondents compared to other spaces and the outside.

The adaptive behavior of building occupants takes two basic forms. These are adjustment by changes in clothing, activity, posture and so on to make the occupant comfortable in prevailing conditions and an adjustment of indoor conditions by the use of controls such as windows, blinds, fans and the occupant may also migrate to find improved conditions [2]. It can be seen in the results that the respondents utilized both forms of adaptive behavior. The second option of use of controls and migration was however more utilized than the personal adjustment option. This is a pointer to the need for adaptive opportunity in buildings to enhance this second option. It was inferred that respondents considered effecting an adaptive change in relation to the building components and spaces first before trying a personally applied action to reduce experienced discomfort.

Correlations of Adaptive Actions with Variables

The statistical tool of correlation was used to examine influencers of adaptive actions of respondents in the study. The opening of windows was found to correlate with colour of curtains ($r = -0.103$, $p=0.018$), indoor temperature ($r=-0.086$, $p=0.049$), mean radiant temperature ($r = -0.096$, $p=0.027$), neighborhood location ($r = -0.109$, $p=0.012$) and building density ($r = -0.110$, $p=0.011$). Opening more portions of the window was correlated with typology (r=0.086, p=0.048), plan form (r=0.086, p=0.048), colour of walls (r=0.098, p=0.024), room window orientation (r=-0.128, p=0.003), relative humidity (r=0.105, p=0.016), electric lighting fittings (r=0.102, p=0.019), outdoor air velocity (r=0.238, p=0.000), neighborhood location (r=0.115, p=0.008), building density (r=-0.086, p=0.048). Drawing the curtains was found correlated with typology (r=0.106, p=0.015), plan form (r=-0.102, p=0.019), percentage window/wall areas (r=0.101, p=0.020), room window orientation (r=0.132, p=0.002), protection of window (r=0.154, p=0.000), percentage window/floor area (r=0.152, p=0.000), neighborhood location (r= -0.100, p=0.000), building density (r= -0.110, p=0.012).

Opening the door was correlated with typology (r=0.200, p=0.000), colour of wall (r=-0.140, p=0.001), roof material (r=0.162, p=0.000), fenestration type (r=0.120, p=0.006), number of semi-outdoor spaces (r=0.157, p=0.000), number of cross-ventilated spaces (r=0.101, p=0.020), protection level of windows (r=0.128, p=0.003), electric lighting fitting (r=0.121, p=0.005), indoor temperature (r= -0.108, p=0.013), outdoor temperature (r= -0.109, p=0.012), outdoor air velocity (r=0.172, p=0.000), building density (r= -0.199, p=0.000). Putting on fan was correlated wth typology (r= -0.168, p=0.000), plan form (r= -0.095, p=0.028), wall material (r=0.153, p=0.000), colour of wall (r=0.085, p=0.050), roof material (r= -0.152, p=0.000), orientation (r= -0.114, p=0.009), fenestration type (r= -0.147, p=0.001), number of cross-ventilated spaces (r= -0.171, p=0.000), percentage of spaces cross-ventilated (r= -0.0.114, p=0.009), percentage of window/wall area (r= -0.124, p=0.004), percentage window/floor area (r= -0.127, p=0.004), curtain texture (r= -0.121, p=0.05), indoor temperature (r=0.169, p=0.000), outdoor temperature (r=0.177, p=0.000), mean radiant temperature (0.149, p=0.001), relative humidity (r=0.191, p=0.000), building density (r=0.159, p=0.000). Sitting closer to window or fan was correlated with percentage of spaces cross-ventilated (r=0.097, p=0.025), percentage window/wall area (r=0.122, p=0.005), building density (r= -0.118, p=0.007).

Movement to different position in the room was correlated with number of spaces cross-ventilated (r=0.094, p=0.030), curtain texture (r= -0.095, p=0.029), electric lighting fitting (r= -0.131, p=0.003), indoor temperature (r= -0.167, p=0.000), outdoor temperature (r= -0.159, p=0.000), mean radiant temperature (r= -0.168, p=0.000), relative humidity (r= -0.097, p=0.026), neighborhood location (r= -0.171, p=0.000), building density (r= -0.151, p=0.001). Movement to verandah, porch, courtyard was correlated with typology (r=0.153, p=0.000), wall material (r= -0.100, p=0.021), colour of wall (r= -0.100, p=0.021), roof material (r=0.222, p=0.000), orientation (r=0.130, p=0.003), fenestration type (r=0.145, p=0.001), number of semi-outdoor spaces (r=0.187, p=0.000), number of spaces cross-ventilated (r=0.129, p=0.000), percentage of spaces cross-ventilated (r=0.189, p=0.000), percentage window/wall area (r=0.157, p=0.000), room window orientation (r=0.099, p=0.023), protectin level of window (r=0.174, p=0.000), percentage window/floor area (r=0.219, p=0.000), electric lighting fitting (0.107, p=0.014), indoor temperature (r= -0.184, p=0.000), outdoor temperature (r= -0.181, p=0.000), mean radiant temperature (r= -0.220, p=0.000), neighborhood location (r= -0.095, p=0.028), building density (r= -0.289, p=0.000).

Movement to another room, space was correlated with colour of wall (r=0.106, p=0.015), room window orientation (r= -0.091, p=0.037), protection level of window (r= -0.113, p=0.009), colour of curtain (r=0.087, p=0.045). Movement to outside of building was correlated with plan form (r=0.106, p=0.014), wall material (r=0.141, p=0.001), fenestration type (r=0.106, p=0.015), protection level of window (r= -0.125, p=0.004), curtain texture (r= -0.151, p=0.001), colour of curtain (r= -0.102, p=0.019), indoor temperature (r= -0.143, p=0.001) outdoor temperature (r= -0.133, p=0.002), mean radiant temperature (r= -0.123, p=0.005), neighborhood location (r= -0.149, p=0.001), building density (r= -0.183, p=0.000).

Removal of clothing item was correlated with typology (r=0.103, p=0.018), wall material (r= -0.103, p=0.034), roof material (r=0.102, p=0.019), fenestration type (r=0.099, p=0.023), number of semi-outdoor spaces (r=0.185, p=0.000), number of spaces cross-ventilated (r=0.136, p=0.002), percentage of spaces cross-ventilated (r=0.101, p=0.021), percentage window/wall area (r=0.087, p=0.044), protection level of window (r=0.093, p=0.034), percentage window/floor area (r=0-127, p=0.003), indoor temperature (r= -0.152, p=0.000), outdoor temperature (r= -0.148, p=0.001), mean radiant temperature (r= -0.093, p=0.033), outdoor air velocity (r=0.130, p=0.003), neighborhood location (r= -0.118, p=0.007), building density (r= -0.204, p=0.000).

Use of hand-fan was correlated with typology (r=0.192, p=0.000), roof material (r=0.186, p=0.000), orientation (r=0.170, p=0.000), fenestration type (r=0.200, p=0.000), number of semi-outdoor spaces (r=0.237, p=0.000), number of spaces cross-ventilated (r=0.148, p=0.001), percentage of spaces cross-ventilated (r=0.209, pp=0.000), percentage window/wall area (r=0.128, p=0.003), protection level of window (r=0.091, p=0.003), percentage window/floor area (r=0.134, p=0.002), indoor temperature (r= -0.242, p=0.000), outdoor temperature (r= -0.239, p=0.000), mean radiant temperature (r= -0.206, p=0.000), relative humidity (r= -0.138, p=0.001), outdoor air velocity (r=0.085, p=0.050), neighborhood location (r= -0.122, p=0.005), building density (r= -0.294, p=0.000). Taking cold drink was correlated with wall material (r=0.145, p=0.001), colour of wall (r=0.112, p=0.010), roof material (r= -0.109, p=0.012), number of semi-outdoor spaces (r=0.106, p=0.015), curtain texture (r= -0.089, p=0.040), relative humidity (r=0.091, p=0.036). Adjustment of posture was correlated with percentage window/wall area (r= -0.086, p=0.048), room window orientation (r= -0.087, p=0.045), colour

of curtain (r=0.124, p=0.004), outdoor air velocity (r=0.092, p=0.035). Other action like taking a bath was correlated with plan form (r=0.103, p=0.018), roof material (r=0.120, p=0.006).
The correlation of adaptive actions of the respondents to many spatial design elements was significant in the study.

VI. CONCLUSION

Adaptive actions were utilized by the residents in response to the discomfort felt within the buildings. Respondents considered effecting an adaptive change in relation to the building components and spaces first before trying a personally applied action to reduce experienced discomfort. The verandah, porch and courtyard offered better alternative of comfort to the respondents compared to other spaces. The results indicated that the residents' adaptive actions were correlated with several of the identified variables under the categories- building spatial, neighborhood locational, climatic (indoor and outdoor). The building spatial characteristics were found to have played the dominant and significant aspect in influencing the residents' adaptive actions. The correlation of adaptive actions of the respondents to the spatial design elements constitute a substantive recognition of the impact created by spatial elements on the comfort of building users. It is concluded that the design decisions on several aspects of a residential building can greatly impact on both the adaptive actions of users and indoor comfort levels.

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