Mechanical and Electrical Systems for the Tallest Building/Man-Made Structure in the World: A Burj Dubai Case Study

Roger Frechette
Director of MEP
Roger.Frechette@som.com phone: 312.360.4978

Luke Leung
Associate Partner
luke.leung@som.com
phone: 312.360.4256

Jeffrey Boyer
HVAC engineer
jeffrey.boyer@som.com
phone: 312.360.4327

Skidmore, Owing, & Merrill LLP

224 South Michigan Avenue
Chicago, Il 60604
Fax: 312.360.4553

Abstract.

The Burj Dubai (Tower of Dubai) is a mixed-use building of approximately 5 million square feet that will include high end residential, boutique offices and the world's first Armani Hotel. Standing at over 150 stories (final height is confidential); Burj Dubai will achieve the status of the tallest building and construction in the world, upon its completion in 2009. This paper will present the mechanical and electrical solutions purposed by our Chicago engineering team to harsh environment. Additional challenges associated with any super-tall building design, such as reverse stack effect mitigation, will also be addressed. Integral to best design practice was the integration of sustainable strategies to the base building services. These strategies include a condensate recovery system, heat pipes, heat wheels for energy recovery, use of high performance glass, and a ventilated double wall facade in the entry pavilions were all integral aspects of the final design.

GENERAL BUILDING DESCRIPTION

Upon completion, the Burj Dubai designed and engineered by Skidmore, Owings & Merrill LLP (Chicago) will be the world's tallest building as well as the world's tallest man-made structure. When completed, it will hold the record in all four categories as recognized by the Council on Tall Buildings and Urban Habitat and have the highest publicly accessible observation deck.

The Burj Dubai is a large scale mixed-use project primarily consisting of luxury condominiums, and a five-star Armani Hotel consisting of hotel units and hotel residences. The tower's gross area is approximately 312,400 sm (3,362,675 sf) above grade, with a total of 439,935 sm (4,735,430 sf) including below grade levels. Floor plate sizes range from 3,065 sm (33,000 sf) at the lower (hotel) levels to 380 sm (4,120 sf) at the upper level communications floors. Basement levels at the podium are approx 35,300 sm (380,000 sf) per level and are designed to accommodate approximately 2,500 cars. The building has a peak cooling load of approximately 13,000 tons of cooling.

The design of the Burj Dubai is derived from the geometries of the desert flower and the patterning systems embodied in Islamic architecture. It combines these historical and cultural influences with cutting-edge technology to achieve a high-performance building which will set the new standard for development in the Middle East and become the model for the future of the city of Dubai. Beyond simply being iconic, the mechanical systems and innovations incorporated into the design will serve to define a new standard for super high rise design for the hot and humid climate.

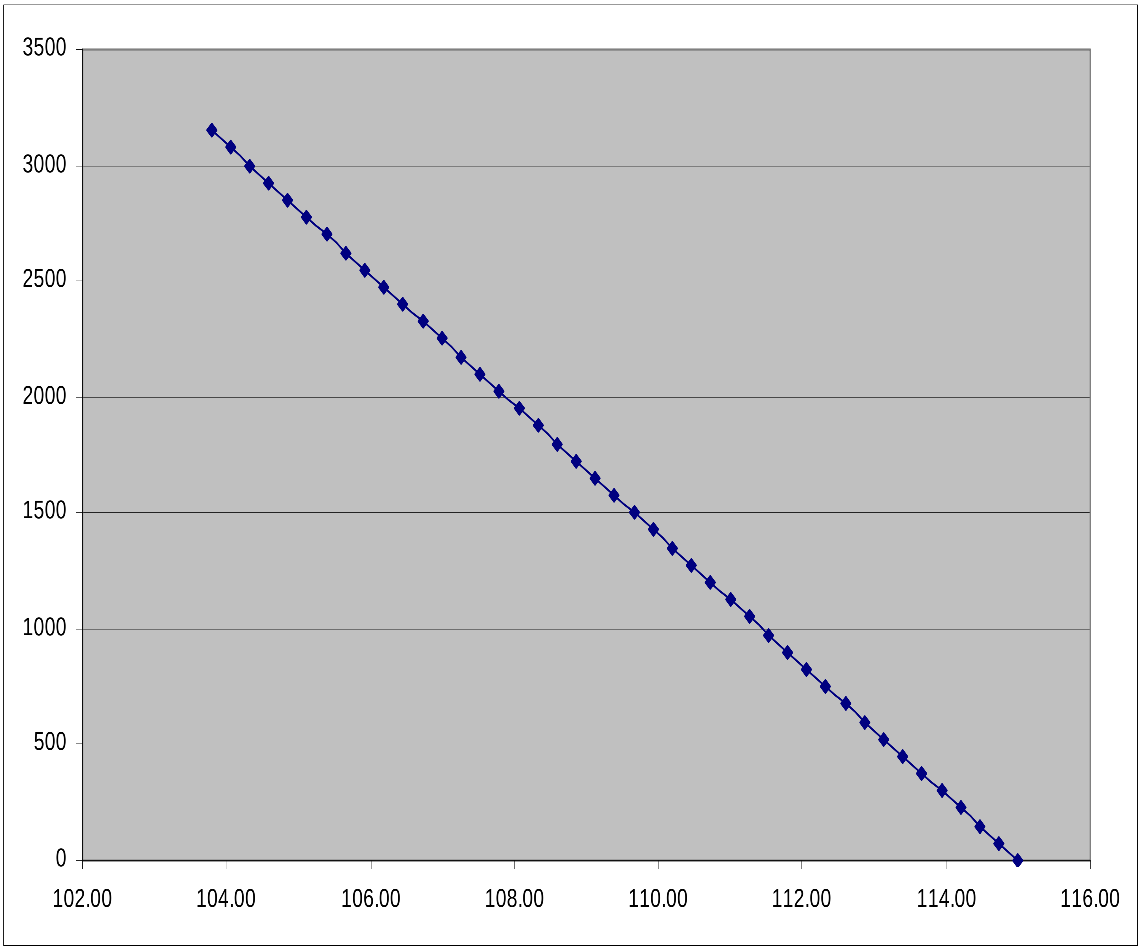
CLIMATE DATA AND GENERAL CONSIDERATIONS

The city of Dubai is located at 25°15' N latitude and 55°19' E longitude and is situated along the coast of the Persian Gulf. Its location coincides with the northern edge of the earth's equatorial region, an area influenced by so-called trade wind patterns. The climate is classified as arid sub-tropical and is characterized by average diurnal temperature fluctuations, dampened by its proximity to the gulf. Winter months are mild with a 50°F design temperature while summers temperatures mid-day may reach a 115°F DB design temperature. Dubai also experiences a greater level of humidity than nearby inland regions, with an 85°F WB design temperature. Rainfall is sporadic, though potentially heavy; typically occurring only during the winter season.

MICRO CLIMATE

Various micro-climatic issues were investigated concerning an elevation up to 3,280 feet (1,000 meters). Temperature, pressure and air density were accounted for in the study, in addition to changes in atmospheric composition. It was found that in both winter and summer months, a temperature difference of 12°F is experienced from the ground level to the study height. This translates into a 20% reduction in sensible cooling required to bring 115°F DB design temperature to a standard 55°F supply temperature (See Figure 1). Air pressures and densities will have a 12% difference at the top compared to the bottom. These micro-scale variations in climate had an impact on motor selection, air cooled equipment selection and air volumetric flow rate.

**Eleva-
tion**



Temperature in Degree F

Figure 1: Temperature and Elevation Relationships for Burj Dubai

In addition to ambient temperature, the local atmospheric turbidity can have a significant impact on façade solar loading. Sea-salt aerosols, sand and urban particulate dispersed into the turbulent atmospheric boundary layer, generally below 1000M in height, resulting in light scattering and a proportional insulation reduction. While the radiation reflected from ground level to the upper floors would be greatly attenuated by the particulate matter in the lower atmosphere, the contrary effect would occur for the direct solar radiation. Thus, radiant loads are expected to increase with the height of the building.

HVAC DESIGN – WATER SIDE

Cooling water for the complex, as well as a near by mall, is provided by central plants located off site. Two (2) incoming lines from different central plants are provided to allow for redundancy. Due to the extreme temperature, the central plants have ice storage to allow emergency cooling for selected equipment. The district chilled water is routed to heat exchanger stations located on the Concourse Level. On the Concourse Level, separate heat exchanger stations will be provided for the office building, residential low zone, residential high zone express, hotel low zone, hotel high zone and cooling of the incoming domestic cold water. Each heat exchanger station will include multiple plate-and-frame heat exchangers and pumps. Risers serving the tower residential and hotel fan coils are piped in a reverse return system.

Given the height of the building, conventional design will require a minimum of 3 heat exchangers and pumping loops to move the chilled water up the tower. By selecting the maximum equipment pressure available and placing them at strategic locations, 2 heat exchanger loops, one runs express from the Concourse Level to the 75th floor, are designed for the chilled water to reach the top of building without the use of custom equipment. This eliminates chilled water temperature decay due to additional heat exchangers. High zone and low zone water pressure is isolated by heat exchangers. In order to prevent possible damage to the water system in the event of heat exchanger breakdown, pressure sensors relayed to motorized valves can isolate the critical zone and additional pressure relief valves are provided as last resort safety relief.

HVAC DESIGN – AIR SIDE

Cooling only, constant volume units or variable volume units are utilized to condition the large public spaces. Due to the higher outside air temperatures, economizer cycles are only provided where 100% outside air can be easily accessible. In the tower, six (6) mechanical zones equipped with centrally treated outside air handling units provide fresh air to the fan coil units located at each floor. Exhaust fans, pressurization fans, chilled water pumps and electrical substations are located in the mechanical zones.

While the scale of the project and searing heat encountered during the peak design load present a formidable challenge to developing the building’s air systems, atmospheric conditions further compound the issue. Given the activities, 939,785 CFM of outside air will be required. Centralized exhaust is design to facilitate the use of heat wheel heat recovery devices for exhaust air cooling recovery to pre-cool incoming outside air to fan coils. The centralized outside air systems are enhanced by including 30% washable filters, special cooling coil coating and aluminum casing provided for the mechanical equipment. Architectural slots are specially designed for lower intake air velocities, with sand stopper and drainage for periods of precipitation.

Other treatments for the HVAC system include specifying an additional protective coating to exposed exterior equipment and cooling coils. While in US the galvanized metal commonly has a Z18 level of Zinc, Z27 is specified for this project as the galvanized agent.

Due to the hot and humid conditions in the summer, outside air will condensate when exposed to indoor design conditions. Frequently traveled doors are equipped with air locks. Diffusers and grilles are specified with aluminum for corrosion resistance. An in-depth study was performed to evaluate the double wall pavilion whether indoor or outdoor air should be used to extract the heat in the double wall and minimize the opportunity of condensation. It was concluded, to minimize condensation the cavity should be vented from the inside. In the event that condensation does occur, it will occur on the outer surface of the outer glass where it will be easy to clean on a regular basis. The space in the cavity will be cleaner than if it were vented with the outside air which contains dirt and particularly sand. The temperature in the cavity will be cooler creating a more comfortable condition in the occupied space due to less radiant heat being transmitted.

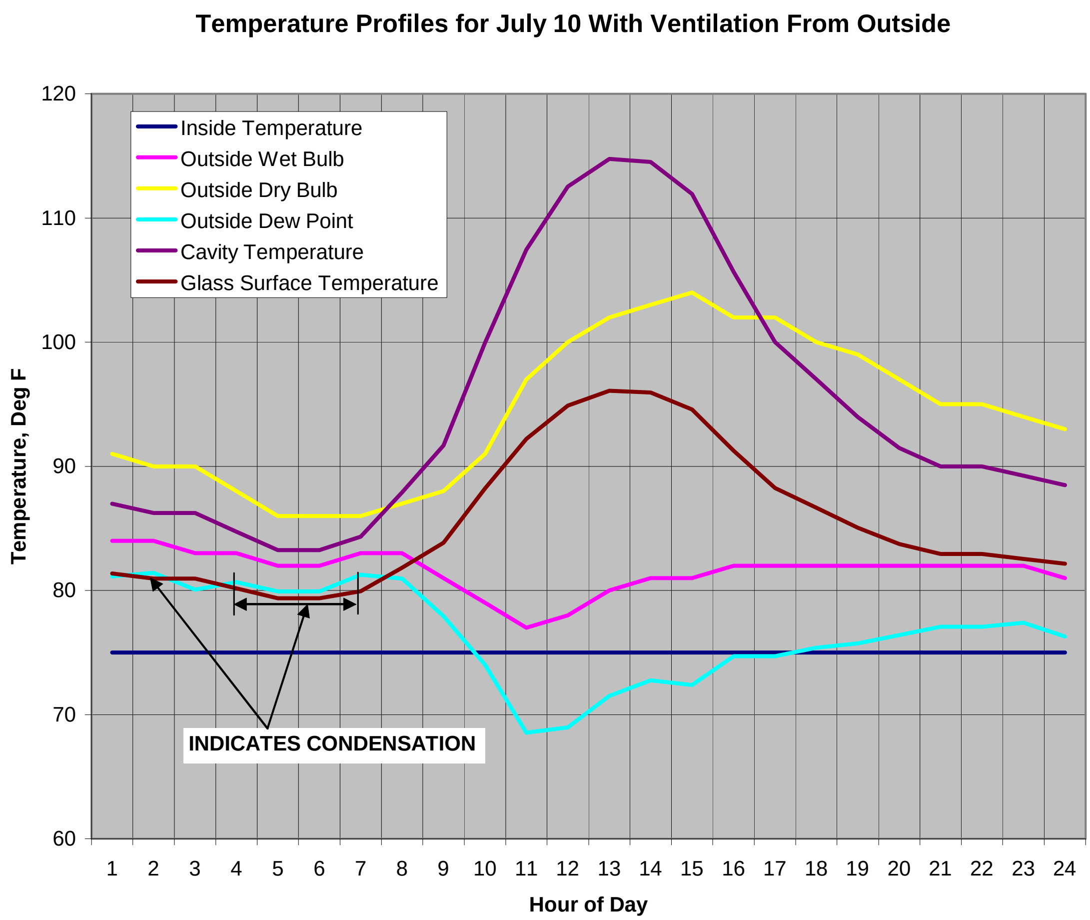


Figure 2: Condensation Study for Double Wall Pavilion

ELECTRIC SYSTEMS

Burj Dubai as one of the first super-tall buildings in Dubai and was also one of the first projects to distribute 11 kV voltage. The provided 11 kV services enter via underground concrete encased ductbanks into the building by the Dubai Electricity and Water Authority (DEWA). Multiple 11 kV risers will provide power to the transformers to produce 400y/230V power. Due to the extreme heat and humidity, the transformer rooms are air conditioned and have ventilation fans as back-up in case of emergencies. The peak demand is 50 MVA Demand. It was also necessary to derate the cabeling because of the extreme heat the system could encounter during summer power failure condition.

The emergency standby power generation system is diesel fueled engine generator set, complete with automatic synchronizing equipment and controls for starting on loss of normal power and for load transfer. Local and remote manual controls are provided for starting of the power generation set. Five (5) 11 kV emergency generators; One (1) at 400 V emergency generator will provide power to the fire, life safety and critical systems. The emergency standby power generation system is sized for the loads including emergency lighting, fire pumps, selected elevators, Stairway pressurization, Smoke purge fans, pumps intended to overcome gravity (i.e., sump and sewage ejector pumps), fire alarms and life safety, Security, Telephone equipment, aircraft warning lights and miscellaneous critical loads (e.g., power generation auxiliary equipment, kitchen freezers, etc.). A central battery system with capacity for three hour operation will provide continuous power for egress lighting.

Given the height of the building and the environment, it is likely that lightning will strike the building during its life time. The lightning protection system acts as a Faraday Cage by using the building structural rebar as down conductors. Copper Conductor tape locate on parapet and conductor loop in slab at each set back and mechanical floor connected to the rebar. The entire system is connected to the ground conductor inside the building foundation piles. Copper is initially selected as the ground conductor. Subsequent field study indicated the corrosive nature of the soil will erode copper in the ground. Stainless Steel was instead selected as the final ground conductor.

The grounding system has multiple dedicated ground conductor risers for normal power system, communication system and emergency power systems. The risers are connected to the counterpoise loop in the podium and finally connected to the ground conductors.

PLUMBING SYSTEMS

The water available at the site is desalinated sea water from the Persian Gulf. 250,000 Gallons of fresh water is required on peak. Due to the water composition, a selected portion of the system was specified as stainless steel to inhibit corrosion. This incoming water can reach as high as 104 F degree in the summer and a minimum of 68 F in the winter. Therefore, pre-cooling of the water is required in the summer before serving the domestic cold water needs of the building. Two points of connection with the incoming city water service are provided for the domestic water system and include connections to water metering assemblies. A single connection with the incoming gray water service will be provided with the condensate recovery to complete the site irrigation water system. The building also features a combined domestic and fire water storage tank.

The hot water system includes liquid petroleum gas (LPG) hot water heaters placed in the podium, to heat the incoming water before transferring to multiple tanks within the tower. Local electric heaters are designed to heat the returning water from the riser prior to reaching the tanks.

Transfer pumps will pump the cold and hot water to the water storage tanks located at multiple levels in the building. The domestic cold and hot water systems will consist of a gravity-feed system from the elevated water storage tanks and will provide water to all plumbing fixtures and equipment requiring cold and hot water. Express water line carries the water to the 40th floor and distributed to the other tanks above.

A complete soil, waste and vent system from plumbing fixtures, floor drains and mechanical equipment arranged for gravity flow and, ejector discharge to a point of connection with the city municipal sewer is provided. A complete storm drainage system from roofs, decks, terraces and plazas arranged for gravity flow to a point of connection with the city municipal sewer system is provided.

A complete low pressure propane gas distribution system is provided including independent incoming service pressure regulator and meter rooms located on the building ground level, gas distribution piping system and pressure regulators as may be required to ensure a steady low pressure gas flow to the equipment.

FIRE PROTECTION AND LIFE SAFETY SYSTEMS

Given the environment and the height of the building, a “defend in place” approach to fire protection in high rise buildings was adopted as the design approach. This approach asserts that, in response to the vertical nature of the building, it is unreasonable and potentially more hazardous to evacuate the building during a state of emergency. Therefore, areas of refuge are provided for throughout the building, respective to occupancy zones. Stairwell pressurization and fire lift vestibule pressurization systems with fire rated enclosure are provided for the tower. Smoke removal systems for different spaces are provided in the public hotel areas. A central smoke removal system for typical tower corridor is sized for one (1) floor. Fan status panel with manual override control switches of major air handling systems for fireman operation will be provided adjacent to central fire control station.

In the event of a fire in the tower, smoke exhaust will be activated at the fire floor, pressurization will be provided in the egress stairs and fireman’s vestibules. Occupants would relocate to designated areas and if need be, evacuate as orchestrated. The hot and humid climate calls for the inclusion of “cooled refuges” consisting of spot cooling in the pressurized refuge areas by fan coil units maintained on emergency power. With outside air temperatures potentially reaching 115°F, this measure is essential to ensure that the space temperature remained safe in the event of power loss to the building. Also, due to the nature of reverse stack effect, all stairwell pressurization, vestibule pressurization and tower smoke exhaust systems will require control that can vary the flow according to the actual pressure in the fire zone.

The building is full-sprinklered. Similar to the domestic water system, a gravity feed system is designed to provide fire water for the tower. Tanks are located on multiple mechanical floors similar to the plumbing system. Fire pumps are provided in the office pavilion and also for the site fire hydrants. A total of 31050 Cubic Feet of water storage is available for the tower, or, up to 90 minutes protection for the lower portion of the tower and 30 minutes for the top portion. *Very Early Smoke Detection Alarm* devices are design into critical spaces with gas based fire fighting systems.

The fire detection, alarm and communications systems is non-coded, zoned, electrically supervised, Class A, addressable, multiplex system, and consists of fire detection and alarm to monitor and control multiple systems in the building including HVAC, plumbing, IT, security etc.

STACK EFFECT AND WIND ALARM

A major challenge, as with any super-tall building design, is stack effect mitigation. The climate of Dubai, being dominated by the cooling design days, will tend to experience a "reverse stack effect" as a result of thermal buoyancy. The top of the building will develop negative pressure relative to outside in the summer to pull in exterior air, which will travel down the vertical riser(s), which the major vertical riser is the vertical lift Building Service-1 that connects the ground level to the 138th floor, and exit out of the building in the lower floors. Collaborating with RWDI from Canada, a series of mitigation strategies were developed to be integrated with the base building systems. Analysis of the pressures within the building due to the combined effects of wind and temperature were accomplished by a network model (see Figure 3). Each floor of the building was modeled as a series of nodes representing spaces within the building, joined by resistances to airflow. Pressure differences between the inner and ambient Conditions is indicated in Figure 3.

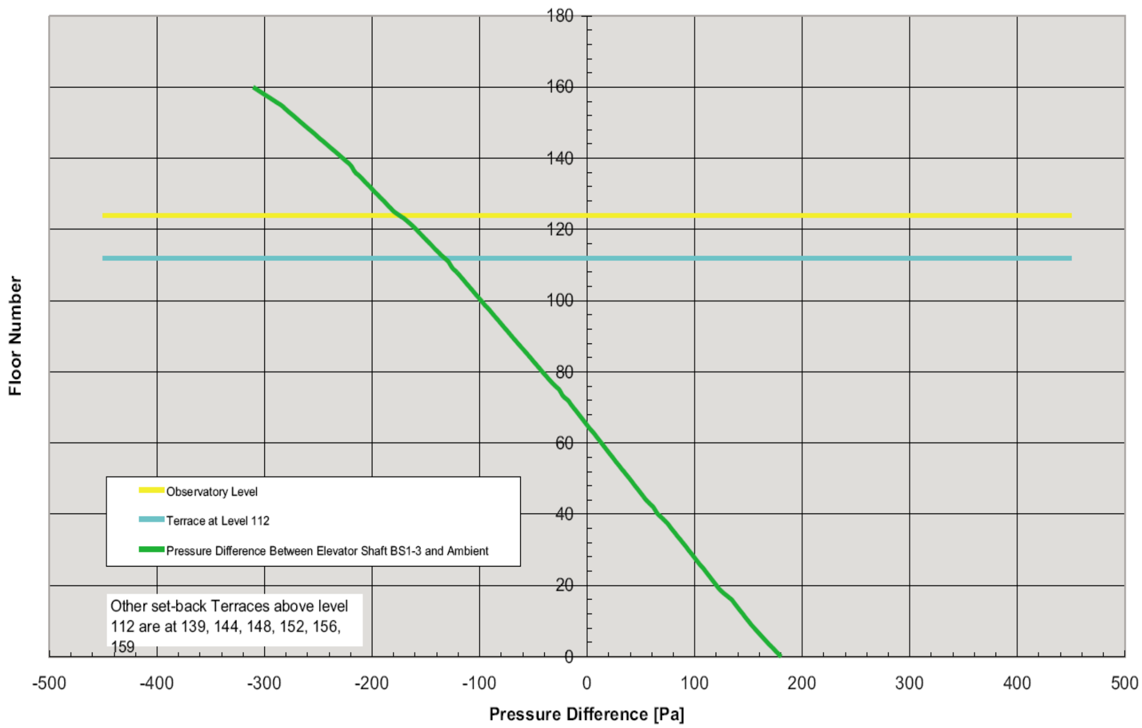


Figure 3: Pressure differences between the inner and ambient Conditions (no wind Effects, no HVAC system pressure set in the Core)

Also stack effect induced infiltration/exfiltration is calculated in Figure 4.

The culmination of these efforts was the development multiple strategies. While air locks, stack effect doors, specially sealed vestibule doors, isolation of architectural zones and tight envelope are developed by the architectural team, two strategies are to be incorporated into the mechanical systems. The first represents conditions when the net supply to each zone (approx. 40 floors) is essentially balanced by the cumulative exhaust flows to that zone. The second HVAC mode represents the case where the mechanical system sets the core pressure to just above the external pressure in a zone by supplying air to the core through a ducted supply air system and controlling the amount of relief. Since one HVAC system serves multiple floors in a zone, the highest level in each zone will be used as the reference floor. The floors below this reference floor will have increasingly higher positive pressure above the local outdoor pressure as one continues down levels within the zone.

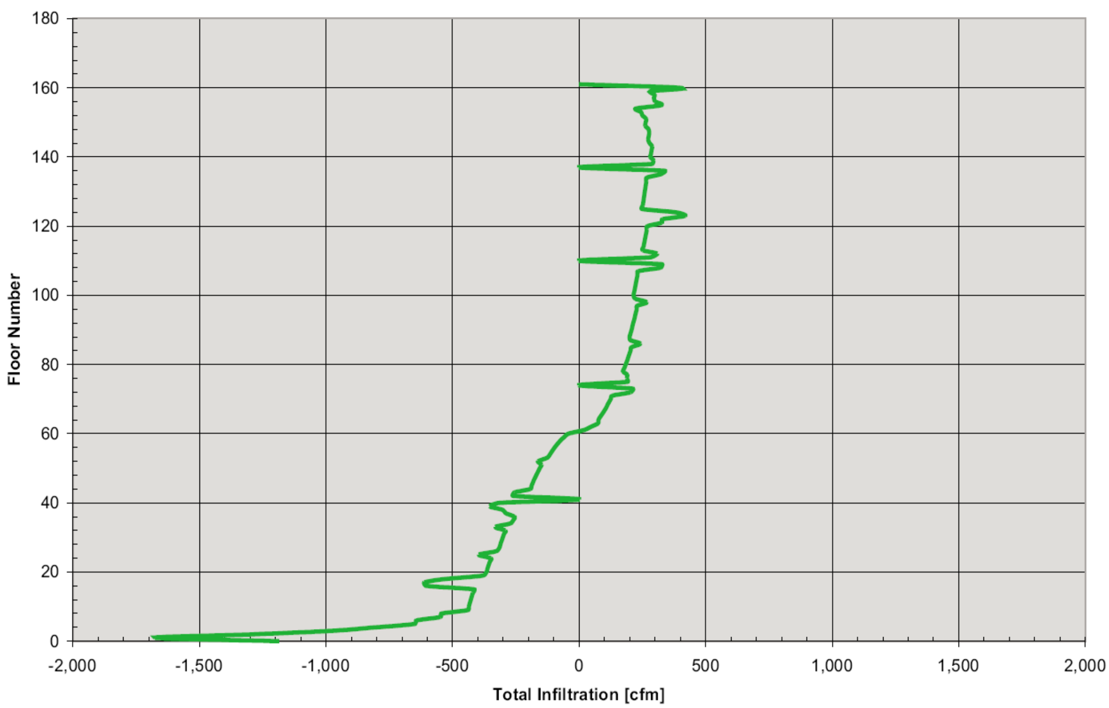


Figure 4: Stack Effect Induced Infiltration/Exfiltration (Total Infiltration/Exfiltration onto Floor, No Wind Effects, No HVAC System Pressure set in the Core)

Burj Dubai has a number of terraces as the building tapers off towards the top. A special study was performed to review the environmental conditions because of potential of high wind speed and possible stack effect impact to the rest of the building during summer time. (See figure 5A, 5B). Special wind tracker panel which identifies wind speed and direction is provided at the tower apartments with terraces to alert occupants of the outdoor conditions.

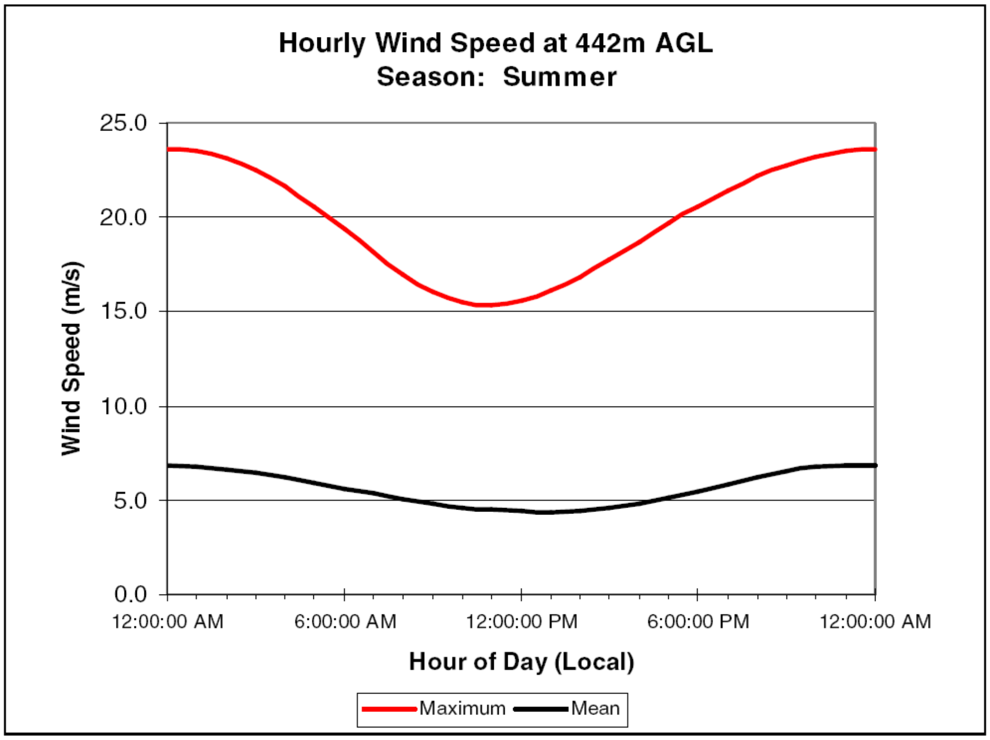


Figure 5A: Hourly Wind Speed at 442M above Grade during Summer

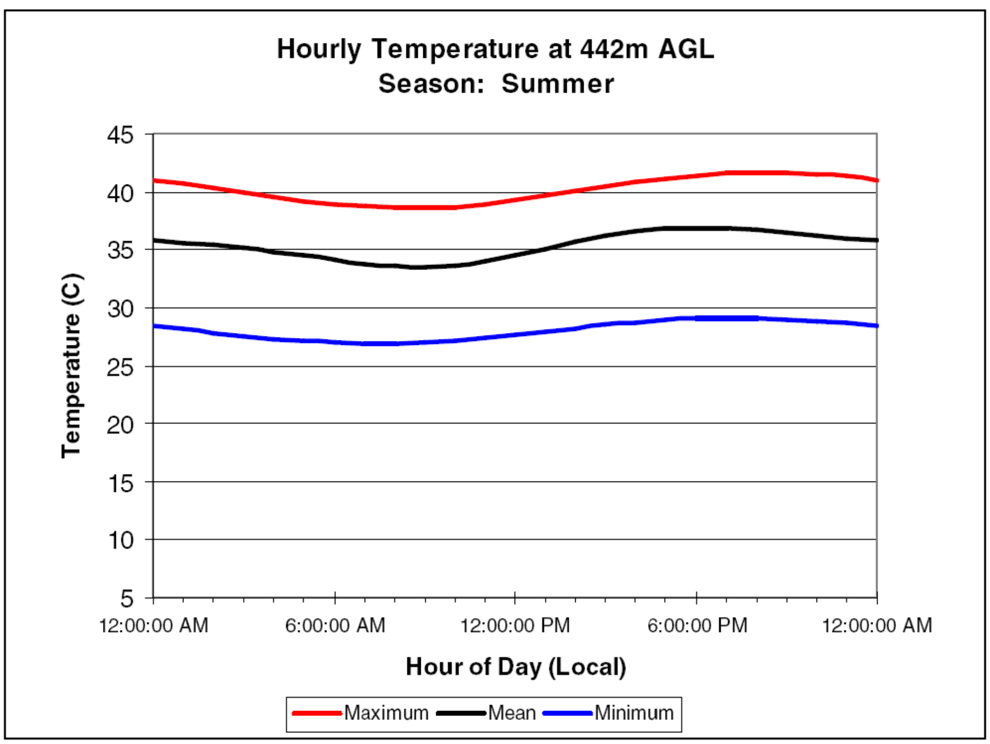
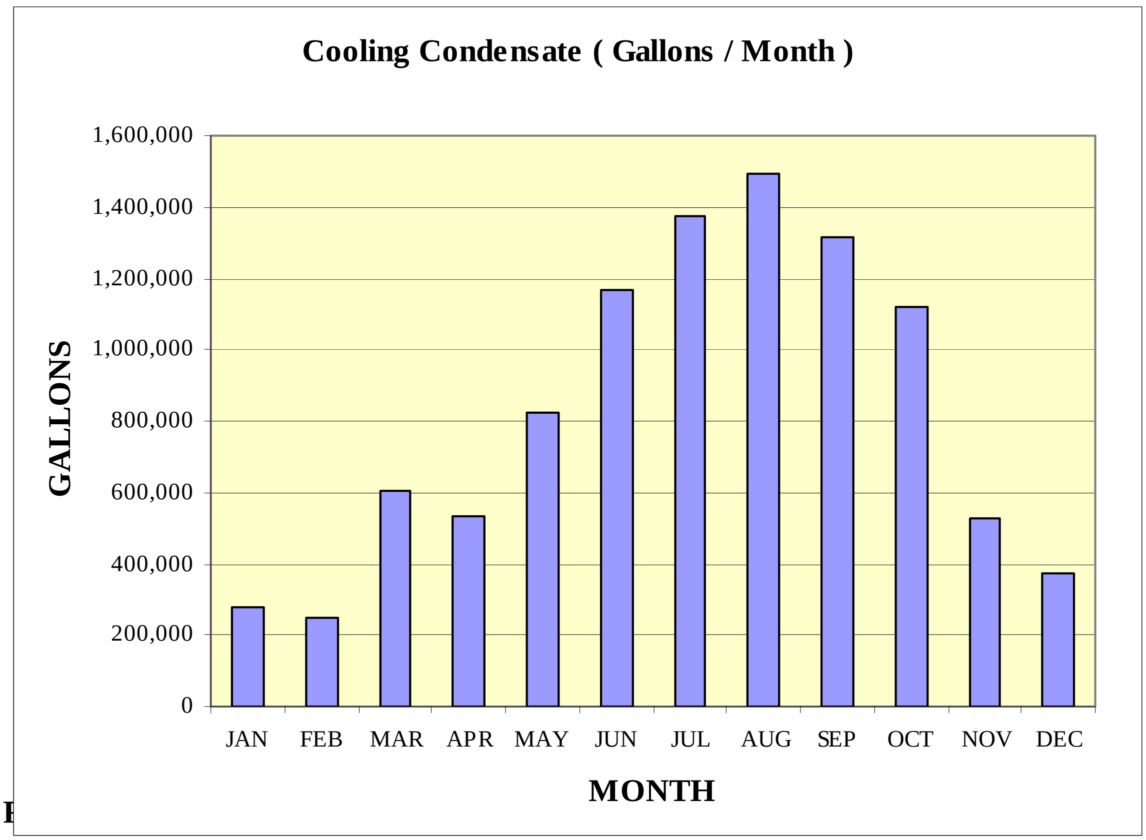


Figure 5B: Hourly Temperatures at 442M above Grade during Summer

The exterior wall of Burj Dubai is made up of high performance curtain wall system, while a double wall is utilized in the glass pavilions to maintain transparency. The building is naturally ventilated, where possible, including the garage and the spire. Carbon Dioxide and Indoor Air Quality sensors are designed to provide demand limit ventilation. An alternate for variable speed fan coil unit is included in the project. Chilled water pumps and air handling unit, where possible, are equipped with variable speed drives. Photovoltaic paneling was considered to be placed on the spire to provide electricity; however, was not incorporated due to economic reasons. Dedicated outside air handling units and fan coil units serving hotel and residential spaces were designed with heat wheels.

A condensate recovery system is designed to collect the condensate from cooling coil to the expansive surrounding landscape and to pre-cool incoming water to the building. Since the incoming water is hot in the summer (refer to "Plumbing Systems" discussion), the incoming city water is cooled by the condensate prior to reaching the storage tanks. It is estimated that this system will provide 9.8 million gallons of irrigation water annually, with a maximum of 6280 cubic feet of water in a single day (Figure 6).



CONTROL SYSTEM

A DDC system with wireless access capabilities ties the control of all the building systems together. The DDC system will interface with more than 30 other building systems to control the building. This includes a "Life Boat Operation" that allows an operator to use joystick to operate a camera to view the integrity of an elevator shaft prior to using the elevator as a means of non-fire related evacuation.

SUMMARY

The culmination of the above efforts is a balanced combination of super tall building systems in hot and humid climate on the forefront of safety, energy efficiency, sustainability, comfort and operation. Systems are derived out of the super high rise nature of the building and the hot and humid nature of the environment. The HVAC system has concentrated outside air intakes to isolate the impact of the outside air and most fan components of the system can be dynamically adjusted according to the micro conditions of the building. The plumbing and fire protection systems utilize the height of the building to provide gravity feed systems and water is treated according to the incoming conditions. The electrical system has to account for the high voltage drop and also the possibility of a harsh environment during power outage. All systems have to work together seamlessly and harmoniously to support the activities in this land mark construction.

References:

*"**INVESTIGATION OF PRESSURE CAUSED BY STACK EFFECT, BURJ DUBAI, DUBAI, UNITED ARAB EMIRATES**", Private report prepared by Rowan Williams Davies & Irwin Inc. , Oct 4, 2005.*