Investigating Thermal Comfort of Chhattisgarh Residents through Statistical Questionnaire Analysis

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Abstract

This article reports on a study conducted to investigate thermal comfort in residential houses in Chhattisgarh,renowned as the heart of rural India. The study used an online and offline questionnaire to assess thermal comfort in different climate regions year-round. The questionnaire evaluated the impact of temperature, humidity, and ventilation on thermal comfort. 2702 valid questionnaires were collected from respondents in different areas during winter, summer, and monsoon seasons. The results showed that those living in rural areas and Kutch houses(mud houses) reported higher comfort levels than those living in urban areas or pucca houses (brick houses) during summer and monsoon seasons. The study also revealed that people in Chhattisgarh experience discomfort during the summer season, with residents in Raipur reporting more discomfort than those in other areas. The report highlights the need for specific thermal comfort standards for urban and rural areas in Chhattisgarh.

Keywords: Questionnaire survey; residential houses; rural area; thermal comfort; urban area.

1. Introduction

Thermal comfort is the state in which a person feels neither too cold nor too hot in a specific environment, and it depends on subjective factors like age, sex, health, origin, and attire [1]. Studies have shown that people's preferences for heat can differ even in environments with similar traits and climates. This preference can also change based on the study location's climate. Therefore, it is essential to ensure that the comfort levels are suitable for the residents' health, productivity, and efficiency at work [2].

Apart from environmental factors, physical, physiological, and psychological components also play significant roles in thermal comfort [3]. Indoor thermal comfort is influenced by air temperature, relative humidity, air movement, clothing insulation, and human activity. As the energy efficiency of buildings becomes a global research focus, international regulations indicate a wide range of comfort levels.Passive approaches enhance indoor thermal comfort by providing a healthy and sufficient energy source [4-5]. However, some residents must rely on energy-intensive ventilation devices to regulate indoor air quality. India has diverse socio-cultural terrain and climatic conditions, with its climate classified into five zones: hot and dry, warm and humid, composite, cold, and temperate. Three major geographical features—the Himalayas to the north, the Thar Desert to the west, and the ocean to the south—profoundly impact the region [6].

In India, decisions are frequently based solely on energy efficiency, which is also true in the built environment [7]. However, designers, architects, and building owners prefer unconditioned constructions as they require less energy during their lifetime than conditioned ones. Natural ventilation can help maintain a pleasant indoor temperature by exposing building occupants to a changing environment throughout the day[8].

Currently, two methods for predicting thermal comfort are human heat-balancing and adaptive approaches[9]. The Adaptive Thermal Comfort (ATC) model was developed after field investigations of thermal comfort to determine the ranges of tolerable thermal conditions for interior and exterior buildings. The adaptive model considers all aspects of the environment, including the interior and exterior of the building, human behavior, environmental control, and the region of the field survey. In naturally ventilated (NV) buildings, the local climate and implementing environmental controls significantly impact the internal atmosphere.

Controls such as openable windows, blinds, doors, lighting, and fans allow occupants to modify the thermal environment for comfort. Standard controls can be used to mitigate the influence of external weather conditions [10-11]. A study found that urban greenery, high albedo surface materials, and proper implementation of urban geometry are important elements for sustainable urban development with improved thermal comfort [12-13]. Another study conducted in the highly altitudinal Darjeeling Himalayan region in eastern India found gender-wise differences in thermal comfort, with female subjects showing a higher discomfort with lower thermal sensation and higher comfort temperature[14]. The study proposes a new comfort zone for regions with similar cold climates.

This study was conducted in four different climates in Chhattisgarh. The researchers used subjective responses about thermal comfort and energy usage in different types of houses in both urban and rural areas. The adaptive method was used, with questionnaires distributed and air temperature, wind speed, and relative humidity measured concurrently in the study area. This allowed for a comparison of the questionnaire-responses to the physicalmeasurements.

2. Methodology

2.1. The study areas

In Chhattisgarh, the climate is tropical and heavily reliant on monsoons for rainfall, resulting in hot and humid conditions. During summer, temperatures can reach up to 45°C (113°F), but the monsoon season from late June to October provides some relief from the heat. The annual average rainfall in Chhattisgarh is 1,292 millimeters (50.9 inches). The coldest months are December and January, with pleasant winter temperatures due to low humidity [15]. The study area of Chhattisgarh comprises four sub-regions: Bastar, Sarguja,

Gariyaband and Raipur, as depicted in Figure 1.

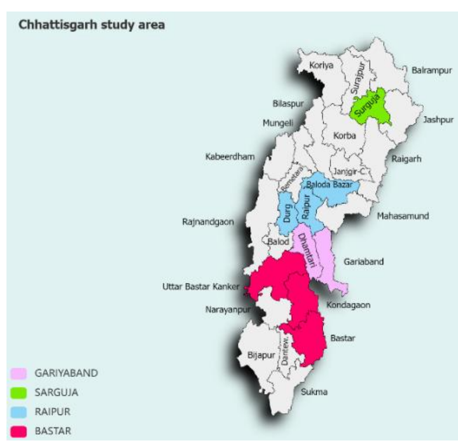

Figure 1 Study area of Chhattisgarh

Bastar has a tropical wet and dry or savanna climate and is situated at an elevation of 0 meters above sea level. The district experiences an annual average temperature of 27.69°C (81.72°F), which is higher than the Indian average. Bastar receives an average annual rainfall of 66.67 millimeters (2.62 inches) with 44.36 wet days (12.15% of the year).Ambikapur (Sarguja) has a Humid Subtropical, dry winter climate and is 0 meters above sea level. The district sees an average temperature of 27.06°C (80.71°F) annually, 1.09% higher than the Indian average. The average annual rainfall in Ambikapur is 51.59 millimeters (2.03 inches), with an average of 35.81 wet days (9.81% of the time).Gariyaband is 347.37 meters (1139.67 feet) above sea level and experiences a tropical wet and dry or savanna climate. The region has annual temperatures of 29.99°C (85.98°F), which is 4.02°F higher than the Indian average. Gariyaband receives an average annual precipitation of 40.47 millimeters (1.59 inches) with 32.54 rainy days (8.92%) per year.Raipur has a tropical wet and dry or savanna climate and is located at an elevation of 296.98 meters (974.34 ft) above sea level. The average annual temperature in the region is 30.4°C (86.72°F), which is 4.43% higher than the Indian average. In a typical year, the city receives 37.38 millimeters (1.47 inches) of rain with 32.19 wet days.

2.2 Instrumentation and field measurements

For this investigation, the weather station system was utilized to record outdoor conditions including temperature, wind speed, and relative humidity. Figure 2 illustrates the daily mean temperature, average high temperature, low average temperature, and average relative humidity for 12 months in Chhattisgarh. The maximum temperature in Chhattisgarh was recorded in May (49.0 ^{o}C), whereas the minimum temperature was recorded in January (7 ^{o}C).

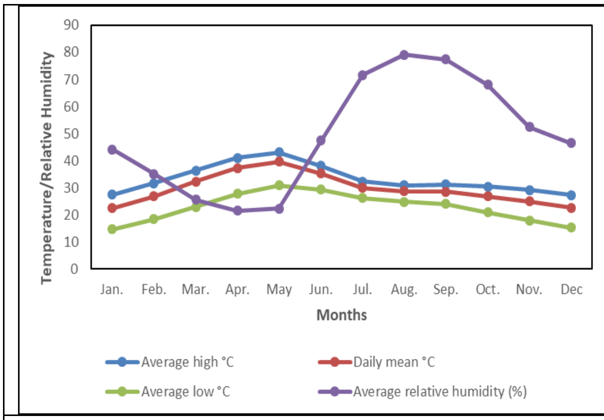

Figure 2 Outdoor Environment data for all month

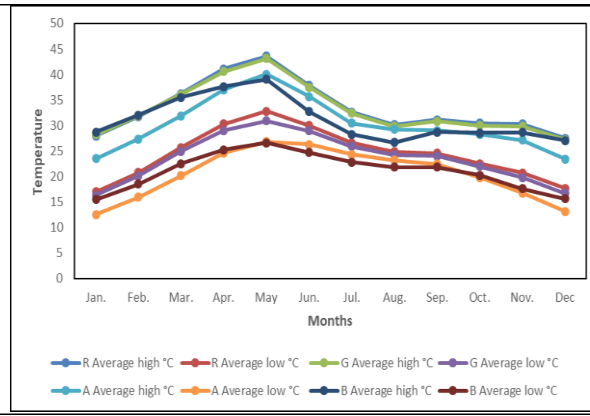

Figure 3 Average temperature data for all months in a different area (A-Ambikapur, B-Bastar, G-Gariyaband &R-Raipur)

Furthermore, Figure 3 depicts the trends of average high and average low temperatures in the Ambikapur, Bastar, Gariyaband, and Raipur regions for all months. It indicates that the Raipur area has the highest average high-temperature area compared to other regions. Ambikapur and Bastar exhibit temperatures approximately 3-4 OC lower than Raipur and Gariyaband areas. In winter, the Ambikapur region displays the lowest temperature in Chhattisgarh, while Bastar shows the minimum temperature during the rainy season.

2.3 Preparation of questionnaire

For the present study, two types of thermal comfort surveys were utilized: Google Forms-based surveys and field studies. The former method involved the creation of a questionnaire comprising four sections that gathered responses from participants. The first section obtained essential information, while the second section provided details about the type of house, flooring type, and types of windows. The third section focused on respondents' thermal comfort factors, and the fourth section-collected information on energy use and related appliances. The questionnaire was designed in both English and Hindi and was administered online to educated respondents with internet access. For those without such access, a face-to-face questionnaire survey was conducted in Hindi and the regional language (Chhattisgarhi). The survey questionnaire was designed based on a thorough analysis of the relevant literature to collect respondents' subjective opinions on several thermal comfort factors, such as temperature, humidity, airflow, and their overall comfort level.

3. Results and analysis

The subjective responses to the questionnaire survey that was conducted over several seasons are shown below, along with responses to various thermal comfort parameters and overall thermal comfort. The end of this section provides an analysis and explanation of the survey's findings.

3.1. Summer Season

The distribution of subjective responses to temperature in the summer shows in table 1. However, just 15.7% of Chhattisgarh (CG) voters chose a neutral temperature. While 31.6% of CG voters preferred slightly warm weather, 31.8% of CG voters preferred warm conditions. 20.9% of CG inhabitants think their buildings get too hot in the summer.

Table 1:distribution of subjective responses to temperature in the different season

Response (%)	Hot	Warm	Slightly Warm	Neutral	Slightly cool	cool	Cold
Summer	20.9	31.8	31.6	15.7	0	0	0
Monsoon	0	0	28.6	34.6	34.8	0	0
Winter	0	0	0	9.6	26.4	38.5	24.9

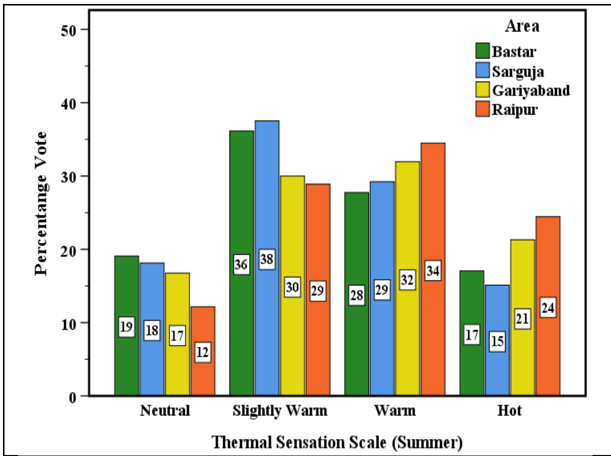

Figure 4 Distribution of subjective response to the temperature in the summer season area wise

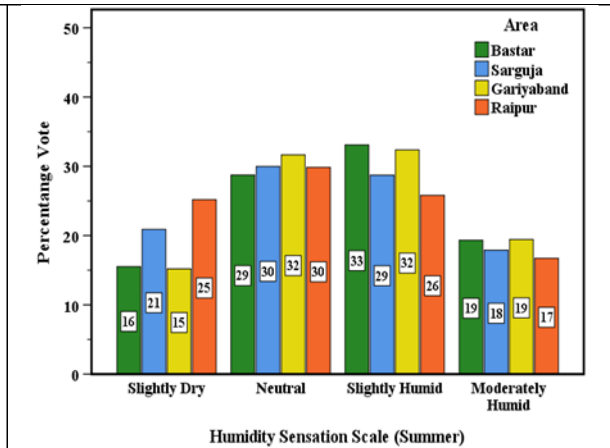

Figure 5 Distribution of subjective response to the humidity in the summer season area wise

Figure 4 shows the distribution of subjective responses to the temperature according to area wise, like Bastar, Sarguja, Gariyaband and Raipur in the summer season. While about 19 %, 18 % and 17% of the residents of Bastar, Sarguja and Gariyaband areas voted for neutral temperature, only 12% of the residents of Raipur voted for the same. Also, 36%, 38 %, 30 %, and 29 % of the resident of Bastar, Sarguja, Gariyaband and Raipur voted for slightly warm temperatures, respectively. Similarly, 28%, 29 %, 32 %, and 34 % of the resident of Bastar, Sarguja, Gariyaband and Raipur voted for warm temperatures, respectively.

When 24 %and 21 % of residents of the Raipur and Gariyaband area voted are Hot temperatures, only 17 % and 15 % of the residents of Bastar and Sarguja believed the same. 37% of the residents of modern buildings voted for the same. Figure 4 illustrates that summertime residents of the Raipur area prefer to vote for warmer conditions than those in Bastar and Sarguja.Figure 5displays the summertime subjective humidity response distribution. From this, roughly a third of residents in the Bastar and Sarguja regions consider their home's humidity neutral during the summer. In comparison, 25% of Raipur area inhabitants favored a slightly dry climate. Only 16% of Bastar voters, 21% of Sarguja voters, and 15% of Gariyaband voters chose this option.

Figure 6 shows the distribution of subjective responses to air movement in the summer season. About 24-26 % of responses voted from m residents of Bastar, Sarguja, Gariyaband and Raipur areas for Acceptable airflow. Around 53%, 49 %, 50 % and 40 % of the occupants of the Bastar, Sarguja, Gariyaband and Raipur areas voted for slight air and very high airflow. Occupants of the Raipur area voted 27 % for slightly low airflow, while 18 %, 20 % and 18 % of the occupants of Bastar, Sarguja and Gariyaband voted for the same, respectively. The very low airflow is also reported by 6- 7% of the occupants of all areas in the summer season.

The distribution of subjective response on overall thermal comfort in the summer season is shown in Figure 7. 29% of the occupants of the Bastar and Gariyaband area voted that their dwellings are comfortable in summer. While 27 % of the occupants of Sarguja voted that their houses are comfortable in summer, only 22 % of the occupants of Raipur voted for the same. Around 32 %,33 % and 28 % of occupants of Bastar, Sarguja and Gariyaband voted for moderately uncomfortable and very uncomfortable in the summer season, respectively. 44 % of the occupants of the Raipur area feel moderately uncomfortable and very uncomfortable during the same season.

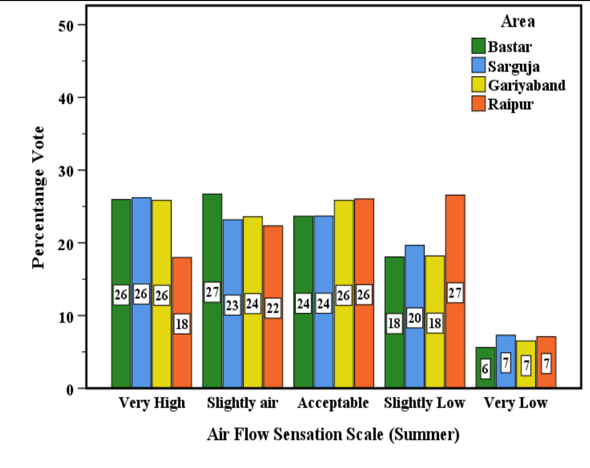

Figure 6 Distribution of subjective response on the airflow sensation in the summer season area wise

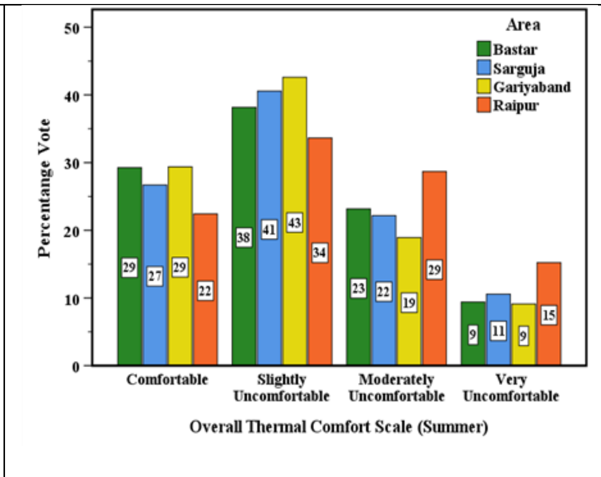

Figure 7 Distribution of subjective response on the overal l thermal comfort in the summer season area wise

3.2. Monsoon Season

Table 1 shows the distribution of subjective responses to the temperature in the monsoon season of Chhattisgarh occupants. 34.6% of Chhattisgarh (CG) occupants chose a neutral temperature during monsoon season. While 34.8% of CG occupants preferred slightly cool weather, and 28.6 % of CG occupants preferred slightly warm conditions. About 56% of Raipur region inhabitants favored a slightly cool and neutral climate, whereas 77%, 74%, and 77% of Bastar, Sarguja, and Gariyaband residents favored the sameis shown in figure 8. Further, while 38% of Raipur locals favored a slightly warm climate, 23%, 26%, and 23% of those residing in Bastar, Sarguja, and Gariyaband shared that opinion.

In the monsoon season, only 6 percent of Raipur area residents think their homes are warm. Based on this data, it's clear that the urbanization of the Raipur region is responsible for the increased comfort experienced by locals there. Figure 9 depicts the spread of individual ratings of relative humidity during the rainy season. According to this data, almost a quarter of Chhattisgarh's population considers their homes to be at a comfortable level ofhumidity during the monsoon.

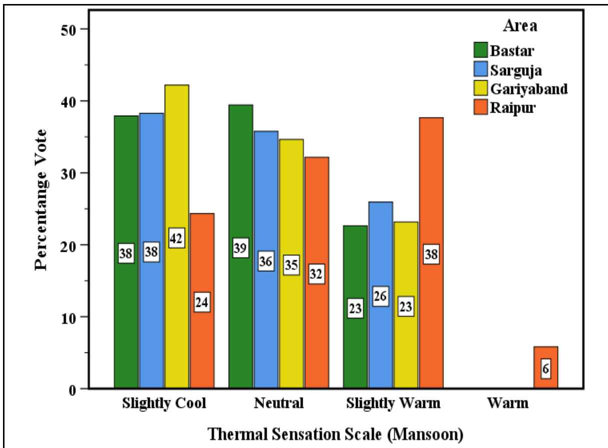

Figure 8 Distribution of subjective response to the temper ature in monsoon season area wise

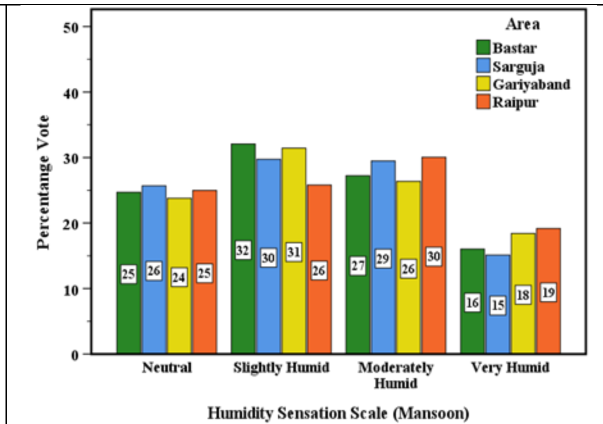

Figure 9 Distribution of subjective response to the humidity in monsoon season area wise

About 31% of respondents in the Bastar, Sarguja, and Gariyaband regions rated the humidity as slightly humid, while 26% of Raipur region inhabitants made the same selection. In the winter, about 44% of people in the Bastar, Sarguja, and Gariyaband areas think their buildings are moderately humid, whereas 49% of people in the Raipur area have the same opinion. The subjective reaction to airflow during the monsoon season is shown in Figure 10. The figure shows that 43 percent of Raipur residents voted in favor of proper airflow, whereas only about 29 percent of the Bastar and Sarguja regions agreed. The remaining 10% of Bastar, Sarguja, Gariyaband, and Raipur respondents voted for relatively low air circulation.The distribution of subjective response on overall thermal comfort in the monsoon season is shown in Figure 11. 53% of the occupants of the Raipur area voted that their dwellings are comfortable and very comfortable in the rainy season. The remaining 47% voted for slightly uncomfortable and moderately uncomfortable by a resident of the Raipur area.

With a distribution of 66%, 63 % and 65% of the occupants of Bastar, Sarguja and Gariyaband voted for comfortable and very comfortable in the rainy season, respectively. The remaining slightly uncomfortable and moderately uncomfortable response was by a resident of Bastar, Sarguja and Gariyaband, with a distribution of 34 %, 37% and 35%, respectively.

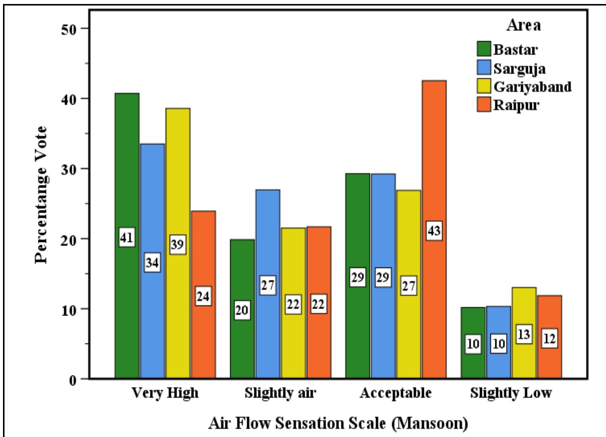

Figure 10 Distribution of subjective response on the airflow sensation in monsoon season area wise

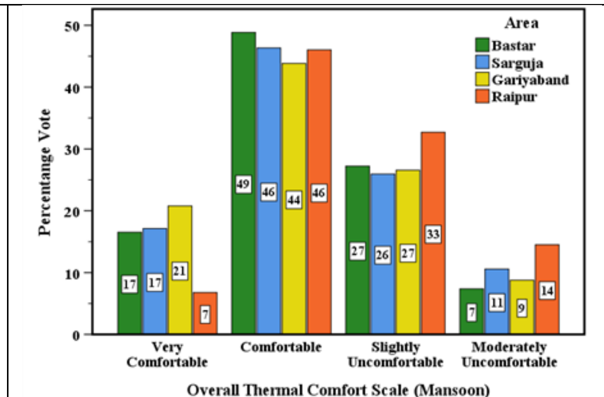

Figure 11 Distribution of subjective response on the over all thermal comfort in monsoon season area wise

3.3. Winter Season

Table 1 shows the distribution of subjective responses to temperature in the winter season of Chhattisgarh occupants. Only 9.6% of Chhattisgarh (CG) occupants vote for a neutral temperature in winter. While 26.4% of CG occupants respond to slightly cool weather, 38.5 % of CG occupants feel cool and 24.9 % of occupants feel cold in the winter season.Only 23% of inhabitants in the Sarguja area favored a somewhat cool or neutral temperature, compared to 30%, 36%, and 44% in the Bastar, Gariyaband, and Raipur areas, respectively, as shown in Figure 12.Furthermore, although 70%, 77%, and 64% of individuals in Bastar, Sarguja, and Gariyaband, respectively, favored chilly and cold temperatures, only 54% of those living in the Raipur area did so. Based on their responses, residents of the Bastar and Sarguja regions report colder temperatures throughout the winter than their counterparts in the Raipur region.

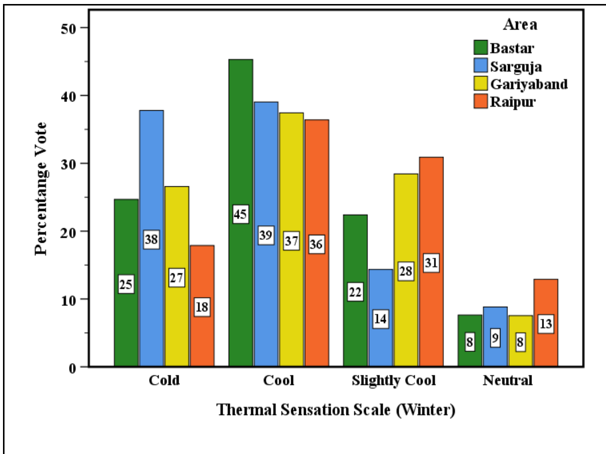

Figure 12 Distribution of subjective response to the tempe rature in the winter season area wise

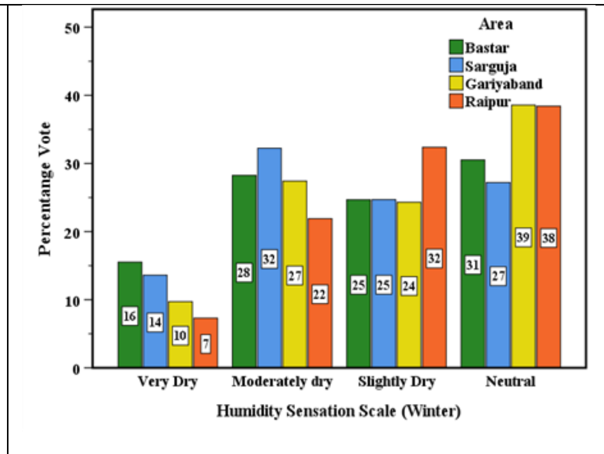

Figure 13 Distribution of subjective response to the humi dity in the winter season area wise

Figure 13 displays the spread of wintertime respondents' subjective ratings of humidity. In the winter, roughly 38% of individuals in the Raipur and Gariyaband areas consider their homes to be at a neutral humidity level. Only 31% of Bastar and 27% of Sarguja area residents report feeling unaffected by the humidity. Only roughly a quarter of voters in Bastar, Sarguja, and Gariyaband favored slightly dry, while 32% did so in Raipur. Approximately 44%, 46%, 37%, and 29% of people in the Bastar, Sarguja, Gariyaband, and Raipur areas agreed that winters are either moderately dry or very dry.

The subjective response distribution to airflow throughout the winter is depicted in Figure 14. As shown in Figure 32, 32 percent of Raipur residents voted in favor of an acceptable airflow. Still, only about 20 percent of residents in the Bastar, Sarguja, and Gariyaband areas did so. 51% of people voted for very high airflow in the Sarguja area, 46% in the Baster area, 40% in the Gariyaband area, and 31% in the Raipur area.

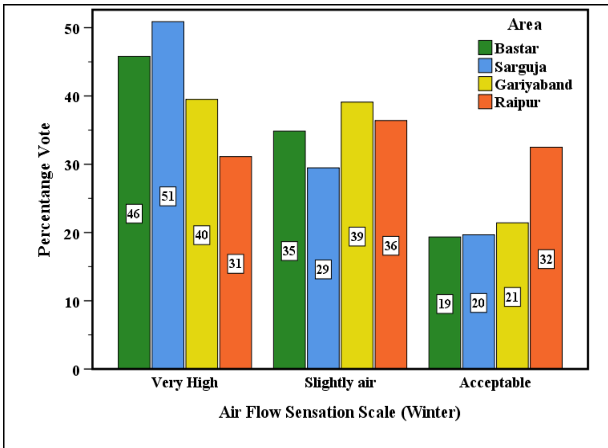

Figure 14 Distribution of subjective response on the airflow sensation in the winter season area wise

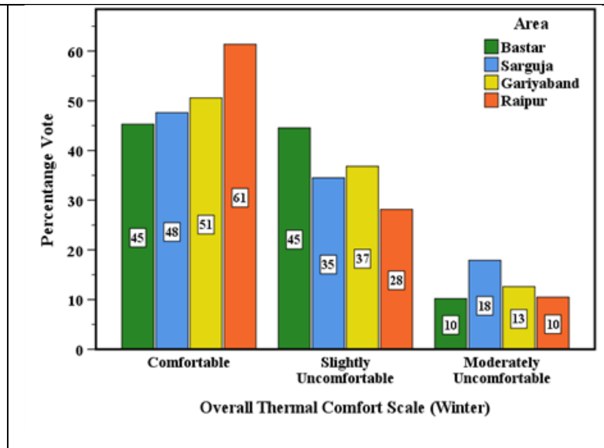

Figure 15 Distribution of subjective response on the overall thermal comfort in the winter season area wise

Figure 15 depicts the frequency of respondents who reported being satisfied with their personal level of warmth during the winter. As the numbers demonstrate, 61% of people in the Raipur region are comfortable during the winter. The Percentage of comfortable voters in Bastar, Sarguja, and Gariyaband were 45, 48, and 51 percent, respectively. Some 38% of Raipur area residents said they were only slightly or moderately uncomfortable. Approximately, 55%, 53%, and 50% of the locals in Bastar, Sarguja, and Gariyaband rated the winter climate slightly or moderately uncomfortable.

3.4. Rural vs. Urban area

Summer month's subjective heat sensation distribution between urban and rural locations is depicted in Figure 16. Whereas almost 16% of those living in rural areas opted for a neutral temperature, only 14% of those living in urban areas did so. Another interesting fact is that while 36% of rural residents favored a warm temperature, only 22% of urban residents did. From this data, it is clear that neither urban residents nor rural residents complain that their homes are too cool. The urban people voted 39% for warm and 25%

for hot, for a total of 64% who preferred these temperatures. Forty-eight percent of rural dwellers favored the warm and hot options.

The subjective reaction of thermal sensation during the Monsoon (rainy) season is depicted in Figure 17 for both urban and rural areas. About 37% of those living in rural areas opted for a neutral condition, compared to 28% of those living in urban areas.Moreover, while 45% of urban people favored a slightly warm climate, only 22% of ruralites shared that opinion. Only 7% of rural inhabitants feel comfortable in their houses during the rainy season. Only 20% of urban residents believe that the weather is slightly cooler during the rainy season, compared to 40% of those living in rural areas who say the same about their houses. The data reveals that during the rainy season, no one in urban or rural areas finds their homes unusually cool, cold, or hot.

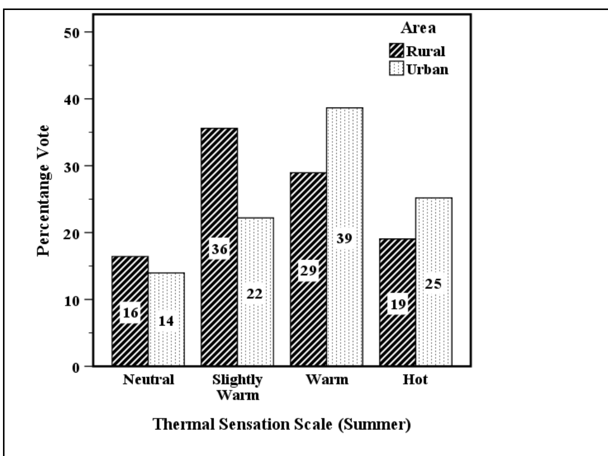

Figure 16 Distribution of subjective response to the tempe rature in the summer season

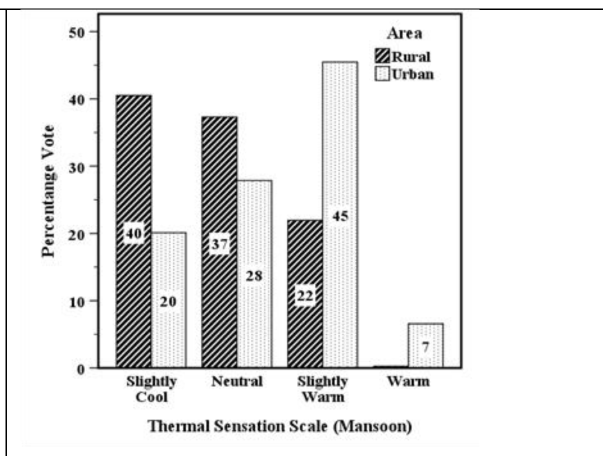

Figure 17 Distribution of subjective response to the tempe rature in monsoon season

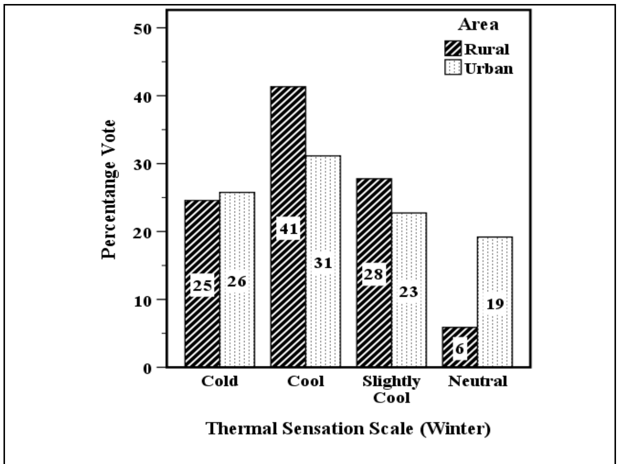

Figure 18 Distribution of subjective response to the tempe rature in the winter season

Figure 18 compares the Percentage of urban and rural inhabitants who preferred a neutral temperature throughout the winter, with 19% of urban residents choosing this option and 6% of rural residents choosing it, respectively. Further, whereas 28% of rural individuals favored a slightly cool climate, 23% of urban residents shared this preference. In contrast to the 31% of urban residents who share this opinion, 41% of those in rural areas say their houses are at least slightly cool. As can be seen in Figure 18, roughly 26% of voters in both urban and rural areas preferred a cold thermal experience.

4. Conclusion

In this statistical analysis, residents from four regions in Chhattisgarh provided their subjective responses on thermal comfort and energy usage in their respective areas. The findings showed variation based on location, type of dwelling, and time of year. Residents in Bastar and Sarguja regions reported feeling cooler during the summer than those in Raipur. Raipur residents, on the other hand, generally felt uncomfortable due to rising temperatures. During the monsoons, Raipur residents tended to select "warm" and "slightly warm" options more frequently. Additionally, people in Sarguja and Bastar reported a milder winter climate compared to the rest of Chhattisgarh. Rural dwellers experienced more comfortable temperatures during the summer and monsoon seasons than those living in urban areas. Furthermore, people in rural areas tended to feel warmer in the cold than their urban counterparts. Overall, residents of rural areas expressed higher satisfaction with their local environment.

Acknowledgments

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