The New Integrated Mumbai International Airport
An Exercise in Energy Saving

By Kishore S. Kalghatgi
Chief Engineering Manager (Mechanical)
Larsen & Toubro Ltd., EFF (EDRC) Division, Mumbai

The Chhatrapati Shivaji International airport at Sahar, Mumbai is undergoing major expansion and upgradation to meet the growing demands of the aviation industry in Mumbai. A new integrated terminal is being built to cater to both the international and domestic operations. When completed, it will cater to 40 million passengers per annum and handle one million tonnes of cargo per annum.

This is a brown field project and covers modernization of both airside and landside facilities. Airside works include upgrading of runaway facilities such as rapid exit taxiways, aprons and relocation of the ATC (Air Traffic Control) tower to enhance airside operations. Landside works include the construction of the common integrated Terminal building and a dedicated link from the Western Express highway to the Terminal at Sahar.

The airport design objective has been to provide international quality facilities with a high level of passenger hospitality and to reflect the heritage and traditions of India.

The entire EPC (Engineering, Procurement & Construction) contract is scheduled for completion by 2013.

Project Description

The airport building is spread over a carpet area of 44 lakh sq ft (0.41 million sq m).

It covers major areas like:

Concourse	Arrival corridors
Arrival halls	Gate lounges
Swing gates (Intl/Domestic)	VIP entrance
Immigration	Transit facilities
Transfer desk	Baggage services
Baggage claim retail circulation	Customs check-in
Main computer rooms	Ground handling agents
Facility maintenance	IT server rooms
Airport operations control centre	Airside canteen
Baggage handling systems	Airline offices
Aerobridges	Transit hotel

As can be seen from *Figure 1*, the Terminal building plan, the 4 piers give a radial form to the building. The piers house the departure lounges, arrival corridors and other service spaces. The central portion, called "processor" houses immigration, check in, baggage claim, retail, duty free and arrival hall areas.

The Terminal building has 3 levels (floors) at the piers and 4 levels at the processor. The roof slopes from the piers to the

About the Author

Kishore Kalghatgi is a mechanical engineer from VJTI, Mumbai with an M.Tech in heat, power and refrigeration from IIT, Powai. He has 28 years of experience having worked in Blue Star Ltd., Blue Star Design & Engineering and has also had a long stint in the Middle East.

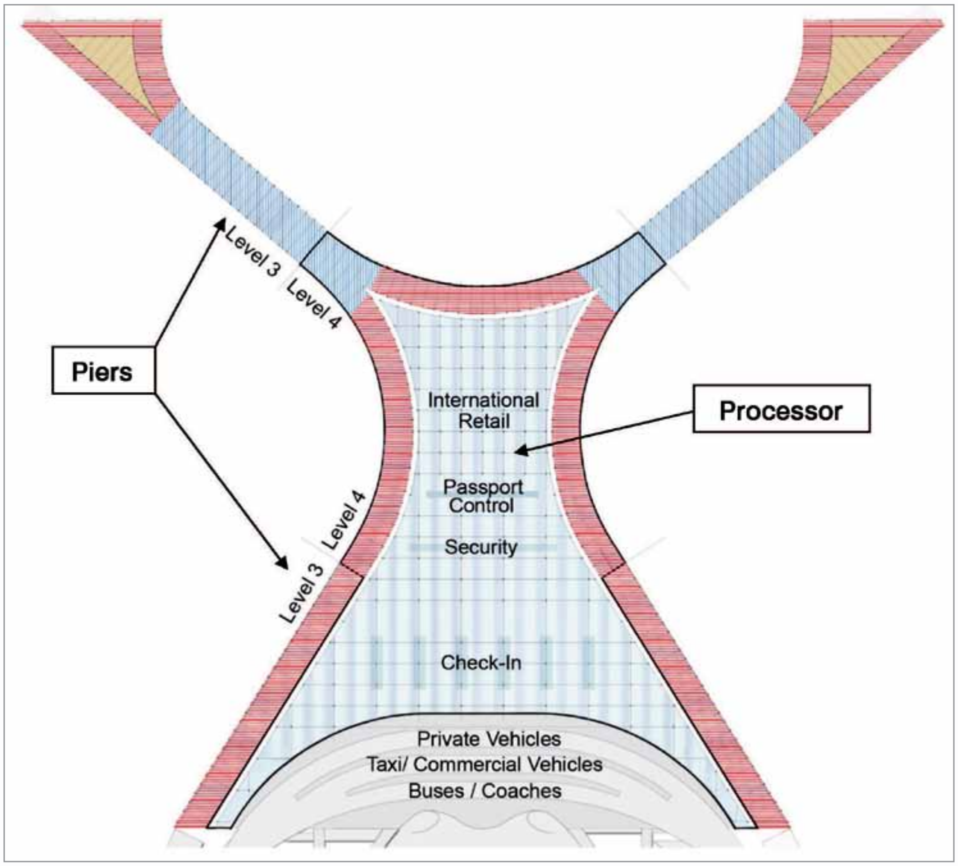

Figure 1: Plan of the teminal building

processor to provide a level change from 3 to 4.

Design Criteria

The HVAC system has been designed to maintain indoor conditions of 23°C±1°C, 55±5% RH.

The occupancy and fresh air loads are based on National Building Code (NBC) - 2005 recommendations. Some areas like retail and duty free have been designed with higher lighting loads considering specific requirements like spot/focused lighting.

The Terminal building has 13 zones with each zone having a mechanical room which houses the AHUs and the heat recovery unit for that zone. The heat recovery unit consists of the enthalpy wheel and supply/extract fans with filters. Some mechanical rooms also include a 100% treated fresh air unit supplying treated fresh air to tenant spaces like retail, duty free, food & beverage, CIP/VIP lounges etc within that zone. These units draw in fresh air from the heat recovery unit within the same mechanical room.

The mechanical rooms are located at ground level (level 1) in the piers and at first basement level in the processor area.

The Terminal building roof is a composite construction with 5" (125 mm) thick polyisocyanurate insulation with a R30 thermal resistance value - sandwiched between 1/2" (13 mm) thick fibre boards thus giving a low thermal mass roof. The roof external surface is covered with a membrane having high emissivity coating to reduce the heat island effect.

The curtain walls and skylight is double wall glazing panels with a U value of 1.65 W/(m^2.K) and a shading coefficient of 0.26. It is provided with a low e-coating on the inner surface of the outer glass with 60% light transmission value. The non-view portions of glass are ceramic fitted to improve its solar characteristics. These special glass characteristics have ensured low overall solar heat gain values.

The life safety systems like smoke extract system and lift/stairwell pressurization systems are based on the respective NFPA codes. The smoke extract systems for public areas include smoke extract fans designed for high temperature (300°C) and fire rated ducts.

Vibration isolation devices are provided for all equipment like AHUs, FCUs, Fans, Pumps etc. All pipe connections to AHUs, FCUs, Chillers and pumps are provided with pipe flexible connectors to prevent transmission of equipment vibration to the piping system.

The Terminal building design is based on Zone 3 seismic criteria. All HVAC equipment including ducting and piping are provided with seismic restraints to meet the seismic requirement.

Details of HVAC system

The HVAC system description is briefly as under:

The AC plant is strategically located in a Utility block about 1500 m away from the Terminal building along with all other major services like Sewage Treatment Plant, DG sets, Transformers etc. The HVAC equipment consists of six numbers 2500 TR centrifugal chillers (all working) with space provision for the 7th standby chiller, horizontal split case type primary / secondary chilled water pumps and condenser water pumps in all (six working + one standby configuration) with ancillaries like air separators, pressurization unit and expansion tanks. Induced draft cooling towers are placed on the roof of the single storey structure plant room.

The Terminal building houses the following equipment:

- 94 nos chilled water AHUs with variable speed drives
- 105 nos chilled water ceiling suspended AHUs with constant speed drives – for tenant spaces
- 7 nos 100% Treated Fresh Air Units dedicated for tenant spaces.
- 14 nos Heat Recovery Wheel units with enthalpy wheel, supply/exhaust fans and filters
- 442 nos Ch W FCUs – mostly catering to fixed bridges.
- 4 nos Precision AC units, also called Computer Room AC

(CRAC) units for Main Computer rooms

- 52 nos smoke exhaust fans
- 101 nos stairwell and liftwell pressurization fans
- 29 km of chilled and condenser water piping
- 3.1 lakh sqm of ducting

Some critical areas like airport operations control centre (AOCC) and MCR have been provided with a standby DX system which can be operated on emergency power supply from DG sets in the event of mains power failure. The AHU for AOCC and the CRAC units for MCR are provided with dual coils-(chilled water and DX) for normal and emergency duty.

Air Distribution System

Medium pressure rectangular ducting (upto 1000 Pa pressure) is used to convey dehumidified air to conditioned spaces. This has helped reduce duct dimensions and shaft sizes, though at the cost of increased pressure drops. To compensate, all AHU supply/ return fan motors are speed controlled by VFDs with VAV boxes at air distribution points. The lower speed of the fans at part loads helps reduce power consumption.

Return/ ventilation ducting is low pressure type (upto 500 Pa pressure). All ducts are rectangular and are concealed type.

All AHUs are typically 2-tier construction, with supply fan section and filters in the lower tier and exhaust fan with exhaust plenum in the upper tier.

Tenant areas like Retail, Duty Free, CIP/VIP lounges and Food/ Beverage are provided with dedicated FCUs / ceiling suspended AHUs which are constant speed type.

Jet nozzles and air towers have been selected for primary air distribution in major (large volume) public areas like concourse and departure lounge where false ceiling heights range from 7 m to 15 m. Cold air is supplied at 3m level, gathering heat from occupants, lighting and low level glass areas. The warm air moves up, picking heat from higher level glass areas and is collected by return air slots in the false ceiling. This concept of air stratification permits higher temperature in unoccupied higher elevations. See *Figure 2*.

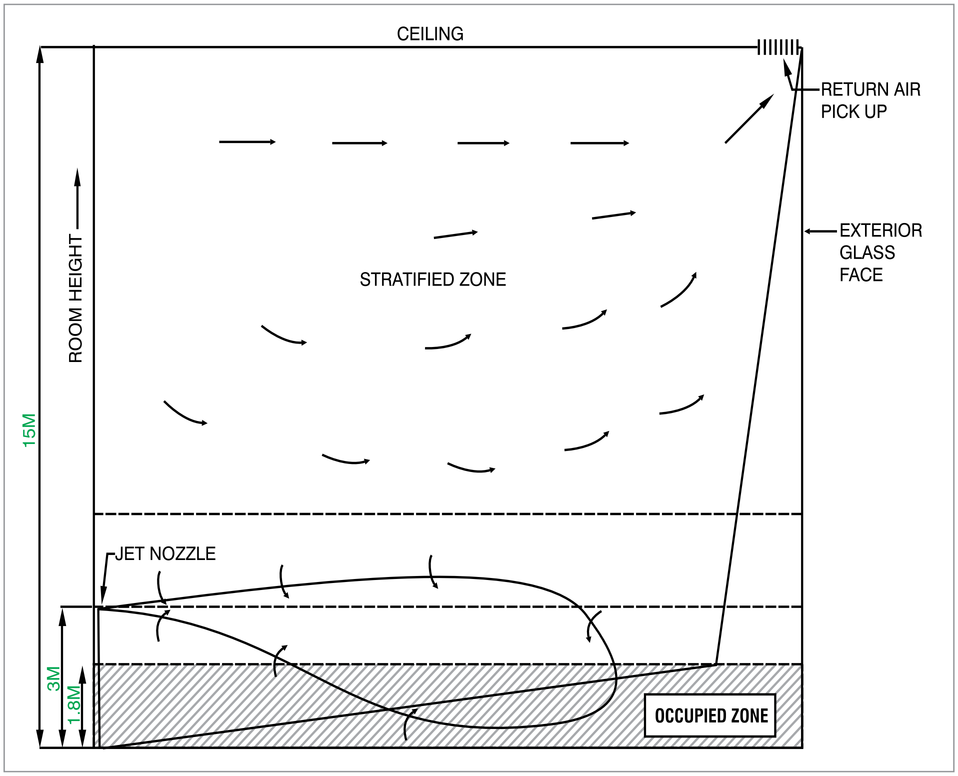

Figure 2: Air distribution pattern

Acoustic Treatment

The mechanical rooms are lined with sound absorbing acoustic material and sound barrier to prevent noise transmission to adjacent public spaces where sound levels of NR 40 are maintained. All supply/return ducts are provided with sound attenuators. Acoustic lining is also provided for the air distribution ducts after the VAV boxes.

Air Filtration

The fresh air filtration system needs special treatment to combat the effects of aircraft exhaust fuel fumes that could be present. For this purpose, gas-based molecular filters have been used, which contain activated carbon and alumina impregnated with $KMnO_4$ (Potassium Permanganate) in equal proportion, contained in stainless steel canisters. On the upstream side, prefilters (MERV 8) and bag filters (MERV14) have been used.

All air intake/exhaust louvers have been placed along the periphery of the building instead of on the roof to maintain the architectural intent.

Chilled Water Distribution System

Chilled water is generated in the HVAC plant room at 42°F(5.5°C) and returns back from the system at 56°F (13.3°C). The higher ΔT allows for lower flow rates and smaller pipe sizes in addition to reducing pumping power.

Chilled water from the HVAC plant room is conveyed by 1100 mm diameter chilled water pipes to the Terminal building. The pipes run through underground, covered trenches and, in some places like road crossings, are buried. The trenches are routed under the mechanical rooms in each zone. Each mechanical room has a tap-off from the headers with isolation and balancing valves. This tap-off caters to the AHUs in the mechanical room and also rises to upper levels to cater to the ceiling suspended AHUs/FCUs of the respective zones.

Pressure independent dynamic balancing valves (PIDBV) modulate the water flow through the cooling coils of the AHUs /FCUs. The chilled

continued on page 84

continued from page 82

water piping is insulated, the insulation thickness selected to satisfy two criteria – (1) Temperature drop not to exceed 0.5°F over the pipe run and (2) No condensation.

Building Automation System

The HVAC control system is versatile and can operate on a standalone basis though it has capability to "talk" to the building management system and can be monitored and controlled by the BMS.

The air distribution system controls for AHUs consists of temperature sensor in the return air path which regulates the opening and closing of the individual VAV box dampers. The resulting variation in supply duct pressure is measured by duct pressure sensors which in turn regulate the respective AHU supply fan speed via VFD controllers.

CO_2 sensors in the return air system regulate the opening and closing of the motorized control damper on the AHU fresh air duct opening. (demand control ventilation)

The chilled water distribution system controls for AHUs have a temperature sensor in the supply air duct which regulates the opening and closing of the PIDBV. The resulting pressure changes in the chilled water headers are measured by the pressure sensor which provides pressure feedback to the secondary chilled water pump VFD controllers which regulate speed to maintain set pressure, thus saving energy.

Some Specific Design Aspects to Save Energy

Chiller Selection

It is quite well known that HVAC plant rooms rarely operate at their full load capacity. Keeping this in mind, AHRI recommends evaluating chillers based on NPLV (Non Standard Part Load Values) where the chiller is assumed to be working at loads of 100%, 75%, 50%, and 25% of total capacity at 1%, 42%, 45%, and 12% respectively of the total working hours and an average iKw/ Ton worked out.

If the load pattern of the plant is known, this concept can be extended further by considering actual number of hours that the AC plant works at various part loads and using appropriate iKw/ Ton figures.

For the airport project, as the cooling load calculations were done on HAP E20II Carrier software, the load pattern could be generated for every hour of the year. To make calculations more realistic, the peak loads for 24 hours of a typical day of each month was taken (software generated). We thus had 288 figures of peak cooling load tons. (24 hours of a typical day x 12 months).

These figures were used to work out the number of operating chillers and their percentage loading. The power consumption of the chillers varies with the condenser water inlet temperature, which in turn depends on the ambient wet bulb. Hence, the iKw/ Ton figure for the 288 points was calculated considering the corresponding ambient wet bulb temperature at that hour.

This exercise helped arrive at the total power consumption for all the chillers. The annual power consumption cost plus the capital cost of the chillers were the governing factors for zeroing in on the make/model of the chillers.

Nowadays, chiller manufacturers can come up with a variety of condenser/evaporator/compressor combinations for varying capital/ running costs and this exercise helps the owner make an informed decision.

While carrying out the above exercise, it should be noted that AHRI tolerances on iKw/TR figures for a chiller range from 5% at full load to 7.1% at 70% load.

A number of other factors in chiller selection can affect this decision making process, notable among them is the fouling factors specified for the tubes of the evaporator and condenser.

The "Indian' fouling factors (FF) normally specified and considered are 0.0005 for evaporator and 0.001 for condenser (hr. sqft. °F/Btu). A chiller machine, selected for the afore-mentioned FF can, in reality, operate at FF which are upto 50% of the above values, if the quality of water is controlled and proper maintenance procedures followed. In which case, annual power savings of around 8 lakh (0.8 million)kWH is possible for an AC plant of this size.

Interestingly, higher savings – upto 12 lakh(1.2 million) units - is achievable if the basic chiller selection itself is carried out at reduced fouling factors. This is because the gear drive selection for the same tonnage for two different fouling factors is different as the lifts considered are different. Having an optimized gear drive at lower FF gives better results.

Cooling Towers

In an AC plant, cooling tower selection is as important as centrifugal chillers. CTI (Cooling Technology Institute) is the certifying agency for cooling towers just as AHRI is for chillers. Air quantities handled by a CTI certified tower vis-a-vis a non certified tower can vary vastly.

Like chillers, cooling towers, too, operate at part load most of the time. Under such conditions, if the cooling tower air flow can be reduced to match the load, good energy savings on tower fan motors are achievable. This is possible by use of VFDs (Variable Frequency Drives) for cooling tower motors. The VFDs modulate fan speed to maintain a set condenser water temperature. This is particularly true for cold climates where condenser water temperature cannot be permitted to fall below a certain value to avoid compressor surge.

However, on the flip side, if the fans work at full capacity even at part load, lower condenser water temperatures can be achieved. A 1°F lowering of condenser water inlet temperature to the chiller can reduce annual chiller power consumption by up to 10 lakh(1 million)kWH units for a plant of this size due to lowering of chiller iKW/TR figures.

The resultant saving in chiller power consumption far outweighs the savings from VFD operated cooling tower fans. Based on this consideration, VFDs were not used for cooling tower fans for this project.

Exposed condenser water piping on the roof can be a source of unwanted heat collection into the condenser water system. Even a rise of 0.05°F can adversely affect iKw/TR, albeit marginally. It would be advisable to carry out some minimal insulation on the piping to avoid this heat gain. The payback period for the

continued on page 86

continued from page 84

additional cost of insulation would be less than a year.

Another good source of energy saving is by pumping the condensate drain collected from the AHUs into the cooling tower sump. The lowering of the cooling tower sump temperature by a fraction of a degree results in a small reduction in the annual power consumption of the chillers - enough to make this a worthwhile exercise. Simplicity of the scheme should be the criteria for implementing this system. The condensate collection tank should be easily and conveniently locatable and the pumping distance to the cooling tower sump should be within reasonable limits.

Enthalpy Wheels

An airport being a high occupancy area, large quantities of fresh air are pumped into the building with a matching exhaust air quantity. In this project, the fresh air intake is of the order of 10 lakh (1 million) cfm. Energy conservation demands that the energy in exhaust air be recovered to cool the outside air.

Enthalpy wheels have a payback period of 2 to 3 years and hence are used in this project.

The enthalpy recovered varies over the year based on outside conditions. It should be noted that heating and humidification occurs across the enthalpy wheel during late evening to early morning hours from December to March. At such times, it would be advisable to shut off the enthalpy wheel operation and bypass the air streams around the wheel. This would also help to reduce fresh air fan energy consumption as air pressure drop across wheel is quite high – of the order of 0.8" WC(200Pa).

It is customary not to consider the cooling load savings due to heat recovery for calculation of the plant capacity. This is because the cooling load reduction can vary widely over the year due to changes in outside weather conditions and secondly, the outside air quantity itself varies as it is controlled by CO_2 sensors (demand control ventilation)

The moisture extracted by the enthalpy wheel from the fresh air reduces the amount of condensate generated by the cooling coils.

The temperature and humidity conditions of the exhaust air as it leaves the enthalpy wheel are at all times better than that for ambient air. However, it is laden with CO_2 at 700 ppm. Instead of exhausting this air directly, it can be used to ventilate unoccupied areas, say parts of baggage handling system, to pick up the enormous amounts of motor heat generated there. Some savings in capital and running costs for the supply ventilation fans can be achieved.

Summary

An integrated airport Terminal of this nature operates on a 24/7/365 basis catering to peak international passenger load in the late night hours and domestic passenger load during the day time. The annual power consumption for HVAC services alone could be of the order of Rs 90 crores. It is necessary that the design process takes care of the widely fluctuating loads keeping a strong focus on energy conservation at all times. ❖