# HVAC System Design for Super High-Rise Buildings

*The earliest high-rises in Mumbai - Air India, Oberoi Sheraton and Indian Express at Nariman Point*


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**Editor's Note**

Pankaj Dharkar & Associates are presently involved in MEP design of several tall buildings under construction in India and some of them are:

| | | |
|---|---|---|
| 1. | India Tower, Mumbai | Tallest Hotel, 705m high |
| 2. | Orchid Crown, Mumbai | Three Residential Towers, each 337m high |
| 3. | Palais Royale, Mumbai | Residential, 333m high |
| 4. | Orchid Heights, Mumbai | Two Residential Towers, each 328m high |
| 5. | Orchid Turf View, Mumbai | Commercial & Residential, 273m high with 74 floors |
| 6. | City View, Bengaluru | Mixed Use Hotel, Retail & Offices, 210m high |
| 7. | Oberoi Commerz, Mumbai | Hotel & Commercial, 192m high |

## High Rise Buildings-Indian Scenario

Since the dawn of history, man has been trying to build the 'tallest building', 'tallest tower' or 'tallest structure' in the world. One school of thought continues to believe that tall buildings around the world are created mainly as a symbol of vision, determination, innovation and achievement.

During the first 90 years of this century, USA dominated the race for the title of the tallest building in the world, and constructed a range of famous buildings. But since the ninetees the USA has got some stiff competition from Asian countries. Today, several countries are in the competition for constructing the tallest building.

According to the Emporis Standards Committee, today the world's Top Ten high-rises are scattered across the globe in Taipei, Shanghai, Kuala Lumpur, Chicago, Hong Kong, Guangzhou, Shenzhen, Canada and New York. On January 4, 2010, Dubai unveiled the world's tallest building – the 'Burj Khalifa' having a height of 828 metres. It has been declared recently that Kuwait is building the world's tallest tower at 1,001 metres in Madin at Al Hareer.

India clearly has a long way to go in a world that's increasingly embracing high-rises as an acceptable solution to house a growing population on a limited land mass. We were lagging behind in the development of high-rises compared to other countries till now. Given the

### About the Author

**Pankaj R. Dharkar** has 30 years of experience in HVAC and has designed over 3000 projects for various applications in India and abroad. He is the the past president of ASHRAE W.I. chapter and past national president of ISHRAE HQ. He is on the committee of BEE to promote ECBC and presently a member of ASHRAE Nominating Committee. Currently he is planning several green and sustainable buildings.

population growth in India and the increasing pressure on land in urban metros over the last few decades, we have realized that we cannot afford to lag behind anymore but build tall. In the last five years Indian cities have shown considerable growth and progress in this direction and several projects are now in the pipeline.

Specially, in a city like Mumbai, where availability and access to land is at a premium, it is essential that maximum economic benefit be derived from the limited space. In such cases, high-rise buildings hold the potential for larger real estate development, while being financially viable. This is the reason most of the super high rise buildings are being developed in Mumbai.

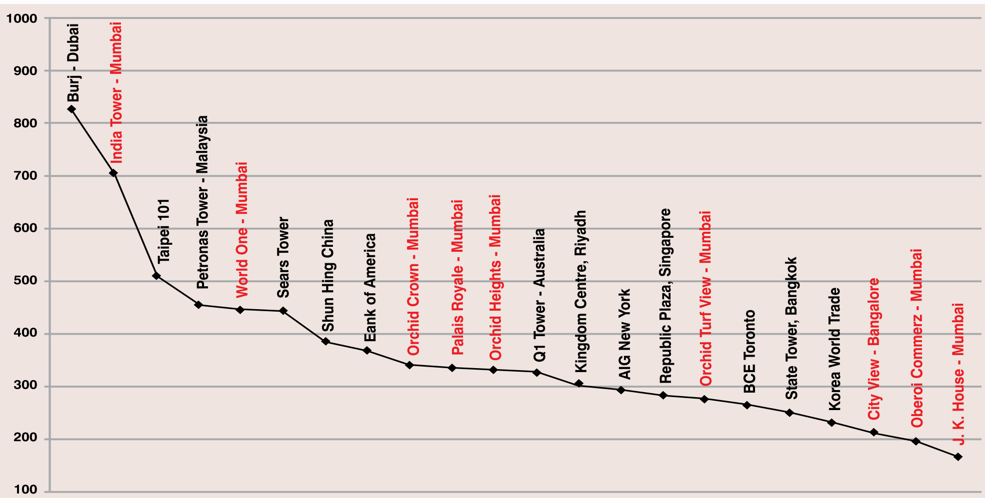


*Figure 1: Height of some high rise buildings given in metres*

## Super High Rise Buildings

ASHRAE Technical Committee for Tall Buildings TC 9.12 has defined "A tall building as one whose height is greater than 300 feet (91m).

The recognition of the tallest building in the world, is the responsibility of the Council on Tall Buildings and Urban Habitat (CTBUH) today, which has been set up to report and study all the aspects of construction of tall buildings

The Council on Tall Buildings and Urban Habitat (CTBUH) defines a tall building as one in which the "tallness" strongly influences planning design or use.

By certain other standards and estimations, buildings are classified as high-rises when their heights range from 35-150 metres, while anything above 150 metres might be classified as a skyscraper or super high–rise building.

## Types of High Rise

***Commercial Tall Buildings:*** These types of buildings are entirely for commercial use having multi tenant offices at various levels. The core in the centre of the building is common for the tenants at every level with respect to supply of ducting, chilled water/ refrigerant piping and other MEP services. The central core does impose challenges for pressurization of lobby / lift and additional challenges for transfer of services at lower levels.

***Residential Tall Buildings:*** Residential tall buildings are more common and cater well to the needs of people in a densely populated country like India. These types of tall buildings are only for residential purposes and have mainly two types of area:

a) Apartments (owner's area)

b) Public Amenities (common areas which includes foyer, lobby, club house etc)

*Photo courtesy: Palais Royale, Green Residential Tower in Mumbai*

Residential towers usually have a number of shafts catering to each flat for different MEP services, while the lift lobbies and other common areas are served separately.

***Mixed-use Tall Buildings:*** Mixed-use buildings have offices/ retail/hotel/service apartments etc in the same high rise and are important today because they enable the most efficient use of building and land space. In such buildings, retail, offices and hotel public areas are at lower levels while the guest rooms and service apartments are at upper levels.

Buildings conceived for mixed use for residential, recreational and commercial purposes can actually be energy efficient as they ease pressure on land, while freeing up the surrounding area for creation of infrastructural facilities and landscaping purposes.

Additionally, with varied services and amenities offered potentially under 'one roof', there is an ease in urban sprawl with a larger segment of population serviced by existing public transport and infrastructure.

*Photo courtsey: Orchid Crown, (DB Reality) Residential Tower in Mumbai*

Such mixed use buildings are a challenge for the designers of various services due to diversity in its usage and ownership issues besides safety and security issues.

## HVAC System Design for Super High Rise Buildings

The strategic objectives of good HVAC system design and its management is to provide a comfortable environment and to limit the spread of fire and to control the movement of smoke within the building during an emergency.

HVAC system design for very tall buildings is a specialized application and hence ASHRAE has provided "HVAC Design Guide for Tall Commercial Buildings" for general reference. However, while designing tall buildings in India, importance to the local regulations and city codes needs to be given besides following other standard guidelines. The main standards to be followed are International Building Code (IBC), International Code Council (ICC), and National Fire Protection Association (NFPA) and many others. There are 32 standards for fire fighting and another 132 standards in place for fire fighting equipment as mentioned by the Bureau of Indian Standards. In Mumbai, a special "High Rise Building Committee (HRC)" has been formed to compliment and support the BMC on issues related to very tall buildings.

*Photo courtsey: Orchid Crown ( DB Reality) Residential Tower in Mumbai*

There are stringent guidelines specifying all aspects of compliance as required for disaster, fire safety and structural safety for high-rises in the National Building Code that have to be followed, without which, the mandatory approvals required to develop such projects are not forthcoming.

But the current Indian Standards-National Building Code (NBC) has limitations with respect to providing detailed guidelines for designing of building services for super high-rise buildings. It is likely that in the next amendment of NBC, may be in 2011, the concerned authority will try to address all technical aspects of designing tall buildings.

## Challenges in HVAC System Design

The biggest challenge faced while designing of HVAC systems for very tall buildings is integration of HVAC services with other mechanical, plumbing and electrical services and also working in coordination with Architects, Structural consultants, Façade/

*Photo courtsey : City View, Bengaluru. Mixed Use Building*

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Glazing consultants, Lighting consultants, Landscape consultants, Kitchen & Laundry consultants, Aviation consultants, Acoustic consultants, LEED and Sustainability consultants etc.

The factors playing an important role while designing of HVAC systems are :

- Proper selection of air conditioning system
- Location and size of equipment room
- Optimum utilization of service space: mechanical service floor and shafts.
- Ease of maintenance and its provision
- Stack effect and ventilation / air conditioning of atrium
- Smoke extraction system at each level and from atrium area
- Seismic considerations
- Wind pressure considerations
- Noise transmission and acoustical considerations
- Design and location of cooling towers

## Air Conditioning System Selection

HVAC system selection largely depends on the type of tall building - commercial, residential or mixed use, its topography, the load pattern, energy source availability, structural and architectural constraints besides following the applicable building codes. An air conditioning system falls into two major categories – the first can be the central air conditioning supply system located in a mechanical equipment room that would serve multiple floors above or below. The choice for selection of a refrigeration system is usually limited to water cooled centrifugal machines because of their greater efficiency in terms of energy consumption, controllability, longer life and space savings. The second category can be a local floor air conditioning system that usually serves the floor within which the equipment is located.

### Central Chilled Water System

The chilled water system is commonly used for a commercial building having a shell and core structure. The location of the central plant is crucial for tall buildings as it will affect the structural costs, architectural design, noise pollution, construction time and also the effective functioning of the selected air conditioning system. The chilled water plant can be located below grade, in the basement or in a separate service block which will house the chiller, primary pumps, secondary pumps and other accessories of a chilled water system. Chilled water piping rises from the basements to levels above serving various other levels.

The designing of piping for a chilled water distribution system also needs special care to be taken due to hydrostatic pressure created as a result of the height of the building.

The following factors need to be specially taken into consideration while designing of chilled water system for "Super Tall Buildings":

***Use of PHE to break pressure due to static head:*** A single chilled water riser will not be able to serve the entire building, because of the static pressure created. The pressure at the bottom will rise e.g. for a building having height of 200 metres, vertical risers will create pressure at bottom equivalent to 20.6 kg/cm$^2$. This will lead to selection of all the equipment with high pressure rating, which is not a feasible solution in terms of issues related to design and costing of the project. Hence, we need to break the pressure at an intermediate level with the help of PHE (Plate type Heat Exchanger). The PHE will generate two separate chilled water zones, one between the chiller and PHEs and another between the two PHEs. *Figure 2* depicts the arrangement of PHE for a pressure break requirement. The selection of PHE requires special emphasis to be given to the issue of temperature loss. Temperature drop greater than 1°C should not be allowed, because higher temperature drops will make it difficult to control the humidity at higher levels. While a lower temperature drop across the PHE will increase the size of PHE significantly. Hence one needs to plan the service area for the same accordingly. Other factors which will affect the selection of PHE and the number of breaks in the given height depends on the permissible temperature loss across the PHE, permissible or selected pressure rating of pipes, valves and other equipment, and the building heat load above the PHE.

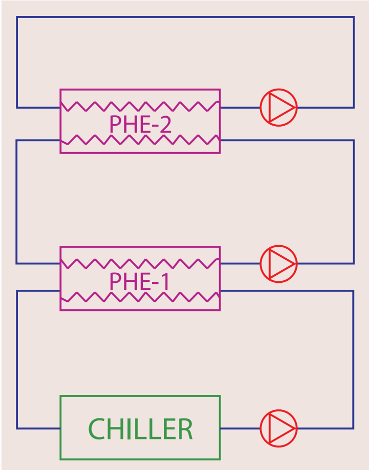


*Figure 2: Pressure break schematic*

***Appropriate Chiller Selection:*** The type of tall building and its overall load profile will determine the selection of the chillers in terms of number and their relative capacities .

The consideration of higher temperature differentials in both chiller and condenser to lower flow of water and consequent reduction in diameter of piping can lead to significant savings in the cost of piping, fittings and valves.

The outlet temperature from the chiller should be selected lower than the conventional selection taking into account the temperature loss in the PHEs and energy consumption.

***Efficient Pumping System:*** Energy use in the pumping system may be reduced by sizing pumps based on actual pressure drop through each component in the system as well as actual peak chilled water flow requirements. The pressure on the pump casing can be reduced by planning equipment which has considerable pressure drop e.g. PHE, on the suction side of pump. Installation of variable speed drives on pumps can help to save energy.

***Efficient Chilled Water Piping System:*** The design of the piping must take into consideration factors like expansion and contraction in the piping and the static and dynamic loads of the piping.

It is necessary to determine the working pressure of the piping and the equipment that is connected to the piping at various elevations in the buildings. This is done by adding the hydrostatic pressure head at the specific location to the dynamic head that can be developed by the pumps at that location.

The working pressure on piping, valves and fittings at various

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levels must be determined to permit proper specification of the piping material. Pipe joints and supports also need to have enough flexibility and strength against the lateral forces in case of a very tall building.

***Selection and Location of Cooling Tower:*** Proper sizing and control of cooling tower is essential for efficient chiller operation. It will be difficult to place the cooling towers on the terrace of very tall buildings as per the conventional design but can be planned in a separate utility block.

## VRF System

VRF systems offer owners and developers considerable savings in energy, costs and space besides providing comfort and convenience. VRF system is a preferred solution for a residential building or a multi-tenant building because of the several advantages it has over a chilled water system or split/window type DX unit, specially in the case of residential tall buildings.

***Advantages over Chilled Water System:*** In the case of a central chilled water system in a residential tall building, a special billing method has to be implemented to be charged as per the individual tenant energy usage. Also, this billing system requires considerable amount of initial investment and manpower. Maintenance and regular service of the central chilled water system is also an additional cost to the occupants.

While in the case of a VRF system, the headache of a central billing system can be avoided by locating the outdoor unit in a mechanical service floor/ refuge floor in coordination with the architects and providing electrical supply to the VRF through individual tenant's electrical meter directly. Also a VRF needs negligible maintenance in comparison to a chilled water system. Other advantage of a VRF system is the size of refrigerant piping which is less than 1/3rd of the required size for a chilled water system for the same load and hence can save on the shaft size and benefit the developer. The biggest advantage to the architect will be the aesthetically located condenser/outdoor unit considering the advantage of piping length and also the vertical height. The current development in VRF technology will also help extract hot water from the unit bringing down the total connected electrical load of the complex and also save considerably on the operating cost.

***Advantages over Split-Window Type DX System:*** Split / window type DX systems are very popular in regular residential applications. Here each room is fitted with individual splits/ window units which project out of high end buildings spoiling the complete elevation. Several old high rise buildings are fitted with such protruding units without caring for the elevation of the building. A split system requires space for the outdoor unit mounting in the ratio of 1:1 and the biggest limitation here is the length of refrigerant piping which cannot be more than 15 metres. This further complicates the integration of the unit with architectural layout and hence spoils the elevation.

While in the case of a VRF system, the outdoor units can be planned at the mechanical service floor/ refuge floor in coordination with the architect as the refrigerant piping length allowed is much longer than in a standard split unit. In the case of *Palaise Royale, Mumbai* (platinum rated green residential building under construction) planning of the outdoor units is done at refuge / service floor level.

Some owners/developers would prefer to have the outdoor units placed at individual floor levels to save service floor space and the cost of copper piping. The high-rise residential project of *Orchid Crown & Orchid Heights* under construction in Mumbai is planned with outdoor units at each apartment level. Also, the VRF system is a completely variable system and hence it is more energy efficient.

## Portable Units

Portable air conditioning units can be selected when architectural constraints do not allow other systems to be installed in certain areas of high-rise buildings. They are generally used to cool small spaces such as a small bedroom or office or a small meeting room crowded with people. Portable air conditioning units are often used to supplement a central air conditioning system, in situations where a little extra cooling may be needed. This might include a computer server room, where the computers give off a lot of heat but must be kept fairly cool to operate properly.

A portable air conditioning unit works in much the same way as a standard window unit, only the hot air has to be vented through an exhaust hose, which is routed out of a window or into an adjoining space such as the attic, or into the space between the walls. Many units can be used as dehumidifiers, and some offer heating options as well. There are even models that offer air purification filters and ionizers, making the air clean and fresh while they cool.

There are also a few disadvantages of portable air conditioner units. They only cool the air in small spaces, and even though they are on casters, the units still tend to be heavy and large and take up a lot of space in the room. If the high rise has non-standard windows or rooms without windows, one has to become creative in figuring out how and where to vent the unit, because it must be vented somewhere. It would be extremely difficult to release air against the high wind pressure at high altitudes. Portable air conditioning units also collect condensation from the air that is cooled, so most units have a water reservoir that must be emptied from time to time. Portable air conditioners also tend to be less efficient and very noisy.

## Ventilation & Smoke Management System in Atrium

An atrium is an integral part of any tall building and usually acts as a focal point for communicating with all other areas. Some very tall buildings may have more than one atrium usually starting at different levels. Atria typically involve large open spaces connecting multiple floors and in some instances the spaces can be large enough that individual zones of greatly varying temperatures may exist within the atria. Design concept of spot cooling only the occupied areas can be done but high diffuser throw velocity must be maintained to counter act any thermal induced air currents. Usually an atrium has to be viewed as a three dimensional volume from the start of the project for which CFD analysis becomes necessary.

The smoke control system requirements for an atrium will usually dictate the design of the HVAC system instead of only cooling

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*Table 1: Smoke movement and its extraction*

| No | Fire location | Smoke Movement | Smoke Extraction |
|---|---|---|---|
| 1 | Atrium | Upwards, hitting the atrium top in case of large fire or spillage in case of low intensity fire | • Smoke extract fans at roof level to operate or to have an openable roof system<br>• Atrium side throw nozzles to operate<br>• Smoke curtain at refuge open area to shut off<br>• Local smoke extract |
| 2 | Corridor | Upwards, hitting the ceiling & spilling over to corridors above & atrium area | • Local smoke extract fans on refuge levels to operate<br>• Misting sprinklers at edge of corridor to start<br>• Smoke curtain at refuge open area to shut off |
| 3 | Floor levels | Spillage to floor levels | • All doors at the apartment entry to be fire rated<br>• Floor to floor barriers to check upward travel and entrance to floor above |
| 4 | Electrical shaft in escape core | Vertically upwards in the shaft | • Smoke extraction system within the electrical shaft to operate<br>• Pre action / gas suppression system in the shaft to start<br>• Shaft door to be fire rated |

or heating requirement of that space. The smoke management system design has to be developed before the designing of the thermal comfort system is done. Again, it is important that these have to be incorporated into the architectural design at the building planning stage for successful implementation.

Design of atriums of very tall buildings is critical in terms of smoke extraction which requires special engineering solutions such as:

- Providing effective smoke extraction system to control the smoke movement in the atrium area and its removal with the help of exhaust fans at a higher level of atrium.
- Providing smoke curtains which will isolate the atrium from the floor where smoke is generated.
- Providing water mist nozzles and side wall sprinklers in the atrium area.

## Smoke Management System for Super High-Rise Buildings

The central air conditioning system in the case of high-rise buildings needs to be well equipped with fire and smoke dampers, smoke detectors and arranged to shut down the system and operate the fire and smoke dampers to close during an emergency. In addition to this, the fresh air branch should have fire and smoke dampers set to close in case of fire. The system should be so designed that the combustion products can be easily removed from the building without spreading to the adjacent areas.

A fire fighting system also plays an important role in the design of a tall structure. The prime considerations for fire safety include different aspects such as the standard means of fire escapes, provision of smoke control devices, facilities to assist fire services, use of fire resisting materials, separation of floors, fire escapes, firefighting shafts and vertical transportation. See *Table 1*.

## Seismic & Wind Load Consideration in the Design

Lateral forces due to wind or seismic loading must be considered for tall buildings along with gravity forces while designing. Very often the design of tall buildings is governed by lateral load resistance requirement in conjunction with gravity load. High wind pressures on the sides of tall buildings produce base shear and overturning moments. These forces cause horizontal deflection in a multi-storey building.

Pipe joints and supports for chilled water piping and fire hydrant and sprinkler riser selection require specific attention. Pipe joints and supports need to have enough flexibility and strength to withstand seismic motion and swing effect due to wind load. It is necessary to get CFD simulation done for understanding the effects of vertical forces before selection of supports and flexible joints.

The horizontal seismic motion of the ground causes the most significant effect on the structure by shaking the foundation back and forth. If the equipment at plant levels at higher altitude are not provided with special installation features, they will act as projectiles in case of an earthquake. The installation of all equipment should be such that in case of an earthquake and swing effect due to wind the equipment should not get displaced from its location. For this the equipment needs to be fixed and held in its position in such way that the degree of movement in all the directions should become nil.

The designing, selection and installation of HVAC systems in super high-rises is a specialized job that involves several structural, safety and design challenges wherein lateral loads, increased wind pressures and gravity loads are also major factors influencing final decision.

## Conclusion

Skyscraper construction and design has to deal with complex challenges of balancing construction management, engineering services and financial considerations. Design of building services is a complicated issue especially in case of the super-tall structures. It has become necessary today for new high-rise buildings to be designed in such a way as to reduce energy consumption and increase efficiency.

In a super high-rise building, all the structural, mechanical, electrical and plumbing systems need to be well designed and integrated to incorporate innovative technologies for energy efficiency. Building automation integrated computer controls should also be effectively used in monitoring of HVAC, lighting, security, fire fighting and vertical transportation in a super high-rise building.

It is a very important fact that the success of any tall building lies in the collaborative effort of owners, architects, structural engineers, mechanical and electrical engineers and other specialized engineers and consultants. ❖