709: A Low Energy Passenger Terminal Building for Ahmedabad Airport, India: *'Building Envelope as an Environment Regulator'*

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Abstract

High energy consumption due to extensive use of artificial lighting and HVAC systems in passenger terminals of airports is one of the most serious environmental concerns caused by the aviation industry. This design research investigates how this issue has been addressed for the proposed Ahmedabad International Airport through a conclusive design response for the building envelope aided by stepped thermal conditioning to achieve energy efficiency. Using the existing design proposal of the new airport as a base case, the potential of the building envelope to mediate the internal environment of the passenger terminal building (PTB) to achieve thermal comfort of passengers and energy savings has been explored. The design research recommends the use of transient environment within the PTB along with passive strategies like daylighting, natural ventilation, passive downdraught evaporative cooling system. Implementation of above recommendations within the framework of the existing design proposal leads to considerable energy savings as observed through tests and software simulations for daylighting, operative temperatures and cooling loads.

Keywords: thermal comfort, transient environment, passive design strategies, energy consumption, building envelope

1. Introduction

The aviation industry has chartered unprecedented growth in the 21st century. The potential for further growth in terms of passenger traffic is massive given that only around 1% of the population has ever flown [1]. While augmenting economic growth in a significant way, the industry is accountable for contributing to environmental controversies like fuel and energy consumption, emission issues and global warming. The impact is also enhanced by the changing concept of an airport from a simple aerodrome to one of an airport city.

Given the fact that the passenger terminal building (PTB) has high levels of energy consumption compared to other buildings. It also attempts to identify various design responses that could be adopted for the building skin to achieve stepped temperature transitioning in the terminal, for the climate in context.

Project Scope: This paper focuses only on the passenger areas of the PTB and does not take into consideration other components of an airport such as master-planning, design of airport systems, security issues, services and other technical areas.

2. Background Review

2.1 Impacts of Aviation and the PTB

The environmental impact of the aviation industry has been in the form of energy and fuel consumption; noise, water and air pollution; waste production; land utilization and contribution to climate change. As per Stern's Review [2] by 2050, CO_2 emissions from aviation are expected to account for 2.5% greenhouse gas (GHG) emissions, contributing to about 5% rise in global warming. This huge environmental impact is a potential threat to the growth of the aviation industry..

For a sustainable and holistic aviation system, the following three areas viz. the aircraft, the airport and the terminal need to be addressed for improvements in design.. The terminal has significantly lower levels of energy consumption and carbon emissions when compared to the aircraft and airfield operations. But compared to other building typologies, it consumes the highest amount of energy as much as one and half times that of other commercial buildings (based on study for Helenic islands 2003, [3]).

2.2 The Indian Context

As per the Investment Commission of India [4], the passenger sector of the aviation industry in India is expected to grow at a rate of 15% in the next five years, exceeding a level of 100 million passengers per annum by 2010. But infrastructure and facilities provided have not been able to keep pace with this growth, 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 contributing to almost 10%-15% and 60-80% respectively of the total energy consumed in an international airport (Delhi, Mumbai, [5,6]) in India. In most of the existing airports, the potential for daylighting and natural ventilation has not been explored adequately. 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.

3. Research Hypothesis

Unlike occupant behavioural patterns in home or office, in buildings such as airports and railway stations; the behavioural pattern is largely transitional. Transient environments may be caused by the space as a whole changing over time or by the occupant traversing a space with varying local conditions like in airport terminals [7]. In airports, these environments result from the effects of varying occupancy patterns in spaces, changing activity levels of passengers, nature of the built environment and thermal conditioning of the spaces. Thus, while designing such built environments; the climate in context and the factor of a gradual thermal gradient from inside to outside and vice versa, should be considered.

Typically, thermally conditioned buildings aim to maintain a uniform thermal environment throughout the building, which would necessitate an energy intensive HVAC solution. This may further lead to conditions of thermal shock for passengers in very hot outdoor conditions due to the disparity between the external and internal environment. The building could have a selective combination of tight thermally conditioned spaces and loose thermally conditioned spaces (Fig1) based on the function or requirement of conditioning achieved by selective preference of outdoor environment through the building envelope. Thus transient environments can be used to save energy and satisfy occupants [7].

This paper investigates the possibility of this design approach of transient, time varying environments for buildings like an airport terminal in the form of stepped thermal transitioning through its building fabric, leading to substantial energy savings whilst still achieving passenger comfort.

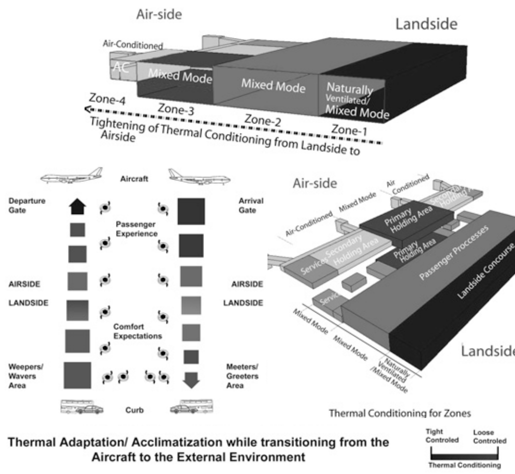

Fig 1. Thermal transitioning in PTB

4. Case Studies

Some of the fine built examples of the past were PTBs that have displayed a strategic approach to optimize energy consumption along with high standard of experiential quality. The *Hajj Terminal of King Abdul-Aziz International Airport, Saudi Arabia* has adopted an innovative design solution of 'selective environments' with two distinct set of spaces. These were enclosed air-conditioned spaces meant for passenger processes and the second set was a huge naturally ventilated and uniformly day lit waiting space, covered by a mammoth roof canopy. This led to cost effectiveness and minimized use of energy for operations

Stansted airport terminal building (London, UK) is another example where energy used for artificial lighting was minimised by taking advantage of daylighting through fenestrations in the roof and thus achieving a sufficient 3% daylight factor on an overcast day. The roof was freed of any services as they were housed under croft. This allowed the roof to take a free form, with clear double glazed roof lights that cover 8% of the roof area, maximizing daylight entry into the deep floor plate. Issues pertaining to glare, contrast and solar gains within the interior spaces were ingeniously solved by the provision of metal perforated panels, with a light transmittance of 50%, underneath these glazed roof lights.

The *New Bangkok International Airport, Suvarnabhumi* attempted to optimize energy use with an approach of thermal stratification. The large voluminous cross-sectional space has been taken advantage of, to address thermal comfort at the occupant level rather than the whole volume. The total volume of the building was split into unconditioned zones at higher levels and cooled occupied zones at low levels, thus drastically reducing the total cooling demand. As per Lechner [8], by optimizing the building envelope and improving the cooling system, the total cooling demand reduced by 35%, and an annual cooling demand of 513kWh/m^2 was achieved.

The success of these projects lies not only in their response to passenger comfort achieved through an architectural solution for minimized use of energy for operations, but also in terms of the architectural identity of spatial experience and image of a national gateway to international passengers.

5. Fieldwork

The field work covered the S.V.P. International Airport, Ahmedabad (SVPIA) and the Vadodara Domestic Airport, Vadodara (VA) (Fig2), characterised by distinct architectural language but having similar climatic conditions due to their geographical proximity. Physical measurement, data-logging and recording (for temperature, humidity, illuminance); comfort survey of passengers and staff; and semi structured interviews (with engineers, officials and operators) were carried out to understand the airport operations. The study was conducted in August 2007 during the warm and wet period of Ahmedabad.

Fig 2. S.V.P. International Airport, Ahmedabad (left); the Vadodara Domestic Airport (right)

Field Work Observations and Inferences: SVPIA terminal, on one hand, is a completely air conditioned, unprotected glazed box with a deep plan; with no scope for natural ventilation during favourable seasons. The envelope had poor thermal inertia with large amounts of infiltration, insufficient spatial volumes and inadequate daylight in the interiors for a deep plan building, despite 64% glazing to floor ratio. In contrast VA terminal is a robust building as it gives the operators an opportunity to decouple the air-conditioned interiors from the external environment during the harsh months and re-couple them with the environment during moderate months through natural ventilation. This is possible because of the location of windows and presence of a courtyard allowing cross ventilation.

The total annual energy consumption for SVPIA was approximately 263kWh/m^2 (equivalent to annual load of 5.9kWh/pax) and the consumption of VA, 183.5kWh/m^2 (equivalent to annual load 4.5kWh/pax)[10]. VA performed much more efficiently as compared to SVPIA. The better performance of VA building fabric is owing to optimized shading devices, appropriate window to floor ratio, thermal inertia of the building envelope, provisions for natural ventilation, appreciable spatial volumes for various passenger processes, provisions for sufficient daylight in the form of clerestory windows and an open to sky courtyard that brings in more options for daylighting. In the case of the SVPIA the air-conditioning of the terminal alone contributed to 66% of the total energy consumed by the PTB. Although the loads cannot be directly compared due to the variation in the size, operation patterns and passenger capacity of the airports, they convey a broad assessment of performance as an indicator of efficiency of the terminal. The field work revealed that the poor performance of the SVPIA PTB in terms of passenger discomfort and energy consumption can be categorically attributed to the design of the building and its envelope

Comfort Survey: A survey involving 128 respondents was conducted in order to understand the comfort judgments and preferences of passengers at various stages of passenger processes, at different locations in the SVPIA terminal. According to the comfort survey, the comfort votes ranged from temperatures 24-32^{o}C in an air-conditioned environment of the PTB. While transitioning, passengers expressed a higher thermal tolerance from a familiar local environment to a conditioned environment, and a higher comfort expectation when transitioning from one conditioned space to another. These interpretations could be used to support the widening of the indoor comfort temperature range while allowing parts of the terminal to be naturally ventilated, rather than entirely air-conditioning the PTB or alternatively adopting a mixed mode approach.

The survey informs that on one hand there are high thermal expectations from passengers in term of provision of air-conditioning in airports. On the other hand, high thermal tolerance levels in transient spaces can be observed in terms of comfort votes. This confirms acceptability of indoor temperatures that can be easily achieved by passive design of the built environment for most periods of the year.

6. Contextual Research

6.1 Climate: Ahmedabad (23.67^{o}N Lat., 72.63^{o}E Long.)

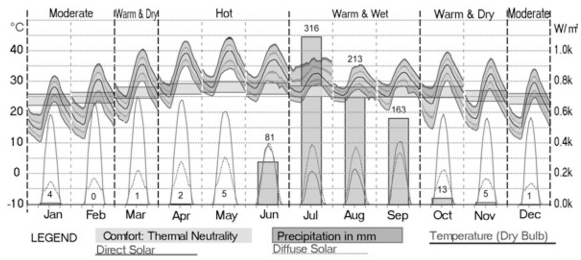

Fig 3. Climate data for Ahmedabad (Source: Meteonorm v6. WeatherTool)

Weather data for Ahmedabad (Fig3), highlights four distinct periods: a *'moderate'* period (December to February with a mean daily ambient temperatures of 21-23^{o}C), a *'hot'* period (April to June; 32-34^{o}C), and a 'warm' period' (25-29.5^{o}C) that can further be classified on the basis of humidity levels and precipitation into '*warm and dry'* (March, October and November) period and '*warm and wet*' period(July to September). The annual average relative humidity is around 52% except during the 'wet' period, which witnesses an average of 79%.The 'moderate' and 'warm and dry' periods record an average of below 10g/kg absolute humidity causing discomforting dry spells especially during mid-day.

The 'semi-arid climate' of Ahmedabad is characterized by high outdoor air temperatures, intense direct solar radiation (4.4 to 7.3kWh/m2 daily global solar radiation), fairly high humid and dry months, high diurnal temperature difference (12 to15K), an average precipitation (rainfall) period and fairly good wind velocities (3.2m/s annual average) almost all year round predominantly from south west. The annual average mean sky luminance is about 25,500 lx. Thus 1 to 2% of the outdoor illuminance would be sufficient to provide an indoor illumination level in the range of 300 to 500lx

6.2 Thermal Comfort

The monthly thermal neutral temperature for Ahmedabad based on Auliciems' empirical equation [9], with a +/-2K gives an adaptive comfort range of 22-30.1^{o}C over the annual cycle. However, as per Nicol [11], when occupants have the ability to adapt to familiar environment of free running buildings, this range can be broadened to +/-3 ^{o}C for new buildings or renovations and to +/-7 ^{o}C for existing buildings. This adaptive comfort range can be considered as the design range for set points of air-conditioners or mechanical cooling/ heating devices as per seasonal variations. Thereby, substantial energy savings can be made by considering thermal comfort of an occupant with respect to climate while designing a building.

6.3 Vernacular and Modern Precedents

A significant wealth of knowledge can be drawn from the climate responsive buildings of Ahmedabad in the past, integrated well with the environment. In these built examples, cool indoor spaces in harsh climatic conditions have been achieved by resisting solar heat gain and permitting heat loss. The design approach that helped in achieving this included consideration of orientation towards prevailing wind and sun, high thermal storage capacity, provisions of transitional spaces like courtyards, adorned by screens or 'jalies' that allow good air movement, deep shading devices like brises-soleil, use of water features and plantation and several other passive measures

A study conducted by Ali and Yannas [12], measured temperatures in naturally ventilated spaces in exemplar modern buildings in Ahmedabad such as IIM, Sarabhai House and a few others. The recorded temperatures ranged from 27 to 33^{o}C while the corresponding range of external temperatures ranged from 26 to 36^{o}C in the month of August. They stated that despite the high temperature, the occupants felt comfortable due to good air movement indoors, which was enhanced by provision of fans.

The potentials of passive cooling strategies like evaporative cooling within indoor spaces can be best demonstrated in the vernacular archetype of the Stepwells and Passive Downdraught Evaporative Cooling (PDEC) system with micronisers of the Torrent Research Centre (TRC) in Ahmedabad. Indoor air temperature was recorded as 10 to 14^{o}C below external peaks (38^{o}C as per Ford,[13]) with the exclusion of the 'warm and wet' period. In TRC the passive design approach led to electrical energy savings of around 64% despite the fact that internal gains ranged from 20 to 25W/m^{2} on each floor (Thomas and Baird, 2004).

7. Design Program for New Ahmedabad International Terminal (NAIT)

7.1 Project Brief:

The international passenger traffic in Ahmedabad has been growing at a rate of 15% per annum since 2004, and is estimated to escalate by another 7% by 2012 [16]. Given the inadequacy of the existing facility (SVPIA), a proposal for constructing a new terminal has been developed. The terminal, designed for a total annual passenger capacity of 0.86million would have a peak hour passenger (PHP) of 500 passengers each for arrival and departure. The design had to take into consideration the proposed expansion of the terminal after 2013 and also aimed at enhancing its capacity to 0.97million pax by 2025, with a PHP of 850passengers each on arrival and departure.

NAIT can be categorized as a 'small airport' and would have to be designed within the standards defined in Airport Development Reference Manual (ADRM) of International Air Transport Association (IATA) for small airports.

The details of the project brief are as mentioned below:
Client: Airport Authority of India (AAI)
Peak hour passenger (PHP) Traffic :
Arrival and Departure Passenger = 500 each
Peak day to average day traffic = 1.32: 1
Design Year = 2012-2014
Total annual passenger capacity (pax) = 864,000pax
Area required = 27,331sq.m

7.2 Current Proposal for New Ahmedabad International Terminal (NAIT)

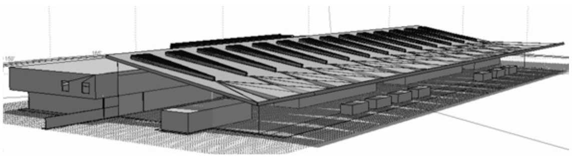

Fig 4. Current proposal for NAIT

A current proposal for NAIT (Fig4) that has been developed for client AAI, aims to provide facilities and experience that meets international standards and is touted to be an energy conscious solution.

The proposal is a linear terminal with singly loaded pier arrangement for four in-contact aircraft parking stands with options for doubly loading, pier arrangement. The terminal is aligned to the runway with longer sides oriented to the southeast-northwest direction. The PTB is designed to be a 'one and half level' terminal with waiting and boarding areas at the mezzanine level and the rest below. The terminal design is aimed at simplicity in flow, flexibility in passenger areas and aircraft movements and compatibility of the layout.

As a part of this study, the proposal for the new terminal was analysed for its orientation, planning, internal gains, internal layout, zoning design of building envelope and building materials. The building envelope comprised of PVB laminated clear single glazing (18mm) on all sides of the landside concourse with a roof overhang as solar control element and roof lights. The airside facade comprises a fully glazed north-west facade protected by louvers and steel mesh. A 64% glazing to floor ratio has been adopted for the terminal including the openings on the roof.

A building performance study was conducted using various simulation softwares such as TAS, Ecotect, Radiance to analyse the design of the building envelope in protection from heat ingress, excessive solar radiations, allowance of sufficient daylight and to determine energy consumed in maintaining comfort conditions.

A shading analysis of the terminal in Ecotect software for various days in the year at 9:00am, 12:00pm, and 5:00 pm was tested to see the performance of the building envelope in providing protection from direct sunlight. From the tests as in Fig (5), it was concluded that the building envelope lacks appropriate shading devices and fails to give complete solar protection at most times of the year. The insolation analysis shows 30% of the total solar gains from direct radiation. The roof design defectively failed in providing thermal and visual comfort owing to poor solar control, leading to overheated interiors, resulting in high cooling loads on the air-conditioning system, combined with problems of glare and contrast within the interiors.

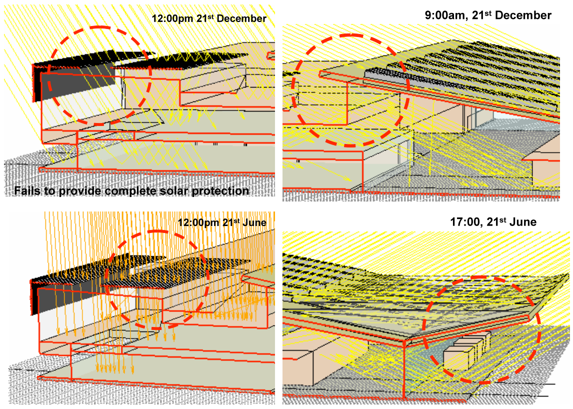

Fig 5. Solar Penetration through building skin of NAIT

The developer's proposal was simulated through TAS software, and a detailed schedule of internal gains was calculated for each of the different spaces assuming occupancy for peak hour passenger numbers. Despite the air-conditioning, the operative temperature in some of the zones like airside corridor or arrival lounge, rose to around 29^{O}C due to over exposure to sun on the Southern side.

The total annual cooling load for the proposed PTB was approximately 462kWh/m^2 (equivalent to 9.8kWh/pax/yr) for a 100% night-time PHP and 50% daytime PHP. Thus it is observed that the equivalent annual cooling load consumption per passenger (pax) has increased by 66% as compared to the existing facility SVPIA..

The result of analysis on the current proposal shows that it is an energy intensive structure failing to meet the comfort conditions (enabled by its building envelope), required for the climate of Ahmedabad. The structure due to its poor thermal inertia, lack of appropriately designed shading elements and extremely high exposed facades to heat ingress fails to provide essential comfort conditions for passengers. Thus, this is an example of a developer proposal where the whole building has been considered for mechanical cooling and no scope has been left for any passive means to reduce cooling loads of the PTB.

8. Parametric Research Analysis for a Low Energy PTB.

Significant energy savings can be made by an efficient design supported by efficient systems. Thus it is essential to identify parameters that contribute to an energy efficient design at the outset.

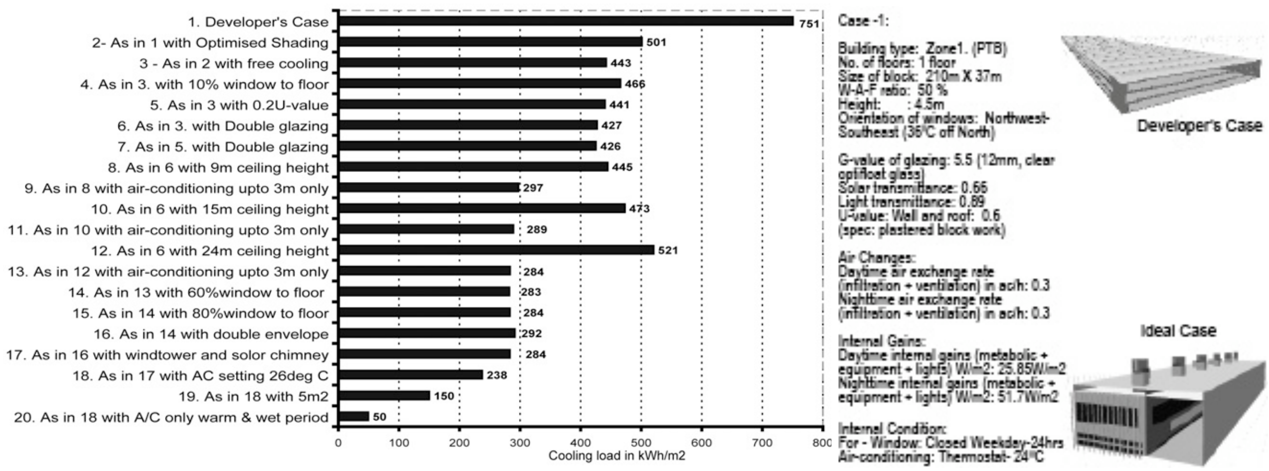

Fig 6. Design strategies applied to test performance of Base case to derive 'Ideal case' (Source: TAS software)

8.1 Environmental design challenges in a PTB

Some of the most prominent environmental design challenges faced in the design of PTB's are deep floor plans; restricted facades as compared to the floor area for ventilation or daylighting; and no control over orientation of the longer sides of the building (in most cases). As a result, the roof becomes the largest mediating building element with the external environment, which can be used skilfully to allow sufficient natural light and ventilation and provide protection from sun, ambient temperature, wind and rain.

This built typology is occupied round the clock at different intervals depending upon the air traffic flow. Owing to the paramount contribution of the internal gains due to high occupancy loads occurring at specific intervals and high comfort expectation of passengers, it becomes more difficult to combat discomforting situations in passenger terminals without the intervention of HVAC system. However, in smaller airport terminals, these issues can be dealt with, and a passive or a mixed mode approach could be adopted.

8.2 Zoning with temperature transitioning

As a responsive design strategy, various spaces in the terminal were combined together as 'zones' based on their function, the nature of passenger activity and process, occupancy, sequential order of spaces and the internal comfort requirements. These zones were characterized independently for their requirement based on spatial quality and thermal environments, area allocation, and layout limitations. The zones (Fig7) can be distinctly identified as: Landside Concourse; Passenger processes; Primary holding area; Secondary holding areas; Airport service offices; Baggage handling area and Service areas. On the basis of relevant literature study for an airport, the target environmental conditions for the zones were determined, with the operative temperature range stretched to meet the adaptive comfort range of the climate in context.

8.3 Analytical studies for a Base case in Ahmedabad:

Thermal simulations for a single zone were performed on TAS software to analyze the potential for a passive or mixed mode building. The thermal simulation approach was employed to study the effect of various parameters such as thermal inertia of the building skin, effect of night ventilation, window to floor ratio, types of glazing, internal gains, ventilation strategies and other parameters governing the design of the envelope. The simulations were carried out for the predicted PHP occupancy for Landside concourse (Zone1). This zone was first modelled as a conventional or developer's case representing a poor design case scenario. Interventions were made to this model by testing each parameter to improve the performance of the base case or developer's case. On the basis of the simulation results, the potential for passive design approaches were understood.

The simulation for the developer's case resulted in a very high cooling load of 751kWh/m^{2f} for .Zone-1. Several parameters were changed sequentially to test for improvements over the developer's case and to arrive at a combination of strategies beyond which there were no obvious possibilities to reduce the cooling loads of the building passively. The 'Ideal case' with the relevant combination of parameters led to a much reduced cooling load of 50kWh/m^2, as seen in Fig (6). The strategies that led to this reduction were optimised shading, free cooling, appropriate u-values for building skin, balanced-stack ventilation, higher room heights for assisting natural ventilation, reducing the cooling set point to 26^{o}C, thermal stratification for cooling up to occupant level i.e. 2m height, and by limiting the HVAC period to the 'warm and wet' period of the year.

The parametric study also indicated that a completely passive or mixed mode approach was possible to only few zones of the PTB owing to high internal heat gains caused primarily due to high occupancy. Zones such as the Primary and Secondary holding areas would require to be supported by an HVAC system to achieve stepped transitioning. Based on the outcomes of the parametric study for Zone-1, design approaches and strategies for other zones were recommended as mentioned in Section 9.

Passive cooling strategies: Drawing from climate and precedent study, potential for evaporative cooling could be taken advantage of, to cool interior spaces when the external temperatures are very high, with help of devices like the Passive down draught cooling (PDEC) system. However, the 'warm & wet' period may require air conditioning or a mechanical cooling device like fans etc to provide thermal comfort as the PDEC system may not be effective during this period and can only act as a ventilation device. In the 'hot' period the PDEC system can be relied on to lower internal peak temperatures from 35 ^{o}C to around

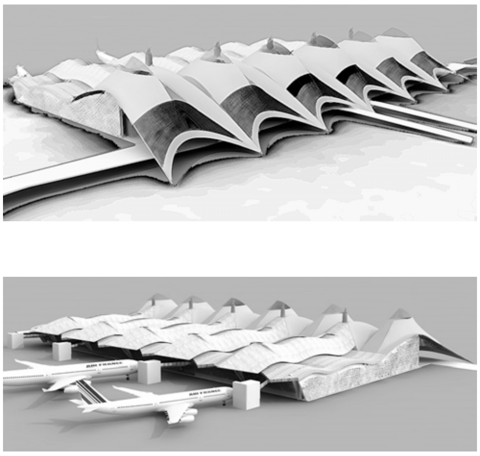

Fig6. Improved proposal for NAIT -Landside view (top); Airside view (Bottom)

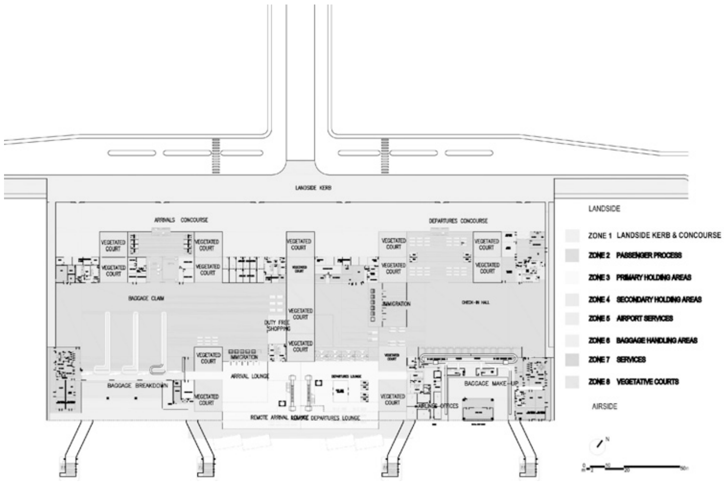

Fig7. Plan of Improved proposal for NAIT

27-29 ^{o}C (to comfort range), as the wet bulb temperatures are much lower than 24^{o}C especially at hottest periods of the day. Similarly in the 'warm and dry' periods the PDEC system shall work efficiently in not only cooling indoors but also humidification of air. Thus, Zone-1 of the PTB can be free running for most parts of the year.

Daylighting Strategies: Shaded Roof opening with 2%, 10% and 20% were tested in Radiance software to understand illumination levels / daylight factor (DF) within the interior. It was inferred from the study that 10% shaded roof openings achieved an average daylight factor of around 7%. Since the requirement of illuminance indoors does not exceed 2%DF, roof lights must be well distributed with a reduced opening to floor ratio of around 2-5%.

9. Design Responses to Parametric Study

9.1 Design Concept for Improved proposal of NAIT

The improved terminal design (Fig6) aims to create specific environments with the help of its building skin to re-couple or decouple with or from the environment based on the requirements of space conditioning, as the passenger traverses from landside to airside and vice versa thus establishing stepped transitioning while traversing (Fig1). These transient environments are primarily aimed at passenger comfort and optimizing energy use.

To achieve stepped transitioning within the terminal, the internal layout of the terminal was divided into different thermal zones as mentioned previously. The improved proposal has been designed to retain the orientation, master planning, site boundaries, layout and other technical aspects of airport systems from the developer's proposal.

9.2 Design strategies:

Temperature transitioning: The thermal simulation and precedent studies indicated that even at peak external temperature, buildings with passive strategies could achieve an internal temperature of 30-32^{o}C. However, owing to higher occupancy gains in a PTB, heat sinks such as vegetation, thermal inertia of the building envelope and the supply of cool and humidified air, have been explored to achieve this range of internal temperature. The evapo-transpiration of vegetation in vegetative courts (Fig 9) and the evaporative cooling in the PDEC system have been relied on to alleviate discomfort passively in the Landside concourse. However, this approach may not be so successful in the warm and wet periods thus, leading to the intervention of mechanical cooling by fan or air-conditioning during some parts of the day when required.

Vegetative courts used as heat sinks have been introduced in the layout strategically to act as thermal buffers and mediators with the external environment. The airport village concept or the airside vegetative courts are meant to be recreating an informal village like atmosphere with spaces of interaction set within the cool vegetative spaces.
The other zones having comparatively higher internal gains could also adopt a mixed mode approach. In the moderate periods night cooling and comfort ventilation could be provided, however mechanical assistance would be required in the rest of the year to achieve target temperatures.

Ventilation Strategy: Balance-stacked ventilation applied (Fig 8), involves air supplied in a cold stack and exhausted out through a warm stack (Ghiaus and Roulet, 2005). This is a combination of wind driven and buoyancy driven ventilation, wherein, cool outside air is caught by wind catchers on the top of the roof owing to positive wind pressures and led through a shaft, to cool the interior spaces. The cold stack takes the form of a PDEC tower with a wind catcher on the top that rotates in the direction of wind, with the help of an aerodynamic mouthpiece. The warmer air of interior spaces combined with negative pressure at the mouth of the exhaust shaft, is sucked out of the room through the shaft. The exhaust shaft is in the form of a solar chimney with the outlet facing the leeward side. The solar chimney is made up of glass, thus the volume of air within gets heated and expels out faster creating a suction effect. Thus, constant air movement and ventilation is ensured.

PDEC system: Considering the evaporative cooling potential of the climate for more than six months in a year PDEC towers with micronisers have been employed. These towers act as wind scoops at the top and have micronisers spraying water that evaporates rapidly and cools the air around as in TRC, Ahmedabad or PDEC towers at the Seville Expo 1992.

Roof: The roof element of the terminal comprises of a double layer that allows air movement between the two layers and entraps air within to increase the heat storage capacity of the envelope

Facades: The building envelope has adopted a double skin strategy. Thus, the facades are protected either by roof overhangs or by screen walls. The screen wall allows diffused light and ventilation and filters dust. The screen wall is designed for 60% aperture size made up of ceramic tubes of different diameters. The size and density of the tubes keep changing from the landside to the airside. The tubes are of smaller diameter and larger densities towards the airside facade to achieve lower thermal inertia. The inner facades of the airport village comprise of glass louvers to enable visibility, daylight and ventilation.

The **Day-lighting strategies** adopted for the building skin are a double layer of translucent fabric with PTFE coating for Zone-1, which cuts down heat but allow uniform light within the terminal; shaded clerestory windows and light tubes/ pipes to ensure homogeneous distribution of light across the floor for the subsequent zones.

10. Conclusion:

On the basis of the above mentioned data and study, it can be concluded that by applying passive design strategies like PDEC systems, temperature transitioning and by adopting an approach of mixed mode in buildings, considerable energy savings can be achieved. This paper also identifies various design responses that have to be adopted by the building skin to achieve stepped temperature transitioning for identified zones in the terminal, for the climate in context.

The study also proves that in a building like an airport terminal, the roof, which is one of the largest elements of the building, can be put to effective use in ventilation, daylighting and temperature conditioning.

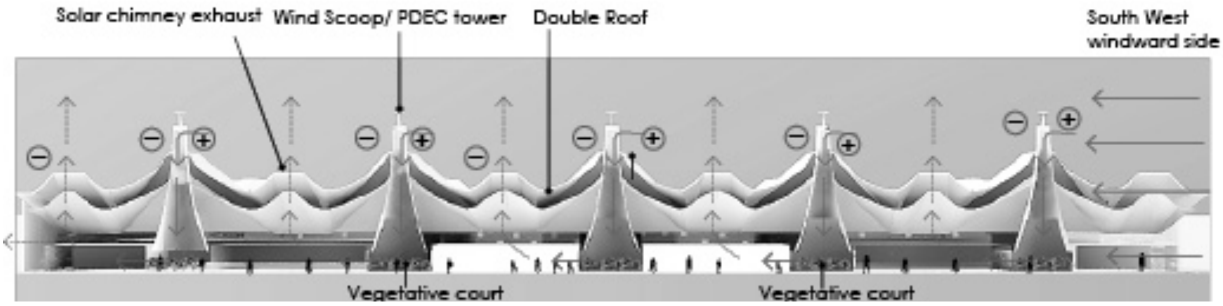

Fig 8. Cross-section through improvised proposal for NAIT showing the ventilation strategy.

Fig 9. Cross-section through improvised proposal for NAIT showing vegetative courts

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