USING ADVANCED TECHNOLOGIES IN THE NEXT GENERATION OF HIGH POWER DENSITY TELECOMMUNICATIONS FACILITIES

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ABSTRACT

The use of wireless data devices is increasing at an unprecedented level both in existing and emerging markets across the globe. The popularity of media sharing, high definition audio and video streaming, interactive gaming and social media dominate the industry. As the content availability, device capability, and service affordability is extended further into the population, the expectation of continued performance increases will be integral to the user experience.

This extreme call for wireless data services is multiplying annually at an exponential rate, driving the evolution of network equipment required to support these services. This new equipment is substantially different from traditional (Original Equipment Manufacturer) OEM voice switching systems which tended to consume lots of space and required only moderate power and cooling levels. The latest high density (Internet Protocol) IP platforms supporting data services have increased processing capacity for given space, but they have also increased power consumption levels disproportionately. The growth rate of these combined services, with the pressure to deploy them cost effectively, has overwhelmed many operators' ability to support the demands. The inability to support these systems has resulted in the delay of equipment deployments and/or placing the (Mobile Switching Office) MSOs themselves at risk of system failures.

This paper will discuss the limitations of current communication facility infrastructure and the latest technology currently being deployed to combat the remarkable increase in capacity needed to support the new services. We will explore the common constraints facility engineers are facing when deploying high power density platforms and the solutions that can provide long term success to support continued growth. Finally we will examine some of the initial field applications of the latest Direct Distribution High Density (Direct Current) DC power, (Sodium Metal Chloride) SMC battery, and direct exchange refrigerant based cooling solutions commercially available.

INTRODUCTION

The communication operators face the difficult task of deploying the latest technologies in pace with growth expectations into critical facilities that were originally designed to support much lower power densities than is required for today's equipment. Any of the newest data support systems being deployed are built from the newest modular hardware, configured into specific application platforms by OEM integrators and other solution providers. These modular building blocks, usually deployed redundant or pooled, commonly range in size from 1 kW to over 18 kW. The combined modules are integrated into core systems, as small as a single rack or cabinet consuming < 2 kW or as large as multiple equipment lineups consisting of many cabinets > 10 kW each.

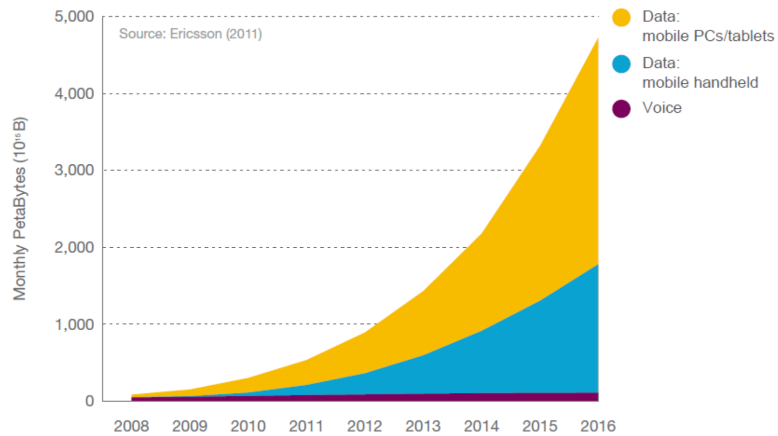

Figure 1. 10X Mobile Data Traffic Growth Predicted[1]

The data use is steeply increasing; the need to quickly resolve the demands on the power and cooling systems the growth requires will be beyond the capacities of the traditional infrastructure. The current data services equipment requires facilities to support cabinet power densities of 3-6 kW each, and the industry growth trends predict > 12 kW cabinets will be required beyond 2016. Engineers will be required to look outside of traditional design methods and equipment to support the trend.

In response to the avalanche of deployments in early 2010, design teams began the development of new requirements to dramatically increase the facility capacity. The key goal was to create an efficient and scalable facility design that could be utilized in both existing retrofits and new ground-up construction. One of the top requirements was to eliminate the restrictive power and cooling elements that have plagued traditional designs and limited maximum power density.

Facility Systems Design Limitations

Over the last 30 years the communication industry has evolved to provide new competitive services. The operators have endured growth organically and through consolidation. The constant changes allowed many of the critical operating facilities to fluctuate in design and capacity; some have reached design life, others are aging or neglected, and many have been unsystematically upgraded multiple times placing them at risk for systems failure.

Communication facility designs range in size by location, from the small 1000 sq. ft. collocation to the largest > 20kft^2 dedicated facilities. Most were designed to support a maximum 40-70 W/ft^2 load power density; even the best-designed and maintained facilities are now having difficulty supporting the latest high-density equipment deployments.

Primary areas of concern that have been restricting growth in the communication facilities are:

1. Confined spaces for the critical power and battery systems restrict growth.
2. Cooling systems unable to support densities above 100 W/ft^2.
3. The requirement to deploy much higher power density equipment than traditional designs tolerate.
4. Facility expansion timelines make it difficult to meet market expectations.
5. The need for new tools to support the next generation of equipment.

Centralized Power Systems

The -48V DC power sources used in many telecommunication facilities have been designed using one or more large single bus systems approaching 500 kW in capacity. The centralized power plant designs utilized large modular rectifiers connected to high current primary load and battery distribution system cabinets. These primary circuit feeders account for a large percentage of the installation costs, require heavy infrastructure to support, and can result in unnecessary power losses in the system.

The critical facilities batteries used to provide backup support have been lead acid technology. Both Vented Lead Acid (VLA) and Valve-Regulated Lead Acid (VRLA) systems have been the accepted solution. Most systems are designed with 4-8 hour battery reserve times. The large physical space requirements and added maintenance clearances with these traditional technologies increase overall consumed floor space and add to the high cost primary cabling.

Centralized battery and power systems are usually deployed in separate specialized rooms that increases the distance between the power source and critical equipment loads, introducing loss and limiting maximum density. The separate equipment areas each require cooling and support systems, consuming additional space and energy.

In summary the limitations of traditional DC power systems are as follows:

1. Centralized systems tend to be less space-efficient in order to support large cabling for primary distribution
2. Traditional designs specified dedicated spaces for battery and power supplies, increasing cost for separate environmental support systems and overall floor space
3. Upgrades or expansions are specialized and risky to existing infrastructure
4. The size and quantity of load circuits needed to support new equipment exhausts traditional primary and secondary distribution systems
5. Primary to Secondary load cabling is very costly, incurs significant power losses, and consumes critical space

Centralized Cooling Systems

Because air is a poor conductor of heat, forced air cooling system designs using ambient air to transfer heat away from the data equipment greatly limits the maximum power density. The facilities using forced air (Direct Expansion) DX cooling type systems tend to consume tremendous amounts of energy without providing effective cooling to high density equipment. Maintaining the efficient operation of these systems has created never ending difficulties for operation and maintenance teams.

In summary the limitations of traditional cooling systems are as follows:

1. Forced-air cooling is ineffective and costly
2. Increasing system capacity to support higher-density cooling is difficult
3. Hot/Cold aisle designs store excess heat energy in critical space until it can be removed
4. High volume air needed to cool high-density equipment creates uncomfortable working environments
5. Mixing of Hot and Cold air flows reduces the efficiency of the cooling units

Combined Limitations Restrict Power Density and Limit Growth

The common design of centralized systems often limits the facility's maximum capacity due to confined floor space and cable congestion. Unfortunately the need to support new data services has now overwhelmed the power and cooling systems using this design technique. As the telecommunication equipment power density demands increase, the design of the centralized systems has several limitations:

1. Segregated equipment rooms create limited space to expand without costly room expansions
2. Expansions tend to move power and cooling sources farther from load, increasing losses and overall cost
3. Upgrades or expansions are costly and risky to complete economically on-schedule
4. Many times ultimate growth is blocked due to poorly planned space utilization.

These conditions lead to very limited cost and/or time effective options to support growth of new equipment.

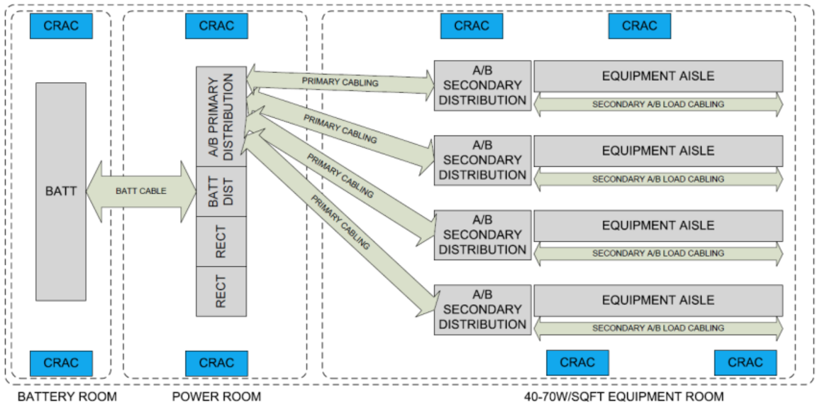

Figure 2. Traditional Facility Design

The High Density Facility Design Provides a Solution for Growth

The need to support increasing power demands over 200 W/ft^2 with scalable and cost-effective modular growth at the highest levels of redundancy and reliability required a new design concept. The Direct Distribution of the critical facility systems was the response to managing the growth. All core facility system elements were optimized to support the highest available power densities in the smallest amount of building space. The design scalability would be intended for equipment room configurations ranging from < 4000 to > 18,000 sq. ft., supporting 200 to 800 high-density equipment cabinets.

The Direct Distribution architecture would minimize power loss, afford a huge reduction in costly cabling, and most of all maximize power density. The design would also improve the facility cooling systems by removing the heat load from the revenue equipment directly at the source and transferring it to exterior spaces with very little expended energy, thus relieving the internal space from additional power consumption and heat dissipation from moving the heat to the cooling sources.

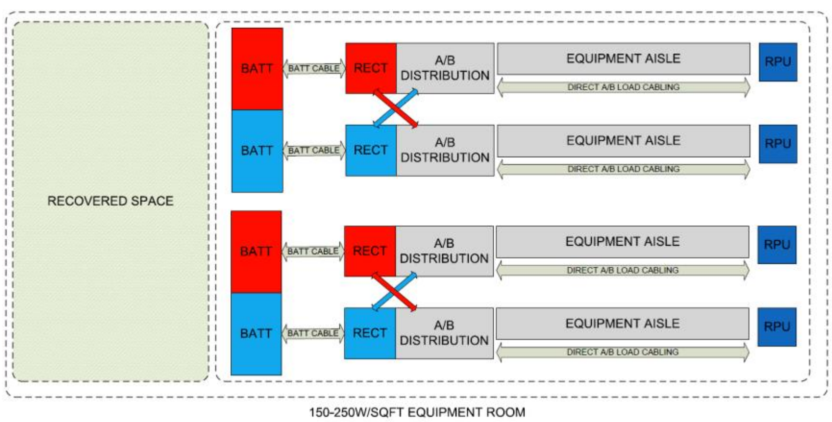

Figure 3. Direct Distribution Facility Design

The Direct Distribution DC Plant Application Details

The key attributes of this new design were to maximize power density within revenue space, support loads up to 135 kW per equipment aisle, and place the power source in close proximity to the load. The DC plants would be deployed in system pairs, one on each production equipment aisle, to create a system group. Multiple system groups would be deployed as demands increased.

To eliminate equipment outages due to a single bus failure, the decision was to configure two direct distribution systems for A/B rectifier and battery redundancy. When full capacity is called for, a system pair would be located every two aisles. Initially, to minimize deployment costs; the system pairs are designed to support additional equipment aisle loads until demands increases, then additional system groups would be added as necessary. The direct distribution power system groups are capable of supporting equipment loads in excess of 135 kW per aisle or multiple equipment aisles at lower power density. Deployment of the direct distribution architecture along every equipment aisle was the one of the keys to obtaining > 200 W/ft^2 load density in a minimal amount of facility space.

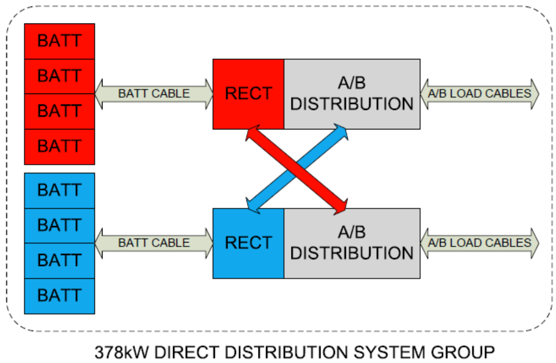

Figure 4. Direct Distribution System Group

The Battery Technology Density Challenge

To reach the high density goals the battery was at the very top of the requirements and required a fresh look at the newest available solutions. The team needed to determine which one was the correct solution to complement the overall design. The solution had to be commercially available and a proven technology.

A thorough evaluation of available battery configurations in both traditional and emerging technologies was conducted. The highest density models of VLA, VRLA (Absorbed Glass Mat) AGM, Tubular Plate Gel (OPzV) Lithium Ion (LI ION), and Sodium Metal Chloride (SMC) were considered for the battery solution to complement the Direct Distribution system design. The key desired attributes the team took into consideration were:

1. The maximum power density of the installed foot print
2. Operation at $C_1 - C_4$ discharge rates
3. Consistent performance regardless of temperature
4. Modular and scalable architecture
5. Facility impact to life safety systems
6. Long service life

The data in Tables 1 & 2 and Figures 5 & 6 represent key attributes evaluated for the goals outlined above.

Battery Type	Ah	Equipment Ah/Ft^2	Installed Ah/Ft^2	Lbs/Ah	Years Service Life	Max Discharge Cycles	Max Discharge Rate
VLA	4000	107	30	4.3	20	40-60	>C1
VRLA	3000	267	99	1.9	20	1200	>C1
OPzV	3000	116	57	4.0	20	1000	>C1
LI ION	3600	400	160	1.3	10	625	C3
SMC	3200	338	171	1.8	20	2000	C1

Table 1. Size/Capacity & Life Comparisons[2]

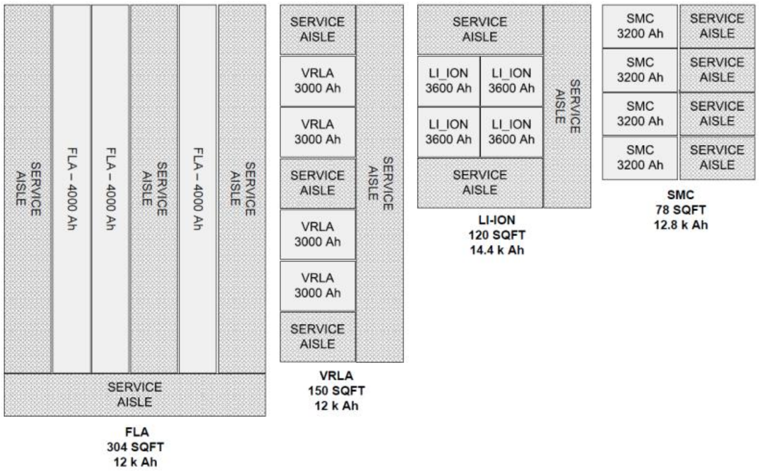

Figure 5. Battery Layout Space Comparison

Battery Type	Ah	C1 Rate	C2 Rate	C3 Rate	C4 Rate	C5 Rate	C6 Rate	C7 Rate	C8 Rate
VLA	4000	1728	1219	959	799	689	610	550	494
VRLA	3000	1662	1053	793	643	544	472	418	375
OPzV	3000	1398	1000	774	635	536	465	410	371
LI ION	3600	**	**	1152	868	712	600	514	450
SMC	3200	2088	1467	1058	800	640	530	450	387
		* rate data not published		** non-operational conditions					

Table 2. Discharge Current in Amperes to 42VDC @ 77F by Type

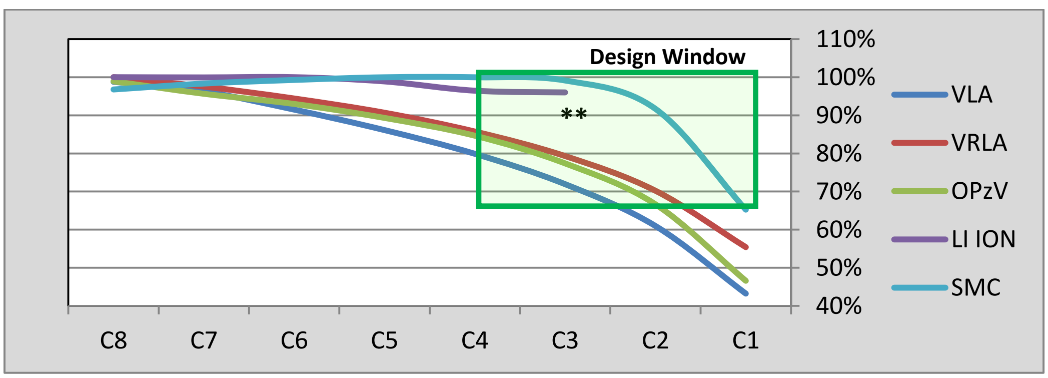

Figure 6. Discharge Performance(C Rate) vs Percentage of Capacity Rating

The SMC Solution to the Challenge

The SMC battery technology was chosen over the other designs to support the high power density requirements. The physical configuration of the battery systems was the first design driver. In Table 1 and Figure 5 the evaluation of floor space needed for the hardware (**Equipment Ah/ft^2**) plus the additional space required to service the batteries was used to determine the final installed value **(Installed Ah/ft^2)**. It was very apparent that even the densest of the traditional technologies consumed considerable more space than newer LI ION and SMC designs.

In Table 2 and Figure 6 the discharge performance shown within the preferred design windows was the secondary core design driver. At higher discharge rates, it was apparent that the traditional technologies provide significantly less energy than newer LI ION and SMC products. Consistent performance regardless of temperature being the third design requirement shows SMC's additional performance advantages. This advantage increases further when the full temperature range is considered, as no capacity de-rating is required between the operating temperatures of -20℃ to +60℃.

The space-efficient, scalable and modular designs (SMC & LI ION) matched core requirement number 4. The ability for the vendor to design the SMC technology in a fashion similar to modular rectifier systems was essential to allowing a scalable buildup to meet required forecasted density goals. The additional benefits of an advanced (Battery Management System) BMS and its capacity monitoring capabilities are a large improvement over existing technologies.

Facility safety concerns in point 5 are improved using SMC's fully sealed system. Both indoor and enclosed environment installations require no venting to avoid the accumulation of any gases. Although SMC technology is very hot inside the cell structure, there is little internal pressure that could cause any gassing or reactions that could rupture the containment in either operating or non-operational conditions. The inherent safety of the SMC chemistry includes no secondary electrochemical reaction producing gaseous chemicals (like Hydrogen or Oxygen) during service operations or storage. Since the failure mode of the SMC cell is a short circuit, the impact of single or multiple failures are minimized by the small impedance differential exhibited between a normally operating and a failed cell(s). Cell failures will not cause catastrophic over temperature events or lead to cascading failures.

Each module's Battery Management System provides an additional layer of safety by analyzing critical parameters, and disconnecting the module to protect system operation if required. The BMS also provides module status, including voltage, current, state of charge, operating temperatures and system warnings and alarms

Cycle and service life performance shown in Table 1 indicates the SMC battery exceeds the compared technologies. Capacity is unaffected by age or extended float service operation as the active materials are never depleted. The capacity of the technology does not degrade during storage or if removed from service for extended periods. Full state of charge can be maintained in storage and recovered if the application requires.

The new technology hardware is a cost premium compared to the traditional equipment. When the initial cost of the hardware, installation materials, and the installation labor is calculated, the pricing gap is reduced to double that of traditional systems. Where the application conditions require high density to support the equipment demands, this can be the solution to continued growth. The calculation of ownership over the full life cycle improves the SMC payback when matched to the overall space used and life expectancy of the more commonly used VRLA products.

The leading performance of SMC systems for this application can be contributed to the manufacturer's product design teams spending the time to learn the requirements and then perfecting the technology to support the application.

SMC Battery Group Application Details

The highest density battery system configuration was critical to the Direct Distribution system to minimize floor space and cabling requirements. The design required supporting redundant critical loads of up to 280 kW @ the 4-hour rate, with a combined group capacity of ~24 kAh. The battery should be constructed with cable-less modules, designed to slide into front access cabinets as load demand grows.

The currently available SMC module selected is a 48 V 200 Ah assembly. Each module is made of individual 40Ah metal-cased prismatic cells. The operating voltage range of each SMC cell is 2.20-2.70V with a fully charged OC of 2.58V. The 48 V, 200 Ah modules are constructed with five parallel strings, each containing twenty cells. The 5x20 cell pack is enclosed inside an interior metal box, and then thermally insulated from the exterior metal container providing double wall protection. The completed module operation range is 42-59 V with an OCV of 51.6 V, the float charge range is 53-59V. Each module contains an output contactor that isolates battery energy from the system bus during initial warm up and protective modes.

SMC technology is considered to be a hot battery, operating at internal temperatures greater than 97℃ (206°F). The internal operating temperature of the SMC cell is between 270℃ to 350℃ (518°F-662°F). The cells are brought to the molten state with two resistive heating elements separately controlled by the BMS. The thermally-efficient, micro porous silica insulation contains the high internal operating temperatures to minimize heat losses to the environment, maintaining the exterior case within 10℃ (18°F) of ambient conditions. Under fully charged condition each 48 V, 200 Ah module will dissipate ~115 W @ 20℃ (68°F). The internal heater uses approximately 90% of this “lost” energy, with the electronics in the BMS consuming the remainder. Each module has a maximum recharge current of 40 A, which will recharge from an 80% DOD in approximately 12 hrs.

The SMC modules are combined into rack level groups rated at 3200 Ah / 153 kWh. The parallel connection of 48 V modules provides a very high level of redundancy in operation. Should a module fail, only a small reduction in capacity will be incurred. Front access shelves can be installed on an energized system with no disruption in service and are a key design element to plug-in battery growth. Once the slide in shelf module is installed, they can be left to self-commission, the additional battery will come on line gracefully, minimizing the upgrade costs and shortening installation intervals.

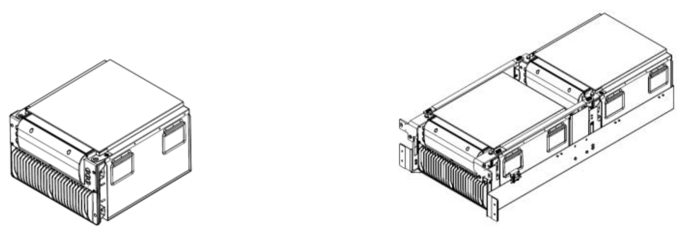

Figure 7. SMC 48V / 200Ahr and 400Ahr bolt-in Shelf Assembly

Figure 7 provides a detail of view of the 48 V 200 Ah / 9.6 kWh building block used in the high density systems. Two modules are arranged into factory-configured 400 Ah / 19.2 kWh, hot-swappable front-access shelf units.

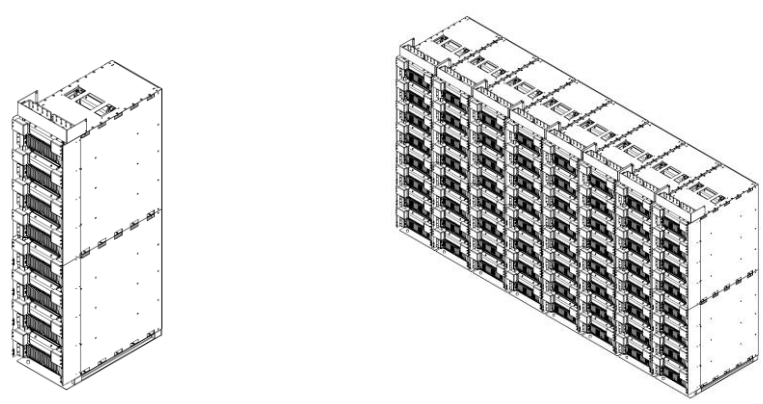

Figure 8. SMC48/3200Ah Group and 25.6 k Ah System

Figure 8 shows the front access 48 V, 3200 Ah / 152 kWh battery group, which contains up to eight 400 Ah modular shelf units. Each shelf module is designed to be installed and then activated with no service interruptions, comparable to when modular rectifier capacity is added to a DC power system. Up to eight 3200 Ah / 153 kWh racks can be combined, with four racks connected to each redundant DC system bus, providing 615 kWh of backup energy storage in 160 sq. ft.

The XD Cooling Systems Design

The final component in the high density equation was to effectively remove enormous heat load generated by the data equipment. The method chosen was to use a pumped refrigerant, two-phase low-pressure process, which efficiently removes the heat from the data equipment and transfers it to the exterior of the facility. The advantage of removing the heat directly at the source creates the highest delta T at the cooling coil, maximizing the efficiency of the heat removal. The RPU consumes very little energy in operation, using a maximum of 800W. The small 24 sq. ft. RPU footprints and coolant distribution systems use much less floor space than (Computer Room Air Conditioner) CRAC systems.

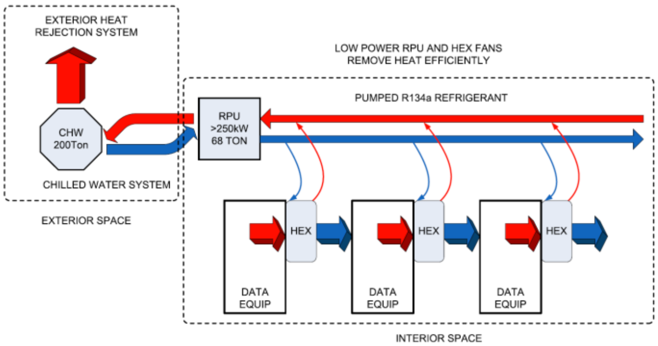

Figure 9. Refrigerant Based Direct Cooling System Design

Figure 9 details the interior and exterior components used in Direct Cooling Systems. The heat is transported away from data equipment to exterior heat rejection systems with up to 80% less energy than traditional Forced-Air systems.

Application of Direct Distribution Systems in operating MSOs

The designs discussed in this document have been applied to functioning MSOs in the United States supporting production systems. The installations are complete at three large facilities and multiple others are in design to early construction phases..

1. MSO 1 – FOA – 4000 ft^2, 150 W/ft^2 - construction completed / certification Q4-2011 - In production Q1-2012
2. MSO 2 – 4000 ft^2, 150 W/ft^2 - construction completed / certification late Q1-2012 - production Q2-2012
3. MSO 3 – 6000 ft^2, 250 W/ft^2 design – construction completed / certification late Q1-2012 - production Q2-2012
4. MSO 4 – 15000 ft^2, 250 W/ft^2 - design complete Q1-2012, construction start early Q2-2012 - completed Q4-2012

SUMMARY

The need to support data services at an escalated rate will continue to challenge the industry for many years to come. The capacity limiting conditions facility operators are contending with have pressed each of them to consider the newest solutions available.

The Direct Distribution solutions discussed in this paper have been successfully implemented in the field, making way for the most demanding data equipment. The facilities upgraded with these systems can support the highest equipment densities very efficiently. These flexible modular systems make use capital funds only when demand increases. The combined components can reduce the costs of heat rejection by 30-50% and lower total PUE by 20% for facility system operators.

This effort required endless hours of work with design teams, equipment suppliers and service providers, pushing for unique solutions in the latest technologies. The output of many had to be realized in an unrealistic time period, commitment to the requirements demanded the highest density and reliability designs the systems could provide.

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[2] EXIDE, FIAMM, FIAMM SONICK, ENERSYS, PUBLISHED PRODUCT DATA SHEETS – 2010/2011.