TITLE Customizing Factory Built Unit for Efficiency,
Reliability and Cost Effectiveness

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KEY WORDS

∞ Air Handling ∞ Energy Award
∞ Energy Conservation ∞ Low Temperature
∞ Operating Cost ∞ Owning cost
∞ Office Building ∞ Energy Management

<u>**CUSTOMIZING FACTORY BUILT UNIT FOR EFFICIENCY, RELIABILITY AND COST EFFECTIVENESS**</u>

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INTRODUCTION

In 1993, City of Riverside (in Southern California) decided to construct a new 'Operations Center' for the Public Utilities Department, which provides electricity and water services to the City. The Operations Center was to include:

- Central Operations Control Center (24-hour operation)
- Data Processing Computer Room (24-hour operation)
- Administrative Offices (10-hour operation)
- Engineering Offices (10-hour operation)
- Conference Rooms (10-hour operation)
- Clerical Staff Areas (10-hour operation)
- Provisions for ± 20% floor space expansion at second floor.

Since the Public Utilities Department provides electricity and water services, the Owner wanted the building to be a 'Showcase and Educational Facility' for the clients, by incorporating energy conservation features, in the use of electricity, water and building envelope. With-in these parameters Owner also wished to showcase the application of thermal ice storage for off-peak cooling and high indoor air quality.

For the heating, ventilation and air-conditioning (HVAC) system, Owner stressed the need for:

(1) Cost effectiveness

(2) Energy efficiency

(3) Serviceability

(4) Accessibility – for clients viewing

(5) Meet the need for future expansion of the building

State of California has energy efficiency standards, known as Title-24, which is somewhat similar to ASHRAE Standard 90.1. This efficiency standards indicate minimum required efficiencies for equipment as well as energy usage in watts/m^2 per year (BTUH/FT^2/YR).

The base HVAC system application for this building consisted of packaged rooftop heat pump units, meeting the minimum energy efficiency per Title-24. Designing an energy efficient HVAC system was a challenge due to constantly fluctuating number of people (50 to 370); some areas requiring 24-hours occupancy; employees being dispatched to field after reporting to work in the morning and meeting at the end of the day for reporting.

Building Architecture

The architectural footprint includes a two-story, 2656 m^2 (28,600 ft^2) structure with future expansion of 465 m^2 (5000 ft^2) at second floor level. The front of the building faces the South side. The metal wall framing has R-19 insulation with drywall board inside and stucco on the outside. The roof metal deck has R-30 insulation. Dual glazed windows with 1.3 cm (1/2 inch) air space and solar gray coating and low 'e' coating to help achieve additional thermal performance benefits. See Figures 1 and 2 for building layout and departmental simulated zones, for first floor and second floor respectively.

HVAC System Alternatives

A 20-year life cycle analysis was performed to review the alternate energy efficient and cost effective systems. The computerized analysis was based on:

- System installation cost
- Annual operating cost
- Annual maintenance cost
- Annual escalation costs

The HVAC systems analyzed, included the application of variable air volume (VAV); electric chillers (R-22), pumps and cooling tower. Since Owner is the provider of electric service, the use of natural gas was not considered. The alternate HVAC systems analyzed were:

1. VAV with electric reheat and air-cooled chiller.
2. VAV with electric reheat, air-cooled chiller and thermal energy storage.
3. VAV with electric reheat and water-cooled chiller.
4. VAV with electric reheat, water-cooled chiller and thermal energy storage.
5. Fan-powered VAV with electric reheat and air-cooled chiller.
6. Fan-powered VAV with electric reheat, air cooled chiller and thermal energy storage.
7. Fan-powered VAV with electric reheat and water-cooled chiller.

Thermal Energy Storage (TES) Considerations

Two (2) conventional system operating strategies of 'load leveling' and 'load shifting', were compared for 'encapsulated ice' thermal storage, with nine (9) TES system operating strategies, based on the Client's use of three (3) basic metering methods:

1) General Service (GS)

2) Time of Use (TOU)

3) Super off-peak (SOP)

The TES system operating strategies for each type of metering included:

1) Load Leveling (GSL, TOUL, SOPL)

2) Load Shifting – 1 (GSS1, TOU1, SOP1) for peak hour shift

3) Load Shifting – 2 (GSS2, TOU2, SOP2) for mid and peak hour shift

The simulation utilized ASHRAE algorithms in its calculations for 'hour-by-hour' analysis using Trace 600 simulation program. The design analysis was run once for each of the operating strategies and meter combination. The chillers either operate to satisfy building load; charge the storage; discharge the storage; or do not operate.

The Client wished to use the 'TES' Study for educational purpose for the customers, therefore, various types of in-depth spreadsheet and graphic analysis for "hour-by-hour", "day-by-day" and "month-by-month" were performed for each strategy listed above.

The time of use load leveling strategy (TOUL) provided a simple payback of 3.5 years; time of use-peak hour shift (TOU1) provided a simple payback of 7.8 years and time of use, mid & peak hour shift (TOU2) provided a simple payback of 17.7 years when compared to the conventional 'Base Case'.

Architectural Considerations

Architect's initial plans indicated the mechanical equipment on the roof. However, the Owner desired to have a mechanical room at grade that would be easily accessible for visits by the customers. The cost of the mechanical room walls, roof, air handlers, pumps, chiller and control room, etc. exceeded the budget by $240,000, out of which $184,000 accounted for mechanical. Therefore, alternative method had to be explored to meet budget and desired HVAC system. Owner provided additional funding of $50,000 towards the additional cost.

HVAC System Selection

Based on the 20-year life cycle analysis, fan-powered variable volume boxes with electric reheat and air-cooled chiller provided a payback of 5-1/2 years over the base system of Packaged Roof Top Heat Pump units. By incorporating the thermal energy storage for peak-hour load shifting the payback period increased to 7.8 years. See Figure 5 for Storage Regeneration/Discharge Profile and Figure 6 for Profile of Load serving equipment for the month of August. The life cycle study showed the Base System's annual power consumption at 855 KWH and for the system selected at 625 KWH, providing a saving of 27%.

The mechanical system described, provides conditioned air during the building occupancy from 800 hour to 1800 hour on Monday through Friday, except for the Computer and Data Processing Room, which is conditioned 24 hours a day by its own computer room cooling unit. A packaged roof top heat pump unit maintains the environment in the Central Operations Control Room from 1800 hour to 800 hour on Monday through Friday and 24 hours on Saturday and Sunday.

The fan powered variable volume boxes include 3-stage electric heater. The fan is provided with a solid state speed controller to help adjust to proper flow of plenum air to mix with low temperature supply air.

Low Temperature Supply Considerations

The application of low temperature supply air at 6^{o}C (43^o F) in-lieu of 13^{o}C(55^o F), provided additional benefits in downsizing of air-handler fans, ductwork, chilled water pump, chilled water pipes, duct and pipe insulation, valves and fittings, dampers, fan and pump motors, etc. A basic comparison is shown in Table-4. Low temperature application helped reduce the material cost by $56,000.

COMPARISON OF SIZES & CAPACITIES

LOW TEMPERATURE SUPPLY AIR VS STANDARD SUPPLY AIR

ITEM	13.0ºC (55ºF) SUPPLY AIR		6ºC (43ºF) SUPPLY AIR		REDUCTIONS
	SI UNITS	IP UNITS	SI UNITS	IP UNITS	%
SUPPLY AIR	16,500 L/S	35,000 CFM	11,800 L/S	25,000 CFM	28.5%
RETURN AIR	13,700 L/S	29,000 CFM	9,000 L/S	19,000 CFM	34.3%
MINIMUM OUTSIDE AIR	2,800 L/S	6,000 CFM	2,800 L/S	6,000 CFM	NO CHANGE

	13.0ºC (55ºF) SUPPLY AIR		6ºC (43ºF) SUPPLY AIR		REDUCTIONS
MAIN SUPPLY DUCT SIZE ±2200 FPM	152 X 102 CM 1.55 M²	60” X 40” 16.67 SF	152 X 76 CM 1.16M²	60” X 30” 12.5 SF	25.2%
SUPPLY FAN SIZE BHP/TSP	125 CM 47.71368 PA	49” AF – PLUG 47.7/5.5” W.G.	112 CM 31.3/1368 PA	44” AF PLUG 31.3/5.5” W.G.	1 SIZE 34.4%
RETURN FAN SIZE BHP/TSP	137 CM 11.4/373 PA	54” AF PLUG 11.4/1.5” W.G.	125 CM 7.0/373 PA	49” AF PLUG 7.0/1.5” W.G.	1 SIZE 38.6%
CHILLED WATER FLOW/ T	16.4 LS/ 5.5ºC	260 GPM/ 10ºF	8.2 LS/ 11ºC	130 GPM/20 ºF	50%
TOTAL COOLING CAPACITY	440 KW	1,500 MBH	440 KW	1,500 MBH	NO CHANGE
PIPE SIZE	10 CM	4”	7.5 CM	3”	25%

TABLE - 1

Factory Built Custom Unit Consideration

Having designed many custom built air-handlers and some as complete units including refrigeration, we developed the concept of a, ‘Factory Built Mechanical Room’, that would house all the elements, which would have been in a field built mechanical room. A preliminary concept drawing and system performance data were distributed to three (3) manufacturers of custom-built HVAC products and all three (3) indicated that proposed concept was doable.

Unit Procurement Considerations

Since the proposed concept was something unique, we advised the Owner to pre-qualify the three (3) manufacturers we had contacted initially, for the purpose of bidding and pre-purchasing of the unit. Performance specifications and a concept drawing of unit were distributed and based on the low bid, a vendor was selected.

Owner also negotiated the percent of mark-up by the mechanical and general contractors for the pre-purchased unit for its handling and installation. This negotiation helped save $27,000.

CUSTOM BUILT UNIT DEVELOPMENT

Performance Criteria

The performance criteria included, insulated double wall construction with interior wall of perforated sheet metal; supply/return/minimum outside air quantities (including for future addition to the building); external static pressure losses; pre-filter and high efficiency filtration; air-foil plenum fans for supply air and relief air; forward-curve fan for minimum-outside air; capacity of compressors; cooling coil capacity; variable frequency drive for supply fan, relief fan and minimum outside air fan; chilled water distribution and ice making pumps; control room with direct digital energy management system and a through the wall air conditioning unit to cool the Control room. Some of the performance quantities are shown in Table-1 on previous page.

Unit Layout

Figure – 5 shows the overall layout of the custom built unit and Figure-6 shows a photograph of actual installation. It was divided into four (4) sections for shipment, identified by 'DM' (demount). Unit's functions are divided into three (3) sections: 1) airside section, 2) refrigeration side section and 3) control room as described below.

1. Airside Section

   With-in the airside section, a minimum outside air fan provides outside air at 9 L/S (20 CFM) per person, for an occupancy of 50 – 300 persons. A CO^2 sensor (set at 700 PPM) in the main return air duct, controls the VFD on the outside air fan to maintain indoor air quality. Additional outside air is brought in via outside air louvers, that modulate to provide up to full outside air economizer. The outside air is pre-filtered with 35% efficiency pleated filters.

   The outside air and return air mixture is filtered through a 35% efficiency pleated-filter and 65% high efficiency filters. Plenum fan pushes the mixed air over the cooling coil for distribution to the building. A 7.6 cm (3" round) blank conduit is connected between downstream of chilled water coil and variable speed drive compartment to cool the drives. The variable speed drive compartment has a 10 cm (4” round) opening for air to return to mix air section.

The supply fan is controlled via static pressure sensor in supply air duct in the building. The relief air fan is controlled via a space-mounted sensor to maintain pressure with-in the building. The relief air is discharged into the refrigeration section where it helps provide ventilation and cools the pumps and compressors.

Flow monitoring probes are located in the main supply air, return air, relief air and minimum outside air. The air flow readings help to identify the air quantities at any given time.

2. Air Side Components

The major components used in this section, their sizes and types are as follows:

∞ Supply Air Fan: 112 CM (44-inches) diameter, airfoil centrifugal plenum fan, single width single inlet (SWSI), Class II rating, protective screen enclosure, blower inlet screens, seismic spring vibration isolators and restraints, fixed pitch sheaves with safety belt guard, extended re-lubrication lines, high efficiency motor with slide out base, and variable speed drive with bypass and direct digital controls.

∞ Relief Air Fan: 125 CM (49 inches) diameter fan with all items as noted for supply fan.

∞ Outside Air Fan: The minimum outside air fan is 40 CM (16 inches) forward curved, double width double inlet (DWDI), Class I rating with other items as noted for supply fan.

∞ Cooling Coil: 12 row chilled water coil of copper tubes, 260 CM fin length x 122 CM fin height (102” x48”). Rated per ARI.

∞ Drain Pan: Insulated stainless steel construction with drain connection.

∞ Filters: 30% pre-filters and 65% high efficiency filters rated in accordance with ASHRAE 52-76.

∞ Dampers: Aluminum airfoil opposed blade dampers with low leakage.

∞ Sound: Double wall construction with perforated panel on inside helped eliminate the need for any duct mounted sound traps.

3. Refrigeration Side Section

Within the refrigeration side section are: two (2) compressors; chiller evaporator; evaporative condenser; loadside chilled water pump; ice making mode charge pump; make-up water tank; expansion tank; relief & ventilation louvers and ventilation exhaust fan.

All components are factory pre-piped, valved with all control sensors, monitors and gages. When relief air discharge into this section is not able to cool this section, a thermostat, located near compressors, brings ‘on’ the wall exhaust fan. In which case, the relief air louver becomes outside intake louver.

4. Refrigeration Side Components

The major components used in this section, their sizes and types are as follows:

- Compressor: (2) open drive compressors with direct drive coupled high efficiency motor. Each compressor rated at 280 KW (80 tons) with 2-step unloading, discharge muffler, test gauges, safety switches, vibrasorbers for suction and discharge lines.
- Refrigerant Circuit: For each compressor it includes all piping with UL approved receiver having relief and outlet valves, filter drier with replaceable core, sight glass per circuit, liquid line and hot gas bypass line solenoid valves.
- Evaporator: Shell and tube evaporator barrel with removable head and fully insulated.
- Evaporative Condenser: 107 CM (42”) adjustable pitch, 9-blade, high strength, glass reinforced PVC airfoil propeller fan, severe duty motor, condenser coil of staggered pattern of copper tubes with copper header, mist eliminator, non-clogging spray nozzles, mastic coated steel pump with fine mesh pump strainer and copper float make-up water valve, close coupled bronze fitted centrifugal type and mechanically sealed pump, and fully corrosion protection coated.
- Expansion Tank: ASME rated horizontal tank.
- Pumps: floor mounted centrifugal pump, direct coupled, and high efficiency motor for chilled water circulation to coil and for ice making mode. Glycol make-up system includes an in-line type centrifugal pump.
- Exhaust Fan: Wall mounted, direct drive propeller fan with discharge and inlet screen.
- Power: Main electrical power panels are located in this section with a single high voltage main power connection, a separate circuit for units lights, receptacles and control room air conditioner, and a separate dedicated circuit for direct digital controls.

5. Control Room

The uniqueness of this custom built unit is the ‘Control Room’, which is equipped with desks, chairs, direct digital control panels, computer monitors and printer. The client can stand with-in this room and see the performance of the unit. A through the wall air conditioner helps cool the control room and the control equipment.

The client already had in place direct digital energy management control system for their facilities. Therefore, same system is housed in this Control Room.

CUSTOM BUILT MECHANICAL ROOM PLAN

FIGURE - 5

ACTUAL INSTALLATION

FIGURE - 6

CONCLUSIONS

Unit Efficiency

In addition to the design and operational efficiencies, the factory built-unit provided added efficiency to the project.

1. Eliminated the need for a site built mechanical room.

2. Custom built unit occupied half as much floor space then would have been required by the field built mechanical room. This helped provide space for TES ice tanks.

3. Factory testing and balancing minimized field adjustments.

4. Minimized field power connections to (1) for high voltage, (1) for lights and receptacles and (1) dedicated power for direct digital controls.

5. Easy assembly of (4) sections with minimum connections for duct and piping by the manufacturer's representative helped assure the integrity of the unit.

6. Major components that helped increase efficiency are: 1) variable frequency drives, 2) low temperature supply air, 3) direct digital controls, and 4) evaporative condenser.

7. Actual power consumption for the 12 month period (April 97 to March 98) was at 567 KWH (in thousands), whereas the life cycle analysis based on 'hour-by-hour' analysis, had shown annual consumption at 625 KWH. This indicates that the system is operating with-in the projected efficiency. This difference can also be attributed to 'actual weather' for operation Vs 'weather data' for life cycle analysis.

UNIT RELIABILITY

In any given mechanical system, the reliability is of utmost importance. This custom built unit helped provide that utmost reliability by:

1. Continued coordination and supervision during fabrication of the unit.
2. Testing and balancing of air and water side systems for capacity and performance.
3. Integration of direct digital controls and ability to test all parameters.
4. Ability to witness the testing by Owner's operating engineer, design engineer, at the factory.
5. Manufacturer's ability to make corrections and/or changes per testing, prior to shipment of the unit.
6. A single source responsibility for training of building operators.
7. A single source responsibility for the warranty.

COST EFFECTIVENESS

Application of custom built units may not be cost effective for every project. However, for smaller projects, value engineering analysis could be performed to determine the cost effectiveness approach, as it has proven to be cost effective for this project. The client realizes additional cost savings than just noted for the initial cost savings.

1. First cost savings include $56,000 for low temperature air application, $150,000 over field built mechanical room and $26,000 in contractor’s mark-up cost on equipment.
2. Owner’s added share was under $10,000 vs. $50,000 budgeted.
3. Owner’s maintenance department saves time and money by having to contact a single source for service and warranty work.
4. Direct digital controls help maintain unit in its peak operating condition by maintaining a trend log of service, failures and operation.
5. Unit helped conserve valuable floor space

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