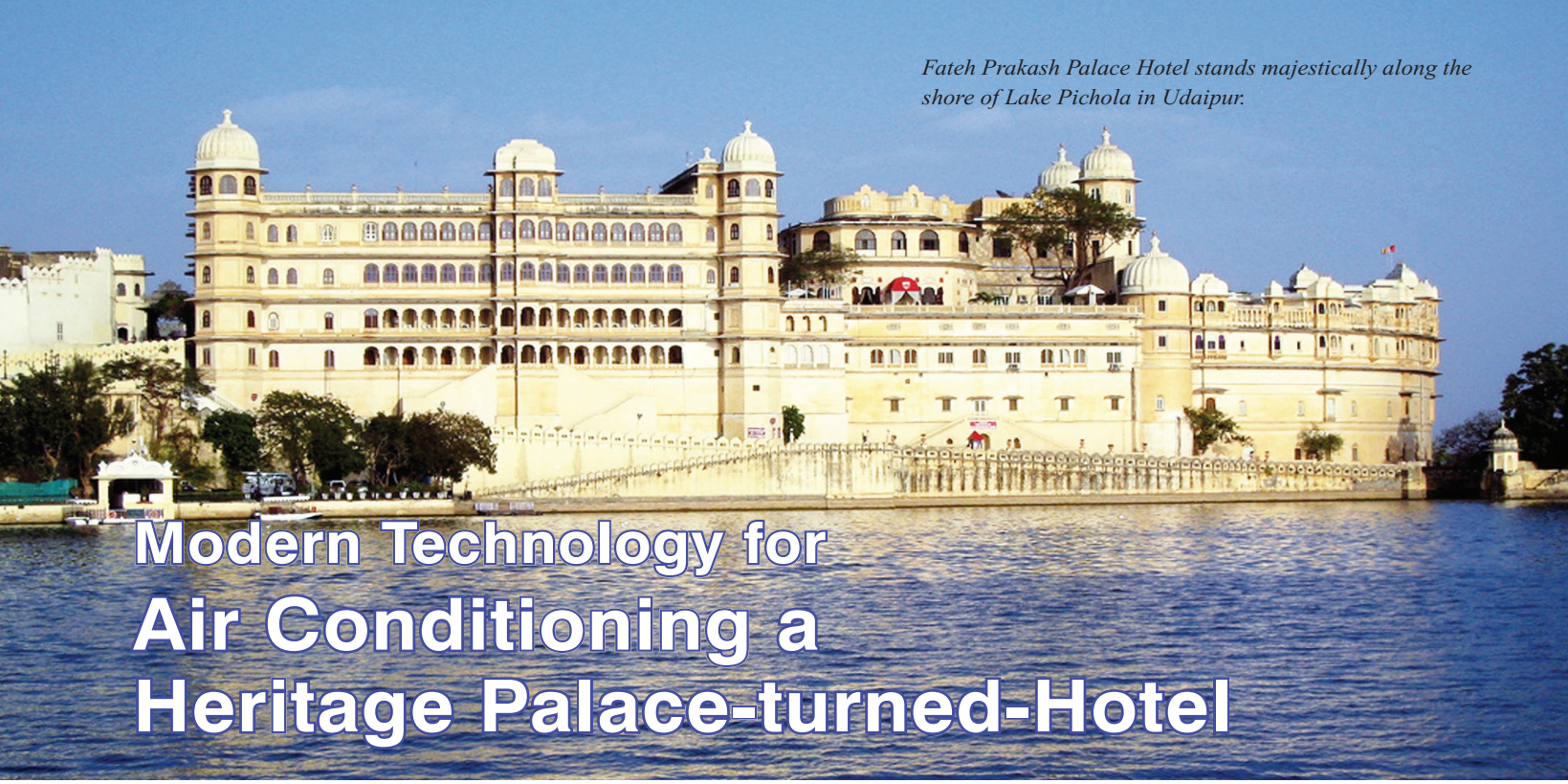

Fateh Prakash Palace Hotel stands majestically along the shore of Lake Pichola in Udaipur.

Modern Technology for Air Conditioning a Heritage Palace-turned-Hotel

By Pankaj R. Dharkar, Member ASHRAE, ISHRAE

At the time of independence from British rule in 1947, India had more than 500 princely states, referred to as "native" states by the rulers, which had not been conquered or annexed by the British and were not part of British India. All of these princely states were merged into the Indian Union and the palaces of the rulers, or "Maharajahs," were slowly converted into luxury hotels for tourists, anxious to savor the opulence and living style of the Maharajahs.

One such heritage palace that was turned into a hotel is the Fateh Prakash Palace, named after Maharana Fateh Singh of Mewar, who ruled from 1885 to 1935. Standing majestically along the shore of Lake Pichola in Udaipur, in the present-day state of Rajashtan, the palace is about 100 years old and has one of the country's largest Durbar Hall (or banquet hall). It is a column-less structure with huge steel girders that were shipped all the way from England.

The present day hotel, with distinctive turrets and majestic domes, is a treasure trove of exquisite chandeliers, priceless paintings, unique crystal and crockery collections and has been certified as the best heritage hotel in the "Heritage Grand" category by the Department of Tourism, Government of India.

Synopsis of System Design

The owner desired the renovation of the palace to be carried out so that some of the existing areas could be refurbished and used commercially. Development was to be carried out in two phases because the hotel was to be kept operational for guests throughout the retrofit work.

In ***Phase 1***, it was proposed to replace the existing 75 ton (265 kW) DX plant for the Durbar Hall and a 15 ton (53 kW) DX plant for the Galleria restaurant (which runs parallel to the hall and overlooks the lake) with a VRF system.

Retrofitting the old DX plant with compact VRF technology was the only option that could have given the flexibility required and, at the same time, save considerable space from the area vacated by the old DX plants. The space was enough to create six new additional guest rooms, as well as a new banquet hall of 5,000 ft^2 (465 m^2) with its kitchen at a lower level, which was originally used as a store and utility area.

After the successful completion of Phase 1, including the creation of six new guest rooms and banquet hall, the management decided to increase the capacity after seeing the growing popularity of the hotel.

Phase 2, comprises an additional 32 luxurious guest rooms, presently under construction.

Air-Conditioning System

Durbar Hall and Galleria Restaurant (or existing areas)

- Durbar Hall was continuously reserved for some function or the other, and so the installation work had to be carried out with minimum shutdown periods and at odd hours.
- A total of 75 ton (265 kW) for the Durbar Hall and 15 ton (53 kW) for the Galleria was the new VRF capacity. With the constraints of a heritage building, the five new 15 ton (53 kW) air-handling units were located in Durbar Hall in the same niches where the old DX units were placed to maintain the integrity of the heritage structure and to avoid altering or breaking any of the walls. The units, weighing 0.66 tons (600 kg), had to be

About the Author

Pankaj R. Dharkar is a leading MEP consultant with more than 32 years of experience in HVAC and has designed more than 3,000 projects for various applications in India and abroad. He is past president of ISHRAE and past national president of ASHRAE's Western India chapter. He is a member of the ASHRAE Nominating Committee for selecting Global Leadership and voting member of ASHRAE Technical Committee 9.12, Tall Buildings. Currently, he is planning several green and sustainable buildings.

Photo 1: Durbar Hall with new AHUs installed.

suspended using special anchor fasteners embedded in the rocky ceiling, which was porous at places (*Photo 1*).

- The outdoor units had to be located far away from the indoor air-handling units, involving extensive refrigerant piping and careful sizing to ensure oil return to the compressors. A total of 736 ft (224 m) was the measured length of the piping, including a 230 ft (70 m) 'U' loop with one arm of 66 ft (20 m) and a second arm of 49 ft (15 m).
- Some ductwork had to cross through 4 ft (1.2 m) thick stone walls, and openings had to be made using wire saw cutters.

New Banquet Hall and Kitchen

- A total of 64 tons (225 kW) for the banquet hall was installed. This area was completely redeveloped, is almost two floors below the ground level, and has surrounding stone walls that are 4 ft (1.2 m) thick.
- The kitchen had a double height, so the kitchen ventilation equipment was planned to be installed at the mezzanine level by casting a slab.
- The challenge was to provide for intake of fresh air and exhaust of stale kitchen air.
- Being at a lower level and very high at the center, an innovative and integrated air-conditioning system was needed.
- The selected system was required to be well-integrated aesthetically, as the hall was voluminous with traditional interiors and arches.
- The kitchen had a very specific exhaust requirement. The exhaust point was very close to the open patio of the owner's residence, so care had to be taken to ensure that the kitchen exhaust does not have any objectionable odors.

Guest Rooms & Presidential Suites

- A total of 44 ton (155 kW) VRF units were installed for the six guest rooms and six presidential suites. The tariff for these rooms was to be in the range of $400 to $800, therefore, the comfort level and environment needed to be commensurate with the high tariff.

Proposed HVAC System

The HVAC system that was installed consisted of a total 256 hp (191 kW) VRF outdoor units that were integrated with a variety of indoor units, including some ductable and cassettes, standard air-handling units for treated fresh air supply and special small duct high velocity air handlers with round flexible ducts and special 2 in. (50 mm) circular air outlets.

The outdoor units of 16 hp (12 kW) each in six modules; two of 32 hp (24 kW) feed the newly created banquet hall and rooms, while four of 48 hp (36 kW) feed the existing Durbar Hall, Galleria restaurant as well as a part of the new banquet hall and guest rooms.

Durbar Hall

- A 48 hp (36 kW) VRF system connecting three AHUs of 15 tons (53 kW) each, and another 48 hp (36 kW) VRF system connecting the remaining two AHUs of 15 tons (53 kW) and five AHUs of 3 tons (11 kW) for the Galleria restaurant was installed.
- Apart from the other benefits of this selected combination of VRF systems, it also enabled the air-cooled condensers to be located far away from Durbar Hall, thereby reducing the earlier noise level of 85 dBA near the owner's residence.
- By shifting the DX outdoor units, which had been placed in the corridor, we facilitated the space to be converted into premium rooms with a picturesque view. This retrofit has generated an additional income of approximately Rs.10.8 million (US$216,000) per annum from the six new rooms created.
- The selected digital VRF system has a full load COP. In addition, the digital scroll technology has a very high Integrated part load value (IPLV).
- Hence, power consumption was reduced from 1.35 kW/ton (5 kW/kW) (with the old reciprocating compressors) to 0.85 kW/ton (3 kW/kW) (with scroll compressors). Because of this energy efficient retrofit, there is a direct saving in the power bill to the tune of Rs.540,000 (US$10,800) per annum.
- The old DX system used R-22, which has been replaced with the eco-friendly R-410A.
- This shifting of outdoor units became possible due to the electronic expansion valve (EEV) kits.

Lower New Banquet Hall

- Catered by three different systems: two of 48 hp (36 kW) and one of 32 hp (24 kW).
- Indoor unit location was a challenge that was met by using small duct, high velocity indoor units.
- The indoor units are installed at the mezzanine level on both sides of the banquet hall.
- Supply and return air ducts are taken to the lower level, and flexible sound attenuator tubing is connected to the supply air duct (*Photo 2*).

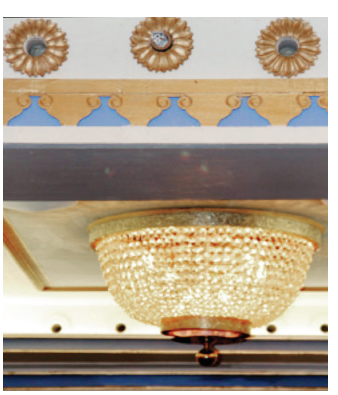

Photo 2: Two inch round supply air outlets blend with interior.

- The round supply air outlets are camouflaged in the interior design.

Guest Rooms in Zone 1

- These six rooms are carved out from the corridor earlier used for installing the outdoor units of Durbar Hall's old DX system.
- These rooms are partially connected to the systems feeding the lower banquet hall.
- Four rooms are connected to one of the 48 hp (36 kW) systems, which caters partially to the banquet hall and partially to these four rooms.
- The remaining two rooms are connected to a 32 hp (24 kW) system, which caters partially to the banquet hall and partially to these two rooms.

Presidential Rooms in Zone 2

- The six newly constructed rooms have an independent 48 hp (36 kW) system feeding the indoor units.
- All six rooms are presidential suites, each with a large sitting area of 320 ft^2 (30 m^2) and a bedroom of 200 ft^2 (19 m^2).
- Three rooms are equipped with indoor units, and the other three with a small duct system to provide better height in the rooms.

Outdoor Units

- A total of 16 outdoor units of 16 hp (12 kW) each are installed, adding to 256 hp (191 kW).
- These 256 hp (191 kW) outdoor units are divided into six different refrigerant circuits: four of 48 hp (36 kW) and two of 32 hp (24 kW), to give higher flexibility and diversity of operations.
- The new location of the entire battery of outdoor units is on the terrace. These units are architecturally camouflaged to merge with the palace in the background (*Photo 3*).
- The new location gives more acoustic comfort as compared to the high noise levels at the earlier location.

Kitchen

- The kitchen is being supplied by an air washer of 22,300 cfm (10 500 L/s).
- A 1,500 cfm (700 L/s) air washer feeds the service corridor.
- The exhaust is planned to go through two dry scrubbers: one for the main kitchen (18,100 cfm [8500 L/s]) and the other for the tandoor area (9,700 cfm [4600 L/s]).
- There was a space constraint in installing such large equipment. Actual measurements were taken and positions marked on the floor before finalizing the dimensions and carrying out the fabrication (*Photo 4*).
- The ducts for fresh air intake and exhaust were restricted to the exterior wall of the palace to maintain the elevation of the heritage building.
- Both scrubbers contain activated carbon filters to completely eliminate odor, and the air exhausted to the atmosphere is almost odorless.

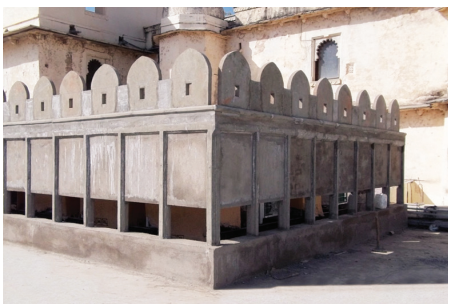

Photo 3: VRF outdoor units installed on the terrace with architectural camouflage.

Latest Technology

The HVAC system installed integrates the latest technology of digital VRF with small duct high velocity system. A digital VRF system was selected especially for this critical application because it provides variable capacity output and is able to maintain room temperatures more precisely than splits, chillers or ducted systems. The small duct high velocity system complements the high-side design in performance and integrates perfectly with the traditional interiors of the heritage building.

Compressor

- The entire design was viable due to the feasibility of long piping lengths, of as much as 734 ft (224 m).
- The VRF system with the digital vapor Injection scroll compressor, along with the adaptability to connect AHUs with EEV kits made it possible to accomplish appropriate equipment selection.
- Vapor injection technology provided the improved subcooling, which is necessary for pipe lengths of more than 656 ft (200 m).
- Vapor injection allows the digital scroll to deliver over capacity when the demand increases.
- This system also has an built-in turbo intercooler that improves the COP of the machine. The selection provides better full load and part load COP.
- Longer piping has resulted in a reduced noise level of around 55 dBA in the area surrounding the Durbar Hall, from the earlier 85 dBA.

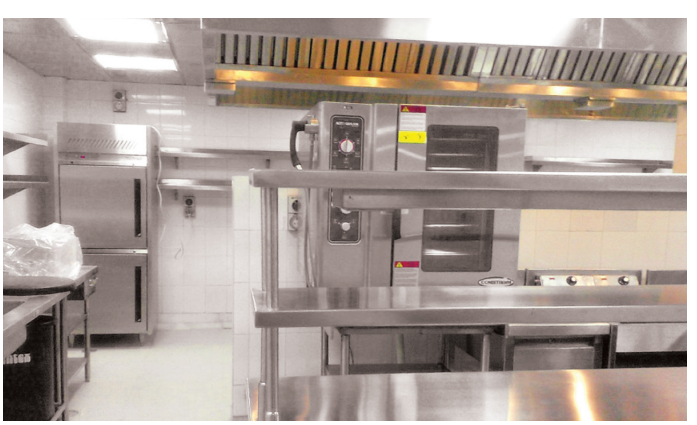

Photo 4: A view of the new kitchen for the banquet hall.

- Other benefits of reliability, better dehumidification, quicker response time and wider capacity range make the digital scroll technology more attractive.

Table 1: Cost benefits due to installation of VRF system with digital scroll technology.

Description	Unit	For DX System	For VRF System
Total Load In Durbar Hall and Galleria Restaurant: 90 TR			
Power consumption	kW/TR	1.35	0.85
Total power consumption	kW	121.5	76.5
Hours of operation per day	Hrs/day	8	8
Total power consumption per day	kW/day	972	612
Working days per year	days/year	250	250
Total power consumption per year	kW/year	243,000	153,000
Electricity cost per unit (kWh)	Rs./$	6	6
Cost of power per annum	Rs./$	1,458,000/ 29,160	918,000/ 18,360
Savings per annum	Rs./$		**540,000/ 10,800**
Total Load In New Banquet and Guest Rooms: 108 TR			
Power consumption	kW/TR	1.35	0.85
Total power consumption	kW	145.8	91.8
Hours of operation per day	hrs/day	8	8
Total power consumption per day	kW/day	1166.4	734.4
Operational days per year	days/year	250	250
Total power consumption per year	kW/year	291,600	183,600
Electricity cost per unit (kWh)	Rs./$	6/0.12	6/0.12
Cost of power per annum	Rs./$	1,749,600/ 34,992	1,101,600/ 22,032
Savings per annum	Rs./$		**648,000/ 12,960**
Additional Income generated due to space utilization for 6 new guest rooms (Rs. 10,000 per day tariff × 180 days occupancy × 6 rooms)	Rs./$		**10,800,000/ 216,000**
Total benefit to the client due to installation of Samsung VRF System with Emerson Digital Scroll Technology (A+B+C)	Rs./$		**11,988,000/ 239,760**

Small Duct, High Velocity System

- In a small duct, high velocity system, the AHU delivers the air at very high external static pressure.
- Heat transfer is higher than in the conventional system; ΔT across the coil is around 54°F to 61°F (12°C to 16°C). Due to these two factors, air quantity per ton can be reduced to 250 cfm to 280 cfm (118 L/s to 132 L/s).
- This enables a small duct size, which can be accommodated in very little space above the false ceiling.
- Ducting is designed using the static regain method to maintain high static throughout the supply duct. The flexible supply tubing plays a large role in minimizing the supply noise.
- The air distribution is called aspiration and is different from conventional air diffusion.
- The supply air velocity (face velocity) is above 800 fpm (4 m/s) and goes up to 2,000 fpm (10 m/s). But the air quantity per outlet is limited to 18 cfm to 40 cfm (8.5 L/s to 19 L/s).
- The supply jet forms a beam at a very high velocity and creates a negative pressure around the periphery of the supply beam. The room air is attracted towards the primary air due to this negative pressure. This is called aspiration.
- The induction of room air with primary air gives an even temperature in the room and hot pockets are avoided. As the air quantity per outlet is 40 cfm (19 L/s) only, the number of outlets per ton of cooling capacity can vary from eight to 10.
- This system can deliver its maximum cooling capacity if the coil inlet temperature of the refrigerant is maintained around 43°F (6°C).
- As the system is integrated with VRF outdoor unit, suitable electronic expansion valves have been used for achieving the required evaporating temperature.

Environment-Friendly System Design

Indoor Environmental Quality

- To maintain indoor air quality, each room is provided with treated fresh air.
- Kitchen exhaust air is treated through electrostatic scrubber units and further purified with activated carbon filters before being exhausted to the environment.
- Sound levels have been drastically reduced from 85 dBA to almost zero near the owner's residence, and around 60 dBA near the outdoor unit battery due to the distant location of these units.
- The old DX system using R-22 is now replaced with eco-friendly R-410A refrigerant.
- The entire system is now controlled from the BMS room, and room parameters can be set through the data management system. Faults can be immediately seen from the central system, which gives the user controllability.

Conclusion

Retrofitting the HVAC system of a heritage building requires sensitivity to the design, materials and other special features of the building. It is important to ensure that the selected retrofitting measures complement the existing building and do not have an adverse impact on its historic or architectural characteristics. It is challenging for a consultant to design and select a system that will promote sustainable performance for existing heritage buildings without adversely impacting their cultural and traditional significance.