Analysis of the Thermal Comfort Conditions in Terminal Buildings at Domestic Airports in India

Kanika Malik
Research Scholar, Department of Architecture, DCRUST, Murthal, Sonepat, Haryana (India)
E-mail: kanikamalik7@gmail.com

Abstract
This paper presents the results from the thermal comfort studies at three airport terminal buildings in India where extensive seasonal field surveys were conducted. The study involved monitoring of the indoor environmental conditions along with questionnaire-guided interviews with terminal users. The paper quantifies the thermal requirements of the terminal population and focuses on the thermal perception, preference and comfort conditions of people in different terminal spaces. The results revealed significant differences between the thermal requirements of people, with them preferring a thermal environment different to the one experienced.

Keywords: Airports, Airport terminal buildings, passengers and staff, indoor thermal comfort

INTRODUCTION
Airports are large scale infrastructure projects with long term impact. Major airports in India operate on a 24 h basis throughout the year, with variable schedules and occupancy during certain periods. Energy and efforts to reduce consumption are becoming significant environmental factors in many Indian airports, while trying to address sustainability issues.

Infrastructure and facilities provided at Indian airports have not been able to keep pace with the unprecedented growth of the aviation sector, leading to poor quality of space available for operations. In most cases, this is coupled with poor ambience and poor comfort conditions leading to an unsatisfactory visual appeal and passenger experience. There is a heavy dependence on artificial lights and air conditioning in India. In most of the existing airports, the potential for daylighting and natural ventilation has not been explored adequately (Babu, 2008).

Airport terminal buildings consist of large, open plan areas, often with high ceilings, ticketing counters, waiting areas, small office spaces, and various types of stores, concessions, and convenience facilities. Internal loads are primarily due to people, with substantially variable occupancy, while lighting and equipment loads are generally average (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], 2003). External loads vary depending on the architecture of the building, although solar gains are usually high because of the large external glazing. Central heating and cooling with all-air systems are preferred (Balaras et al., 2003). This leads to an energy intensive nature of the PTB.

Thus, the need to address the same assumes paramount importance in the wake of the overall energy crisis that India is facing (Babu, 2008).

OBJECTIVE OF THE STUDY
Airport terminals are major transportation facilities. These types of buildings have very distinct operational and architectural characteristics (Balaras et al., 2003). Airport terminals are characteristic of the diversity of spaces and the very different groups of population using these buildings. The indoor microclimatic conditions are expected to provide a comfortable working environment to the small number of terminal staff and at the same time a comfortable transient environment to passengers. Variations in clothing levels and activity, along with time spent in the area and overall expectations are differentiating factors for variations in thermal requirements between the two groups. The diversity of spaces and the heterogeneous functions across the different terminal zones further contribute to thermal comfort conflicts. Understanding such conflicts can improve thermal comfort conditions, while reducing the large amounts of energy consumed for the conditioning of terminal buildings.

However, there are very few published studies on the evaluation of the thermal environment in airport terminal spaces. A study in three Greek airports with 285 questionnaires highlighted the different satisfaction levels between staff and passengers (Balaras et al, 2003). Another study, surveying 128 staff and passengers in the terminal of Ahmedabad airport, India, found a very high comfortable temperature range in the air-conditioned part of the building (Babu, 2008).

The current study investigates the breadth of thermal comfort conditions in three airport terminal buildings in India and aims to quantify the overall thermal requirements.

AIRPORT TERMINAL SURVEYS
India has more than 476 airports that include abandoned and disused airports and aerodromes. Airports Authority of India (AAI) owns and maintains 125 airports comprising 95 operational airports and 30 non-operational airports with no scheduled flights.

The terminals were selected to meet specific criteria, aiming for buildings of different scale and typology and therefore allowing the investigation of a wide range of indoor...
environments. The selection of case studies aimed to allow for a representative range of the indoor conditions commonly encountered in airport terminals. Accordingly, the study sought for buildings which are not similar in a multitude of characteristics that, directly or ultimately, have an impact on the indoor comfort conditions. These include terminal size and capacity, actual passenger traffic, as well as terminal design and spatial characteristics.

Terminal scale was the primary parameter which underpinned the selection process. At its early stage, the focus was on terminal buildings that, in terms of building size and capacity, are good representations of small, medium and large scale airport terminals. Such classification was essential to facilitate the understanding of people’s comfort requirements in operationally dissimilar indoor conditions.

In addition to the interlock between the indoor environmental conditions and the scale of the terminal building, the latter is associated with non-environmental comfort factors in the terminal settings. These include the length of walking distances and passengers’ dwell time, which in turn are related to the activity levels performed in the terminal and the allowable time for adaptation to the indoor environment. As a result of their size, the higher passenger traffic handled and the higher frequency of long-haul flights, large terminals usually require longer periods of time for passenger processing and consequently lengthier dwell times. Therefore, Dissimilarity in terminal capacity and actual passenger traffic between the case studies was necessary to allow the investigation of passengers’ comfort conditions over dissimilar dwell times and occupancy levels.

From a historical standpoint, airport terminals are a fairly new building concept that has evolved in step with the needs of commercial aviation. Despite their relative novelty, terminal architecture is diverse itself as the development of airport passenger terminals is tailored to a number of safety, operational, environmental, economic and national considerations. Accordingly, the case studies were selected to include contemporary terminal spaces characteristic for their large and open areas.

Major part of the country falls in the composite climatic zone. The three selected airports were accordingly selected and since they fall in the composite climatic zone, they have similar climatic conditions as illustrated in Table I. The Table II provides the statistics related to passenger movement, aircraft movement and cargo movement with respect to these three airports for the year 2017-18.

### Table I. Geographical information and monthly mean maximum and minimum temperature of analyzed airports

<table>
<thead>
<tr>
<th>S.No.</th>
<th>City</th>
<th>Mean Maximum and Minimum Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raipur</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latitude: N 21° 10’</td>
<td>Longitude: E 81° 44’</td>
</tr>
<tr>
<td>2.</td>
<td>Udaipur</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latitude: N 24° 37’</td>
<td>Longitude: E 73° 53’</td>
</tr>
<tr>
<td>3.</td>
<td>Aurangabad</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latitude: N 19° 51’</td>
<td>Longitude: E 75° 23’</td>
</tr>
</tbody>
</table>
Table II. Traffic details of the three analysed airports

<table>
<thead>
<tr>
<th>Airport</th>
<th>Passengers</th>
<th>Aircraft Movements</th>
<th>Cargo (In Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aurangabad</td>
<td>344180</td>
<td>3758</td>
<td>1729</td>
</tr>
<tr>
<td>Raipur</td>
<td>1628134</td>
<td>12802</td>
<td>4093</td>
</tr>
<tr>
<td>Udaipur</td>
<td>1147067</td>
<td>9842</td>
<td>13</td>
</tr>
</tbody>
</table>

Extensive on-site surveys were carried out in Aurangabad Airport (IXU), Raipur Airport (RPR) and Udaipur Airport (UDR). The surveys involved extensive monitoring of the indoor environmental conditions across the different terminal areas along with questionnaire-based interviews with terminal users. A weekly survey was carried out in each terminal during summer and winter, to allow for the seasonal variations.

INTRODUCTION TO THE SELECTED CASE STUDIES

Aurangabad Airport

Chikkalthana Airport is a public airport located in Aurangabad, Maharashtra, India. The airport opened to regular traffic on 3 March 2009. It is located about 5.5 km east of the city center, and 11 km from Aurangabad Railway Station, along the Aurangabad-Nagpur State Highway. The airport is owned and operated by the Airports Authority of India. The airport ordinarily only has domestic destinations; however its operators seasonally run Haj services using makeshift immigration and customs counters.

The airfield features one 2,835 m asphalt runway bearing orientation 09/27 with coordinates of 19°51’52”N latitude and 75°23’51”E longitude. It features two parking aprons, one for the passenger terminal, and the other for the cargo terminal. The passenger terminal apron has stands for upto four single-aisle aircraft such as the Airbus A320 family or Boeing B737 family. The total land area of the airport is 557.55 acres. The total built up area is 23220sq.m.

The Airport terminal building area is 20500 sq.m. and out of this 19000 sq.m. is conditioned area. In addition to the above, they have other main buildings i.e. ATS building and fire station building having around 2720 sq.m. covered area of which around 60% area is air-conditioned. It is an Integrated (Domestic + International) two-storey, glass-and-steel terminal building (with four entry & exit points) and a 30m-high technical complex (with a floor area of 620m²) and costing approximately Rs 1 billion. It is a north facing building and having double glazing glass 6mm-8mm-6mm (6mm glass thickness with 8mm air gap) at north & south side and east & West side it has 12 mm thick glass with insulated film. Its roof structure is made of Aluminum sheet - insulation then metal sheet. On the roof around 7 Nos. of transparent sheet made of FRP (Fibre Reinforced Plastic) Hoods are provided for sun light facility at the terminal. It is designed to cater for 800 peak hour passengers. The Figure 2 (i) and (ii) shows the terminal building at Aurangabad Airport. The figure 3 shows the interiors of the PTB at Aurangabad Airport.
**Figure 3.** The Interiors of the Passenger Terminal Building at Aurangabad Airport

![Ground Floor Plan](image1)

![First Floor Plan](image2)

![Terrace floor plan](image3)

![Sections](image4)

![Elevations](image5)

**Figure 4.** Drawings of the Aurangabad Airport New Terminal Building
Raipur Airport

Swami Vivekananda International Airport, Raipur is the primary airport serving the state of Chhattisgarh, India. In 2006, this airport witnessed an 82% increase in passenger traffic (the highest in the country for that year). The airport is one of the 35 non-metro airports recently modernized by the AAI. The airfield features one 2,320 m asphalt runway bearing orientation 06/24 with coordinates of 21°10'52" N latitude and 81°44'18.5" E longitude. It features two parking aprons, one for the passenger terminal, and the other for the cargo terminal. The passenger terminal apron has stands for up to four single-aisle aircraft such as the Airbus A320 family or Boeing B737 family. The total land area of the airport is 638.38 acres.

The site area of the airport is 20,900 sq.m. and the built-up area of the terminal building is 18,500 sq.m. with the ground floor having a building footprint of 14,000 sq.m. and the first floor having a building footprint of 4,500 sq.m. The new terminal building is designed to accommodate 700 passengers, including 200 international passengers. With the increase in passengers is the added pressure on the resources at the airport due to the extensive use of artificial lighting and HVAC systems. The planning team envisioned to globalise the airport terminal, to not only create a world class terminal, but also to direct and integrate the commercial built form into an environmentally sustainable abode. It was inaugurated on 7 November 2012. Figure 5 shows the new integrated terminal building at Raipur Airport.

Figure 5. The New Integrated Terminal Building, Raipur Airport

Master plan and layout plan

Ground floor plan

First floor plan
<table>
<thead>
<tr>
<th>Section</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 6. Drawings of the Raipur Airport New Terminal Building</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Check In Concourse</th>
<th>Security Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 7. Views of the different areas on the ground floor level within the Raipur Airport New Terminal Building</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Security Hold</th>
<th>Domestic Baggage Reclaim Area</th>
</tr>
</thead>
</table>

| Security Hold | Departure Lounge |
Udaipur Airport

Maharana Pratap international Airport or Udaipur Airport is a commercial domestic airport at Udaipur, Rajasthan, India. It is situated 22 km east of Udaipur. The newly built Udaipur Airport, which became functional in 2008, is a state of the art modern airport with passenger friendly facilities. About 6000 aircraft movements take place in a year at the airport.

The airfield features one 2,281 m asphalt runway with width of 45m bearing orientation 08/26 with coordinates of 24°37′04″N latitude and 73°53′46″E longitude. Its 250m apron provides parking space for 3 Boeing 737 or Airbus A320 aircraft at a time. The total land area of the airport is 504 acres.

The terminal building of glass and steel structure is centrally air-conditioned 3-storeyed building having built-up area of 12000sq.m. It is equipped to handle 300 passengers each at departure and arrival with total of 600 passengers. The Figure 9 shows the terminal building at Udaipur Airport.

The complex also includes operational and technical blocks and Air traffic control (ATC) tower besides residential colony and buildings for utilities like power-house pump house and central AC plant room. The operational block is a three storeyed glass gladd structure having an area of 3100sq.m.. The technical block is also of 3100sq.m. area but has masonry walls. The ATC building area is 400sq.m. which mainly consists of a glass dome on top.
FIELD SURVEYS

The environmental conditions were monitored continuously during week-long surveys. The study required investigation of the immediate microclimate people experience.

A microclimatic monitoring equipment was used for monitoring the indoor environmental conditions in the terminal buildings. The equipment is named Multifunction Environmental Meter and conforms to ISO 7726 (ISO 7726, 1998). Humidity, temperature, air velocity, sound and light measurements are combined in this one easy to use instrument.

The spaces monitored included check-in areas, security check areas, security hold retail, departure lounges and baggage reclaim/arrivals halls.

The questionnaire developed intended to collect subjective data for the evaluation of comfort conditions. Interviewees were selected randomly to represent the typical range of terminal users. The questionnaire used the 7-point ASHRAE scale for the assessment of thermal sensation and a 5-point scale for thermal preference. Similar form of questions was used to assess other environmental parameters including air movement, humidity and lighting levels. Interviewees were also asked for their overall comfort state.

DATA ANALYSIS

A total of 1537 people were interviewed in the surveyed terminals. The terminal users were classified into employees and passengers. Airport, airline and retail employees were studied in their work areas. Arriving and departing passengers were interviewed across the different terminal areas.

| Table III. Number and type of interviewees in the surveyed terminals |
|-------------------|----------------|-------------|-------------|----------------|-------------|
|                   | Aurangabad | Raipur     | Udaipur    | Total        |
| Employees Summer | 37         | 75          | 43          | 155          |
| Winter            | 39         | 43          | 49          | 131          |
| Passengers Summer | 164        | 256         | 220         | 640          |
| Winter            | 169        | 219         | 208         | 596          |
| Total             | 409        | 593         | 535         | 1537         |

The operative temperature range in Aurangabad Airport Terminal was 23.94 – 26.5°C in summer and 21.3- 25.0°C in winter. The thermal environment at Udaipur Airport Terminal is characterized by wider temperature ranges; 23.84 – 27.26°C in summer and 21.28 – 25.36°C in winter. As a result of the great diversity of spaces in Raipur Airport Terminal, thermal conditions varied significantly between the different zones, where the temperature range was 23.85 – 26.95°C in summer and 21.40 - 25.36°C in winter. The average air movement did not exceed 0.15 m/s in all three terminals, where the infrequent high air speeds occurred in spaces exposed to the outdoor conditions through the openings.

In summer the terminal population had very similar clothing insulation values, while in winter, the effect of outdoor weather resulted in distinct variations in clothing levels between the groups. In summer, the mean clothing insulation for passengers and staff was very similar across the three terminals. This increased for passengers and staff, in winter, reflecting the greater impact of outdoor weather on passengers’ outfits.
Table IV. Mean clothing insulation (clo) for employees and passengers

<table>
<thead>
<tr>
<th></th>
<th>IXU</th>
<th>RPR</th>
<th>UDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>0.59</td>
<td>0.56</td>
<td>0.58</td>
</tr>
<tr>
<td>Winter</td>
<td>1.01</td>
<td>1.07</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Representative results from the analysis of the employee and passenger questionnaires on selected indoor environment parameters at the three audited airports are below.

**COMFORT CONDITIONS FOR THE TERMINAL POPULATION**

**Assessment of Thermal preference**

In summer, preference over the thermal environment in all terminals converged at two votes expressing the majority of interviewees; “no change” and “a bit warmer”. In winter, preference over the thermal environment in all terminals converged at two votes expressing the majority of interviewees, “no change” and “a bit cooler” (figure 11).

In summer, thermal preference profile at Aurangabad (IXU) was very similar with almost 53% of people in the terminal finding the thermal environment ‘just right’ and nearly 41% preferring warmer conditions. This pattern was reversed in IXU during winter, when the TS profile was suggestive of overheating. In fact, the majority preferred a cooler thermal environment, with nearly 40% of the people preferring “a bit cooler” in particular.

In RPR the percentage of people desiring no change was almost 60% in summer and winter both.

UDR is the only terminal where more people found the temperature “just right” in winter (nearly 60%). Yet, similarly to IXU and RPR, the majority of interviewees requiring a change in winter preferred to be cooler, with such preference expressing 28% of people.

![Figure 11. Percentage distribution of thermal preference votes.](image-url)
Air movement was on average very low with small variance in all terminal buildings. As a result, the relationship between air movement and people’s respective sensation is weak for RPR and UDR, while there is no significant correlation between the two for IXU.

In all terminals air movement was rarely evaluated as “high” and almost never as “very high”. On the contrary, widespread among the population was the assessment of air movement as “neither low nor high” and “low”, with the two cumulatively accounting for 70-80% of the responses in summer and winter. In IXU and RPR the two categories received nearly the same response in both seasons, whilst in UDR the most popular sensation was “low” in summer and “neither low nor high” in winter. Notable is also the percentage of people who felt it was “very low”, particularly in summer when this notion represented nearly 20% of occupants in IXU and RPR and 25% of occupants in UDR.

In both seasons the preference profile was dominated by two responses; “no change” and “a bit more”, with almost the same frequency in IXU and with more people requiring no change in RPR and UDR (figure 12).

As far as the air humidity is concerned, the majority of interviewees in the three terminals assessed the conditions as “neither damp nor dry” in summer and winter. However, the sensation of dryness in winter was increased, as noted by nearly 30% of people in IXU and RPR, while such notion was expressed by 30% of respondents in UDR in both seasons (figure 13).

**Assessment of overall lighting conditions**

This section examines how the terminal population evaluated the lighting environment in the terminal buildings. Perception and preference over lighting are addressed, while further analysis reveals that bright rather dim conditions were preferred. Subsequently, the subjective assessments of daylight demonstrate people’s desire for natural light, with the respective preference being associated with the time of the day.

Overall, the average perception of lighting in IXU and RPR was “neither bright nor dim” and rounds up to “slightly bright” for UDR. The percentage distribution of lighting sensation is representative of the luminous environment in each terminal, with “daylight” being the differentiating parameter between the cases studies. More specifically, the distribution for the uniform spaces of IXU (figure 14a) is dominated by the middle three categories. “Slightly dim” and “slightly bright” represent nearly 25% of the population each and “neither bright nor dim” received the highest response, about 35%. These categories also represent the majority of responses (80%) in RPR where more people, however, found it “slightly dim”. On the contrary, more than half of the population in UDR voted on the bright side of the 7-point sensation scale, with particularly 25% and 30% of interviewees finding the lighting environment “slightly bright” and “bright” respectively, reflecting the abundance of daylight in the terminal.

Unlike lighting sensation, the profile of preference votes is very similar between the case studies. In all terminals, the
majority of people (60-65%) found lighting levels “just right”, while widespread was the preference for brighter conditions among those requiring a change (figure 14b).

**Figure 14.** Percentage distribution of (a) lighting sensation and (b) lighting preference votes.

**Daylight**

People’s perception over the amount of natural light (figure 15a) describes the overall daylight profile of the three terminals. The majority of people in RPR found it “little” or “very little” in the space they were interviewed, with the “sufficient” votes coming predominantly from the few spaces of the terminal that have large sources of natural light; departures lounges and the gates. On the other hand, the extensive sources of daylight in the spaces of UDR is reflected in the majority’s assessment as “sufficient”, while in IXU the assessment is equally distributed between “very little”, “little” and “sufficient”.

The corresponding preference votes (figure 15b) confirm people’s desire for natural light, as this has been reported in a number of studies in other building types (Veitch and Gifford, 1996). More specifically, the majority of interviewees in IXU (70%) and RPR (64%) expressed a preference for more daylight. This desire is further highlighted by the respective figures from UDR. The majority acknowledged the sufficiency of natural light in the building (“sufficient”, “much” and “very much” account for roughly 60% of responses), yet nearly half the population would prefer even more and almost no one less.

**Figure 15.** Subjective assessment of daylight and relevant preference for change.
Environmental parameters influencing overall comfort

Responses with respect to the most important factor in the terminal – among air temperature, air freshness, daylight, air movement and humidity – are remarkably uniform between the case studies. More specifically, nearly half of the terminal users acknowledged temperature to be more important, followed by air freshness which was identified by approximately 25% of terminal users (figure 16). Air movement humidity and daylight share the remaining 25% of votes, with the latter being raised by a marginally higher percentage of people.

![Figure 16. Terminal users evaluating the most important (environmental) factor in the terminal buildings.](image)

CONCLUSIONS

This study investigated the range of thermal comfort conditions in three airport terminal buildings of different size and typology, through extensive seasonal field surveys. The results of the analysis from the environmental monitoring and interviews with 1537 people were presented.

The data analysis showed that the thermal conditions in the three surveyed terminals regularly do not meet people’s thermal requirements. In most cases more than half of the terminal population prefers a thermal environment other than the one experienced.

Differences in clothing levels, time spent in the terminals, as well as expectations are some of the factors differentiating the thermal requirements of these groups, resulting in thermal comfort conflicts.

The analysis also demonstrated that discomfort from higher temperatures was predominant in all cases in winter, although affected by the particularities of each terminal. Where such problems are apparent in winter, lower temperature setpoint of the heating system can improve thermal comfort while leading to energy savings. In the summer, increasing the temperature set-points; would need to be explored to increase the peak temperatures particularly during high occupancy periods.

This study aimed to shed light on the thermal comfort conditions in airport terminal spaces and to quantify the thermal requirements of the terminal population. Such knowledge can be useful in improving thermal comfort while different energy conservation strategies are implemented, as well as in the regular refurbishments of existing terminal facilities and the design of new terminal buildings.

ACKNOWLEDGEMENTS

This paper is based on the author’s PhD research. The author would like to thank the Airports Authority of India (AAI) for the support in terms of information for the successful completion of this paper. The assistance from the terminal staff at the three surveyed terminals is gratefully acknowledged.

REFERENCES


