Modular/Container Data Centers Procurement Guide: Optimizing for Energy Efficiency and Quick Deployment

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Modular data centers, often in International Organization for Standardization (ISO) shipping container form factors, are being deployed by data center operators, and are marketed as an energy efficient and rapidly-deployable solution to enterprise customers, including federal government agencies.

For users, specifying "second generation" modular data centers featuring air-side economizers will ensure not only significant energy and operational cost savings, but also lower deployment costs due to a reduced need for support infrastructure.

This paper describes the key features of modular data centers, and guides potential users in selecting a feature set that best meets their energy efficiency needs.

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1 Executive Summary

Modular data centers reached prominence in 2007, are now offered by many suppliers, and are being deployed by "utility scale" data center operators such as Microsoft and Google and in smaller installations throughout the industry.

These units, which are often packaged in standard shipping container formats, are increasingly being marketed to users as a quickly deployable and energy efficient alternative to traditional data center designs.

Some designs from an early generation of modular units have limited energy efficiency advantages compared to traditional data centers, and their deployment can be complicated by a variety of infrastructure support needs, including the need for chilled water. They may remain a good choice in many cases including use as a short-term solution while existing facilities are rehabilitated, or in regions where climate conditions are not well suited for air-side economizer use. It should be noted that some recent designs using early generation cooling approaches provide excellent energy use performance

The latest modular units, which we have denoted as "second generation", feature on-board air-side economizer capabilities, often supplemented with evaporative cooling, obviating the need for a chilled water supply. These units therefore provide superior energy performance, and could be deployed more quickly and less expensively.

Six companies supplied thermal performance information used for an energy efficiency analysis for this guide. Modular data center offerings are changing rapidly, and the analysis represents a snap shot in time of available selected cooling system designs. The analysis of selected products reveals that modular/container data centers that require a chilled water supply have an average Power Utilization Effectiveness* (PUE*) of 1.16, while second generation units have a PUE* as low as 1.02. [1]

Users considering modular/container data center solutions should carefully consider energy efficiency attributes both as a means of limiting ongoing operational costs and also to minimize infrastructure expenses and installation time frames. Users will have the ability to drive the market to higher levels of efficiency or demand response by placing requirements in their procurement specifications. This could be driven by available power or cooling options or simply for operating cost containment. Eventually as computational metrics are defined (computations/watt), container specification, comparison and selection could be on a holistic basis.

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1 PUE* is defined as *(total power supplied to the module + power to produce externally acquired chilled fluid) / IT power and is* a rating developed for this paper specifically derived for modular/container units, ignoring lighting, UPS, external power transformers and backup generation. See section 5 and Appendix D.

2 Introduction

Container/modular data center infrastructure units came to broad market awareness in January 2007 with Sun's debut of "Project Blackbox", although Google revealed in 2009 that it had built a container data center in 2005 after developing the concept in 2003. (Google was awarded a patent in October 2008.)

Figure 1: Sun "Project Blackbox" Unit

Modular data center units are now available from many vendors including: (see Appendix A for contact information)

- Hewlett-Packard: Performance Optimized Datacenter (POD) family
- i/o Data Centers: i/o ANYWHERE
- SGI: ICE Cube, ICE Cube Air Modular Data Center
- Pacific Voice & Data: MCIE (Modular Critical Infrastructure Enclosure) Solutions and Disaster Recovery Mobile Data Centers
- Elliptical Mobile Solutions: MMDC (Micro Modular Data Center)
- Liebert: MDC20-XDR-53
- IBM: PMDC (Portable Modular Data Center)
- PDI: i-Con
- Cirrascale: FOREST Containerized Data Center (formally Verari FOREST)
- Dell: Humidor
- Oracle: Sun Modular Data Center (previously Sun "Project Blackbox")
- Lee Technologies: ITModules
- Telenetix: T-Cube
- Universal Networking Services: Datapod Containerized System
- NxGen Modular: NxGEN600
- BladeRoom Group Ltd: Blade Room system
- Bull: Mobull

Although most units conform to standard shipping container form factors (10-, 20- and 40-foot units), others are delivering units that are purpose built. Elliptical Mobile Solutions offers units at the smallest end of the scale, featuring single rack size solutions; other vendors such as SGI and i/o Data Centers offer modular units that can be "ganged" together or combined into large-scale deployments.

Figure 2: Data Center Featuring Container Units - Oregon

A large container data center located in Oregon houses forty-five 40-foot modular containers, with each container housing just over a thousand servers and requiring about 250 kW of power. The facility has a floor area of 75,000 square feet, and claims a Power Usage Effectiveness (PUE[2]) of 1.25.

A large container data center in Chicago IL, where facility load total exceeds 100 MW, uses forty-foot modular containers, each housing as many as 2,500 servers has a claimed PUE of 1.22.

Figure 3: A Chicago Area Data Center Featuring Stacked Container Units

Modular units are marketed to data center operators as a means of quickly adding capacity at lower costs compared to development of traditional "brick and mortar" data centers. Vendors are also portraying units as inherently more energy efficient, resulting in operating cost savings.

Potential users of these units should be aware of potential deployment challenges, including provision of utility power, back-up generation, and cooling system support infrastructure. Securing this infrastructure can significantly delay deployments and add capital costs.

Units that feature self-contained, on-board cooling systems using outside air and supplemental evaporative coolers obviate the need for cooling system support infrastructure. This advantage can result in quicker deployment, lower capital costs, and lower ongoing operating costs due to higher energy efficiency.

[2] PUE (Power Utilization Effectiveness) defined as Total Facility Power / IT Power by "the green grid", www.thegreengrid.org, The Green Grid Data Center Power Efficiency Metrics: PUE and DCiE - WP #6

3 Product Description

A primary differentiation between modular unit types is the design of the cooling system. We have defined "first generation" units as those that require cooling infrastructure support in the form of chilled water supply, or that use on-board direct expansion cooling units.

There are a variety of on-board cooling systems used in first-generation units including the following types:

- Chilled water or refrigerant cooling coils located above, behind or on the side of equipment racks. Figure 4 shows a design by HP that uses water coils located above the IT equipment.
- DX cooling coil units in any of the configurations noted above. The compressors and condensers for the DX system are mounted external to the module/container.

"Second generation" units feature essentially self-contained cooling systems relying on air-side economizers, with supplemental cooling such as evaporative coils.

This class of equipment requires no chilled water infrastructure support (water supply is needed for supplemental evaporative cooling).

Some vendors are offering second-generation units with other types of supplemental cooling systems, but fundamentally second-generation units are designed to operate using ambient air for cooling when environmental conditions are suitable.

Figure 4 - HP's POD Unit Featuring a Single Row of IT Rack Space. Cooling Design Uses Overhead Water-Cooled Coils

All currently available units require external power supply (they do not have self-generation capabilities), though several manufacturers offer containerized power generation modules for installations that lack electric utility service. Similarly, packaged chiller plants are available from some vendors.

3.1 Why Consider Modular Solutions

The primary advantages of modular data center units are potential ease and speed of deployment, and possible lower capital and operating costs compared to traditional data centers. See Appendix I for deployment scenarios.

This section includes a comparison of the primary attributes of traditional "brick and mortar" data centers with both first and second generation modular units. The following section contains checklists for operators considering deployment of modular units.

3.2 First Generation Unit Configurations

Vendors offer a variety of configurations of IT equipment rack placement and cooling unit orientations in first generation units.

The most common layout features a single row of equipment racks running the length of the container, with access aisles on either side (though in some cases access to the backs of racks is limited or achieved by physically moving the rack on a roller system). This layout mirrors a typical hot aisle/cold aisle data center configuration, and should provide excellent hot aisle/cold aisle airflow containment.

Oracle (previously Sun Microsystems Inc.) Sun's 20-foot unit, shown in Figure 5, features a unique configuration, with equipment racks arranged face-to-back on either side of a central aisle. Airflow from the back of each rack passes through a cooling unit before entering the face of the IT equipment in the next rack.

Figure 5: Oracle Sun Modular Data Center, Featuring a Unique IT Rack Layout

3.3 Second Generation Unit Configurations

Second-generation modular data centers are differentiated from early product offerings by their use of integral air-side economizers for example in one of HP's POD's, IBM's PMDC and SGI's ICE Cube Air shown in Figure 6. These units often supplement the air-side cooling with evaporative cooling, chilled water coils, or DX cooling units for those times when environmental conditions do not allow full use of the economizer.

The units feature "single pass through" cooling, requiring site positioning that allows for the intake of ambient air on one side of the unit and exhaust of hot air on the opposite side. (In low temperature conditions, the units may recycle a portion of the return air, particularly if humidification is needed.)

A single pass through design lends itself only to linear rack placement. The absence of cooling coils generally allows generous access to both the fronts and backs of racks. Consistent with good air management design rack space should be suitably blocked off to prevent loss of cooling airflow in this configuration.

Second generation units are suitable for placement only outside of structures, or in structures that are suitably ducted to provide ambient air supply and exhaust. Supply and exhaust air flows may be susceptible to mixing or recirculation under certain conditions.

Figure 6: SGI Ice Cube Air Modular Data Center Featuring Air-Side Economizer Cooling

3.4 Primary Attribute Comparison

Table 1 describes the differences in the primary attributes of traditional and modular data centers. Please note that the comparison of energy efficiency (and hence operating costs) can be directly related to the analysis performed for the development of this guide the comparison of time to deployment and capital costs are based on discussions with equipment providers.

Table 1: Comparison of Primary Attributes

Primary Attributes	Traditional "Brick and Mortar" Data Center	First Generation Modular	Second Generation Modular
Time to Deployment	Long – typically two years from design to commissioning	Potentially short – perhaps in months depending on site conditions and available infrastructure	Same as First Gen. Modular with advantage that reduced cooling infrastructure is required
Capital Cost	Highest – generally thought to range from 10-$20 million per MW of IT capacity	Lower – though there is a lack of documented deployment costs	Lowest – marginal increase in cost of unit, made up for by reduced infrastructure costs
Operating Cost	Variable, with legacy data centers having PUE's exceeding 2.0 and best-in-class designs approaching 1.2 or lower if using outside air for cooling	Similar to traditional data center using the same cooling type. Pre-engineering and better system integration may provide some advantages.	Similar to best in class legacy data centers that use air-side cooling.

As revealed in the analysis presented in this paper, second generation units are more efficient than any type of first generation unit. Purchasers should specify the desired energy efficiency using, for example, a PUE like metric. If an air economizer type unit is not possible discuss available chilled water supply options with potential vendors. If an existing chilled water plant will be used provide the thermal performance information to the modular data center vendor for inclusion in calculations of total energy efficiency and discuss the cooling capacity as a function of chilled water supply temperature. Data centers typically operate far below the estimated full load. The cooling design and control system should provide a high level of energy efficiency even when the IT equipment is operated well below its full load capacity. Consult with the IT equipment supplier and obtain the equipment hot air exit temperatures for reduced loads. Provide this information to the modular data center provider and ask for a reduced load estimate of energy use efficiency.

4 Purchasing Considerations

Suggested Modular Data Center Selection Process

- Determine IT Equipment Requirements
- Select Most Energy Efficient Cooling Type
- Decide on Additional Requirements
- Other Considerations

4.1 IT Equipment Requirements

The specification of a modular data center solution must include a listing of IT equipment requirements. The following types of information should be documented before engaging with modular data center vendors:

- Required initial and future rack space
- Required initial, average and future maximum IT power per rack in each module if multiple modules will be needed. Detailed list of IT equipment for each rack desired.
- Allowable maximum IT equipment inlet air temperature
- Minimum and maximum IT equipment cooling air exit temperature
- IT equipment air flow type (e.g. side entry or front to back)
- Required power connections per rack – i.e. single or redundant power input

4.2 Select Cooling Technology

The selection of cooling type can be split into two categories; outside-air cooled and all other types. Select a modular data center that offers outside-air as the primary cooling for the IT equipment. This assumes the site and environment will support an outside-air cooled solution. It is common for these units to have an option for supplemental cooling that will be used for a small percent of the time when the environmental conditions are outside that needed to support the IT equipment requirements. If an outside-air cooled modular datacenter will not be feasible select a cooling solution from the list below sorted by approximate energy efficiency from high to low.

- Tower chilled water
- Water-cooled chiller combined with tower chilled water
- Air-cooled chiller
- DX compressor cooling

Review the following topics with potential modular and IT equipment suppliers:

- For cooling requiring chilled water: highest possible chilled water temperature that will meet the IT air temperature inlet requirements
- Humidity controls and requirements
- Energy for IT equipment cooling air circulation provided by the modular system. This should be in the range of 2 to 4 percent of the IT power.
- Cooling fluid pumping energy
- Modular enclosure heat insulation specifications
- Removal of cooling fans inside IT equipment
- IT equipment DC power
- Part load energy efficiency and controls

4.3 Additional Requirements

- Service Availability (some cooling designs may contain difficult to obtain materials needed for repairs, e.g. fans or specialized coolants, or require specialized tools or specific training to make repairs). For example it may be more convenient to make timely interim repairs to cooling systems using only water, by on-site personnel, compared to systems that use refrigerant that need specialists trained in the use of refrigerants.
- Service access to the unit (clearances to accommodate connections, door openings, weather protection, IT equipment installation, etc.)
- Site security, including lighting, fencing, and access control
- Proximity to existing power and chilled water distribution (if used) systems
- Backup power equipment, if desired (including generators, switchgear, and fuel supply)
- Control and reporting systems for the modular units should be compatible with existing building management systems. Check if software is available for monitoring energy use or calculating energy efficiency metrics.
- Smoke detection and fire suppression systems, and interconnection to existing systems if present
- Site access for delivery and locating, maximum allowable weight, space to operate crane for unloading
- Module orientation relative to prevailing wind direction may be a consideration for units equipped with air-side economizers (outside-air cooling) to realize maximum energy efficiency performance.

- Pad requirements (modular/container units often require significant foundation/pad upgrades)
- Condensation management (local officials may not allow connection of condensate drains directly to sanitary sewer systems without a permit)
- Emergency power-off functionality may be required by fire protection services
- Authorities having local jurisdiction should be consulted to determine agency requirements, applicable building and safety codes, and taxation treatment if applicable.

4.4 Other Considerations

What are the existing and available supporting infrastructure conditions at the deployment site? Is the existing power delivery, back-up power, and chilled water supply available, or does this infrastructure have to be provided or modified to support the deployment?

For first generation units, and for second-generation units requiring chilled water for supplemental cooling, a chilled water supply infrastructure is a key requirement, whether sourced from an existing plant or new equipment.

The IT load capacity of first generation units is typically dependent on both the flow and temperature of the chilled water supply. Many vendors provide IT equipment load specifications at two or more chilled water delivery temperatures (typically in the range of 45°F to 60°F). Obviously lower temperatures will support higher equipment power densities and total loads but one should see if higher water supply temperatures can meet the cooling needs. Higher chilled water supply temperatures increase chilled water plant efficiency and capacity. If using an existing chilled water plant review the required chilled water supply pressure and flow rate for the modular data center being considered.

Chilled water plants that serve existing data centers and most building types generally have supply set points lower than 60°F, so should be suitable for serving modular units if there is sufficient excess capacity in the plant. In some situations the normal chilled water return temperature may support the needs of a modular unit; in that case using the return water should be investigated to save energy at the chiller plant.

Note that for both existing and new chilled water plants, higher supply set points lead to higher efficiency: a rule-of-thumb relates a chiller plant efficiency improvement of one-and-a-half to two percent for each degree of increase in supply temperature. Customers desiring to use the highest possible cooling water temperature should review the requirements with the modular data center supplier to understand the maximum IT load supported.

Also, plants that make use of water-side economizers will capture more free-cooling operation hours when providing warmer supply. In fact, in Santa Clara, CA (used for the efficiency evaluation in this paper), a plant using only evaporative coolers (without mechanical chillers), can supply 60°F water for almost the entire year.

Are the climate conditions at the deployment site suitable for air or water-side economizers? With very few exceptions, air economizers are a highly cost-effective option anywhere in the United States, but extreme environments (notably areas with high temperature and humidity and/or high levels of airborne contaminants) may preclude the use of units equipped with on-board economizers. Locations that have high ambient temperatures and moderate levels of humidity may still be suitable for supporting auxiliary evaporative cooling. Check with the modular supplier to see if your environment will provide the desired humidity and temperature range; don't assume a desired location will or will not support evaporative cooling. Consider start up requirements such as pre-heating if a cold ambient environment is selected.

Will the deployment be temporary or effectively permanent? Units using a standard container form factor or smaller may be more suitable for frequent relocation compared to some modular designs.

See Appendix I for a listing of scenarios where a modular data center could be used.

5 Comparing Energy Efficiency of Modular Data Centers

5.1 Overview – Attributes of Modular Systems

Modular data centers do not guarantee a more energy efficient solution. Brick and mortar sites can be designed for efficient operation but modular designs because of pre-engineering may provide more straight forward sealing between the hot and cold aisles, warmer temperature cooling and are likely influenced by recently published efficiency concepts. These factors and others may produce designs with improved energy efficiency performance.

Energy efficiency advantages for modular data centers can include:

- Cooling systems using fans with variable speed and intelligent controls closely coupled with IT equipment temperature and air flow requirements.
- Replacement of small internal server fans with larger more efficient fans supporting multiple servers or server racks likewise replacement of power supplies.
- Improved hot aisle/cold aisle containment compared to conventional brick and mortar data center room design. This reduces the required air flow and therefore less fan power.
- The ability to use higher temperature chilled water supply.
- Rack level indirect liquid cooling.
- Integral air-side economizers.

5.2 Evaluating and Rating Energy Efficiency

To assist with energy efficiency specification and discussion with potential vendors; six modular data center vendors were selected to participate in an energy efficiency study to provide examples for calculating energy efficiency. There were six different cooling system types offered, and many vendors offer a number of cooling system options. The study uses a Power Utilization Effectiveness (PUE) like metric to compare the selected products. The analysis attempts to provide a fair comparison considering the variety of thermal configuration and specifications received. Many units are offered that require chilled water as a primary cooling medium. In all cases, except for air economizer cooled units, the power needed to provide chilled water or compressed refrigerant accounts for the majority of total energy use in the infrastructure. For the cases needing chilled water, a single chilled water plant model, of a plant using water cooled chillers, providing kW/ton as a function of chilled water supply temperature was used to normalize comparative energy efficiency evaluation results of this major component of energy use. See Appendix B for details. Evaluating relative energy efficiency performance of available products is a challenging exercise. This is due in part to the varied types of information available from vendors and the wide variety of cooling system designs.

Nevertheless, by making reasonable assumptions regarding the efficiency of typical supporting infrastructure equipment, the relative efficiency performance of modular/container systems can be evaluated.

While the metric developed and used here may not match field performance (climate conditions, for example, will significantly affect performance of some cooling systems), the relative performance of a variety of products can be evaluated and used in determining optimum designs for a given customer need.

5.3 Energy Efficiency Comparison Metric "PUE*"

Data center industry groups and government bodies have agreed that Power Utilization Effectiveness (PUE) is a useful metric to evaluate energy efficiency of data center facilities.

As with any other data center design, modular/container units can be evaluated using a PUE type metric sometimes referred to as partial PUE, either from a theoretical basis using design parameters, vendor supplied information or through actual in-use metering.

The analysis here compares the models from six vendors using a PUE like metric "PUE*" which is targeted for use relating to this paper only.

For the comparison using PUE* ratings for selected modular and container units presented in this guide we have undertaken an analysis that estimates cooling system energy use both on-board the unit and in supporting infrastructure, but have not attempted to model power conditioning systems (UPS) or backup generation. (Power delivery losses within the units have been quantified; power delivery losses in support infrastructure have not.)

The PUE* metric calculation is described in Appendix C and D. The *Equation below is a textual description for general reference.*

> *PUE* = (total power supplied to the module + power to produce externally acquired chilled fluid) / IT power*

Further, the analysis results represent an estimate of an average PUE* value that might be obtained over a year period considering the stated assumptions.

As mentioned above, for the units evaluated that use chilled water supplied from a water cooled chiller plant model containing a year round average performance was used to estimate the yearly average energy use rate. The chilled water model used yearly weather data from Santa Clara California and was equipped with a water side economizer. The pumping energy for chilled water distribution was not included in the model and is included in the analysis separately. For units using chilled water the chilled water plant performance is a big part of the energy used, customers should recalculate the results using actual plant performance or adjust the results for plant performance applicable to the deployment site.

Other energy use data supplied by the six vendors was, heat leakage, required water flow and water flow pressure drop, power distribution loses and specified server air inlet and associated water temperatures. The power needed for the modular unit air circulation was provided or determined by calculation.

We do not propose the PUE* metric be adopted for widespread use as a measure of modular data center efficiency by standards bodies or the data center industry; it is merely of use in this particular comparative evaluation and as a suggested guide when discussing energy efficiency performance with modular data center suppliers.

5.4 Selected Modular Cooling System Types

Note: The energy use information supplied by the vendors had the units of power, e.g. kilowatts (kW) reflecting the data usually obtained from steady-state limited duration experimental measurements. The resulting PUE* metric is a dimensionless ratio and can be converted to an energy format e.g. kilowatt-hours/kilowatt-hours as desired.

Modular data center models selected for the energy efficiency comparison had the following variety of cooling system types:

Water-WC

The IT equipment is air-cooled. The air is cooled using air-to-water heat exchangers. The supplied chilled water is produced using a chilled water plant equipped with water-cooled chillers. A plant model is used to calculate the energy needed to produce the chilled water. See Appendix C for the chilled water plant details. The chilled water plant energy rate is a function of chilled water supply temperature. Some modular data center vendors supplied performance for more than one chilled water supply temperature.

Water-WC/DX

The IT equipment is air-cooled. The air is cooled using air to pumped-refrigerant-to-water heat exchangers. The chilled water is produced using a chilled water plant equipped with water-cooled chillers. One or more cooling distribution units (CDU) are required to transfer heat from the refrigerant to the water; the energy required for the CDU is included in the total energy going to the container. The thermal efficiency performance of this cooling type was supplied by the vendor.

Water-AC

The IT equipment is air-cooled. The air is cooled using an air-to-water heat exchanger. The chilled water is produced using a chilled water plant equipped with air-cooled chillers. The estimated energy requirement to produce the chilled water for the table entry (kW/ton) is supplied by the vendor.

Water-AC/DX

The IT equipment is air-cooled. The air is cooled using air to pumped-refrigerant-to-water heat exchangers. The chilled water is produced using a chilled water plant equipped with air-cooled chillers. One or more cooling distribution units (CDU) are required to transfer heat from the refrigerant to the water; the energy required for the CDU is included in the total energy going to the container. The thermal efficiency performance of this cooling type was supplied by the vendor.

DX

The IT equipment is air-cooled. The air is cooled using air-to-refrigerant heat exchangers connected to air-cooled condensers located remotely. The total power (DXPp, rated in kW) required for cooling is provided by the vendor for these units.

Outside-Air

The IT equipment is completely cooled using outside-air pulled or pushed through the container or module. The PUE* analysis does not include energy needed for supplemental cooling systems that may be required in some climates. Many climates require little or no supplemental cooling.

5.5 Evaluation Notations

The evaluation of an array of modular/container units presented is not intended to predict actual field performance due to the use of an efficient generalized water plant model located in a mild climate, but rather to provide a basis for comparing relative performance between unit types.

In particular, the following attributes of the analysis should be noted:

- <u>Product characteristics, chilled water supply from air-cooled chillers or DX system efficiency performance have been provided by the vendors, and have not been independently verified or measured by Lawrence Berkeley National Laboratory.</u>
- Energy for lighting, UPS systems, and backup generation has been ignored in the analysis. Although this will yield somewhat lower PUE ratings than would be expected in actual deployment, there is no known intrinsic difference in efficiency in these two categories for modular/container units.
- No differentiation of products has been made on the basis of AC power provisioning, delivery, and conditioning redundancy. Typically, higher redundancy, often rated in reliability “Tier” ratings defined by the Uptime Institute, yield higher PUE type ratings. Further if actual IT loads fall short of design loads, system performance can deteriorate.

Energy needed to produce chilled water for those units that require it was estimated using a chiller plant efficiency model provided by Taylor Engineering. This model assumes that the chiller plant meets current minimum efficiency standards in the State of California as defined in the building energy efficiency code ASHRAE 90.1 Chapter 11 (EBC Rules). The chiller plant model assumes the use of a water-cooled condenser and a water-side economizer, and assumes deployment in Santa Clara, California (San Jose Airport TMY 3 File). Chilled water plants of a different design or location may have considerably different energy efficiency performance.

5.6 Results of Comparative Analysis of Selected Units

The energy efficiency ranking results, not surprisingly, are in line with the performance commonly found for a given cooling fluid configuration type. As expected the most efficient solution is to select a unit containing an integral air economizer cooling design. This assumes that units equipped with air economizers "free air cooling" can be located at a site with a suitable climate. Figure 7 shows the comparison results for PUE* as a function of cooling system design type.

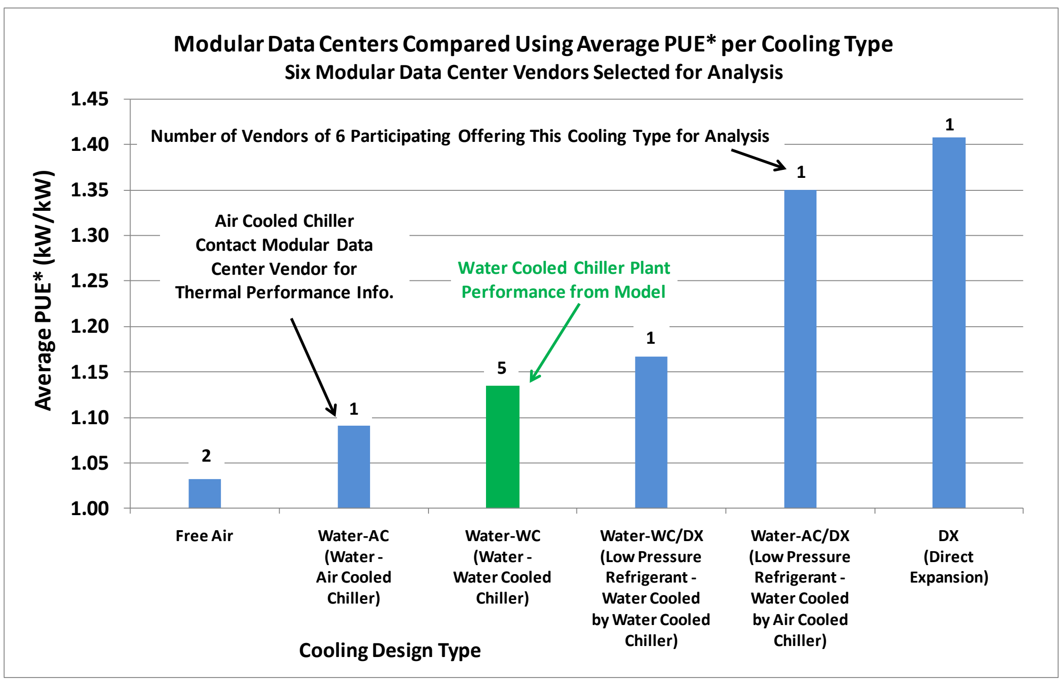

Figure 7: PUE* Comparison of 6 Modular Data Center Vendors

Note: The "Water-AC" PUE* results based on the thermal performance provided by one company appears to be superior to the average performance expected from an air-cooled chiller. Potential purchasers are encouraged to contact the company (PV&D) to learn more about the unique design and performance parameters of this air-cooled chiller if this type of cooling solution can be considered.

Appendix E lists the supplied information for each example provided from the six vendors participating in the comparison. Appendix F lists the final results for all examples.

The performance of air cooled chiller type plants and units cooled by DX were provided by the vendors. The energy required by the modular system to circulate the cooling air ranges from approximately 2 percent to 4 percent of the IT equipment power. The cooling fluid pumping power delta pressure required ranged from 6 to 45 feet of water column.

Averaging all of the PUE* ratings for equipment requiring chiller plant or DX infrastructure resulted in a rating of 1.16 while the average for outside-air cooled “Free Air” modules is approximately 1.03. See Appendix G for a table of results.

5.7 Utility Energy Efficiency Program Applicability

The deployment of modular data center infrastructure may be eligible for utility energy efficiency program financial incentives. Typical program designs reward the installation of new facilities that exceed applicable energy efficiency standards or codes, or the replacement of existing infrastructure with more efficient technology.

For a complete description of the potential applicability of utility energy efficiency programs for modular data center deployments, see Appendix H.

6 Conclusions

Modular data center units can provide a solution to challenging IT capacity requirements in both temporary and long-term deployments. In general, these units can have lower initial capital costs and speedier deployment timeframes when compared to traditional "brick and mortar" data centers.

Modular units may provide some inherent energy efficiency advantages compared to traditional data centers as a result of implementing more optimum pre-engineering such as effective close-coupled cooling designs.

Second-generation modular/container units provide superior energy efficiency performance compared to first generation units because they feature on-board air economizers. These units can rely on highly efficient on-board evaporative cooling units or another supplemental cooling technology for those conditions where environmental conditions are not always suitable for air economizer operation.

Whether they are deployed in utility-scale data centers, as adjuncts to existing enterprise data centers, or even in mobile and disaster recovery scenarios, units that feature on-board air-side economizers as the primary cooling system will provide the lowest deployment costs, deployment timeframes, and ongoing operational expenses.

Modular data centers may facilitate a convenient process for return and recycling when the IT equipment reaches its end of useful life. In addition, if a modular data center is purchased from the same vendor as the IT equipment a single point of responsibility for service of IT and modular data center equipment may be a possibility.

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- Hewlett-Packard Co. – Greg Palmer, US Federal Sales, greg.palmer@hp.com
- i/o Data Centers – Andreas Zoll, Engineering Director, azoll@iodatacenters.com
- SGI- Daniel Robbins, Principal Program Manager, drobbins@sgi.com
- Pacific Voice & Data – Nick Glinkowski, Executive Vice President, nickg@uspvd.com
- Elliptical Mobile Solutions - Paul Kemmeter, WDM Innovative IT Solutions, paul@wdminc.com
- Liebert – Fred Stack, VP Marketing – Precision Cooling, Emerson Network Power, fred.stack@emerson.com

8 Appendix A: Resources - Vendor Contacts and Product Information

The authors note that the modular/container data center industry is evolving rapidly, with new market entrants and new product designs from existing vendors appearing regularly. Information presented here should therefore not be considered comprehensive or current.

Vendor	Product	Contact	Website
Hewlett-Packard	HP POD Family	Greg Palmer US Federal greg.palmer@hp.com	www.hp.com
	Performance Optimized Datacenter (POD) offered in a container form factor, using chilled water cooling or more modular air-side economizer cooling		
i/o Data Centers	i/o ANYWHERE	Andreas Zoll Engineering Director azoll@iodatacenters.com	www.iodatacenters.com
	The i/o ANYWHERE™ modular data center Includes 100% of the critical infrastructure required for a high-density, always-on data center. From power delivery to cooling to network connectivity to 24x7xForever infrastructure monitoring and management, this patent-pending service is a fully integrated data center. Not to be confused with a stand-alone ISO container, the i/o ANYWHERE™ service is comprised of up to 20 modules, can be customized to the customer's requirement and can be delivered to the customer's location or e dedicated offsite location in a matter of weeks.		

Vendor	Product	Contact	Website
SGI	Ice Cube Ice Cube Air	Daniel Robbins Principal Program Manager drobbins@sgi.com	www.sgi.com
	Standard container form factors available for first generation units requiring chilled water supply; modular second-generation units can be "ganged" together. Second-generation units feature full air-side economizer with supplemental evaporative cooling; supplemental DX or chilled water coils can be added at customer request. Both first and second-generation units available		
Pacific Voice & Data	MCIE Solutions and Mobile Data Centers	Paul Kemmeter WDM Innovative IT Solutions paul@wdminc.com	www.uspvd.com
	PVD offers Modular Critical Infrastructure Solutions and Mobile Data Centers for High Density Server Enclosures, High Capacity Power Enclosures and Mobile Data Centers. Options include but not limited to High Insulation Factor, UV reflective, Tempest Shield, Satellite, Anti Ballistic, and onboard power generation and packaged free cooling chiller applications. All enclosures are fabricated for low and high ambient outdoor conditions. PVD can provide a standard ISO container or PVD fabricated enclosure including 10' and 12' wide options in 20, 40, 53' lengths.		
Elliptical Mobil Solutions	MMDC (Micro Modular Data Center)	Paul Kemmeter WDM Inovative IT Solutions paul@wdminc.com	www.ellipticalmedia.com
	EMS offers modular rack level cooling solutions. Air-cooled water chillers can be coupled with higher density units		

<table>
<tr><th>Vendor</th><th>Product</th><th>Contact</th><th>Website</th></tr>
<tr><td>Liebert</td><td>MDC20-XDR-53 refrigerant to water cooling system</td><td>Fred Stack
VP Marketing
fred.stack@emerson.com</td><td></td></tr>
<tr><td rowspan="2">IBM</td><td>Portable Modular Data Center (PMDC)</td><td>Brian Canney
Services Executive
bcanney@us.ibm.com</td><td>www.ibm.com/services
Site and Facilities</td></tr>
<tr><td colspan="3">IBM offers modular data center units in 10-, 20-, 40- and 53-foot lengths. Multiple cooling options such as DX, chilled water, including the IBM rear door heat exchanger, cooling block and free cooling are offered.</td></tr>
<tr><td rowspan="2">PDI</td><td>i-Con Modular Data Center refrigerant to water cooling system</td><td>David Mulholland
VP Marketing
dmulholland@pdicorp.com</td><td>www.pdicorp.com</td></tr>
<tr><td colspan="3">20-, 40-, and 53-foot container form factors; supports 25 to 35 kW per rack depending on chilled water supply temperature; units use on-board refrigerant loop, cooled by chilled water heat exchanger; serviceability based on movable racks (mounted on sliders) allowing 48U and better aisle access; because access doors are on end of container only, units can be placed at higher density in a utility-scale deployment; units feature robust metering, monitoring, and control system.</td></tr>
<tr><td>Cirrascale</td><td>Forest Container</td><td></td><td>www.cirrascale.com</td></tr>
</table>

<table>
<tr><th>Vendor</th><th>Product</th><th>Contact</th><th>Website</th></tr>
<tr><td>Dell</td><td>Humidor</td><td></td><td>www.dell.com</td></tr>
<tr><td rowspan="2">Oracle</td><td>Sun Modular Data Center MD S20
MD D20</td><td></td><td>www.oracle.com</td></tr>
<tr><td colspan="3">20-foot container form factor; Oracle indicates units can be ordered but are not being actively marketed.</td></tr>
<tr><td rowspan="2">Lee Technologies</td><td>ITModules</td><td>Mike Hagan
mhagan@leetechnologies.com</td><td>www.leetechnologies.com</td></tr>
<tr><td colspan="3">Lee offers units in 20-foot container form factors, with on-board air-side economizers that can be supplemented by DX or chilled water cooling units. IT equipment densities of up to 14 kW per rack are supported; with total unit IT load of 60 or 84 kW depending on supplemental cooling system option.</td></tr>
<tr><td>Telentix</td><td>T-Cube</td><td></td><td>www.telenetix.co.za/</td></tr>
<tr><td rowspan="2">UNS</td><td>Datapod
System</td><td>Ryan Mordhorst
VP of Global Sales
r.mordhorst@apcdistributors.com</td><td>www.apcdistributors.com</td></tr>
<tr><td colspan="3">20-foot, with 40-foot available; customizable to user requirements; supports 5 to 30 kW per rack; uses APC in-row units for on-board cooling, served with chilled water.</td></tr>
</table>

<table>
<tr><th>Vendor</th><th>Product</th><th>Contact</th><th>Website</th></tr>
<tr><td rowspan="2">NxGen Modular</td><td>NxGEN600</td><td>Dan Kleiman
dank@nxgenmodular.com</td><td>www.nxgenmodular.com</td></tr>
<tr><td colspan="3">Complete customized modular prefabricated turnkey data centers provided, options include power distribution selection, security features and a variety of cooling system types to meet customer requirements, an air-side economizer cooling system is available that is 100% outside air capable. The standard critical load steps are 600kW</td></tr>
<tr><td>BladeRoom</td><td>Blade Room
Modular Data Centers</td><td></td><td>www.bladeroom.com</td></tr>
<tr><td>Bull</td><td>Bio Data Center</td><td></td><td>www.bull.com</td></tr>
</table>

9 Appendix B: Chilled Water Plant Model

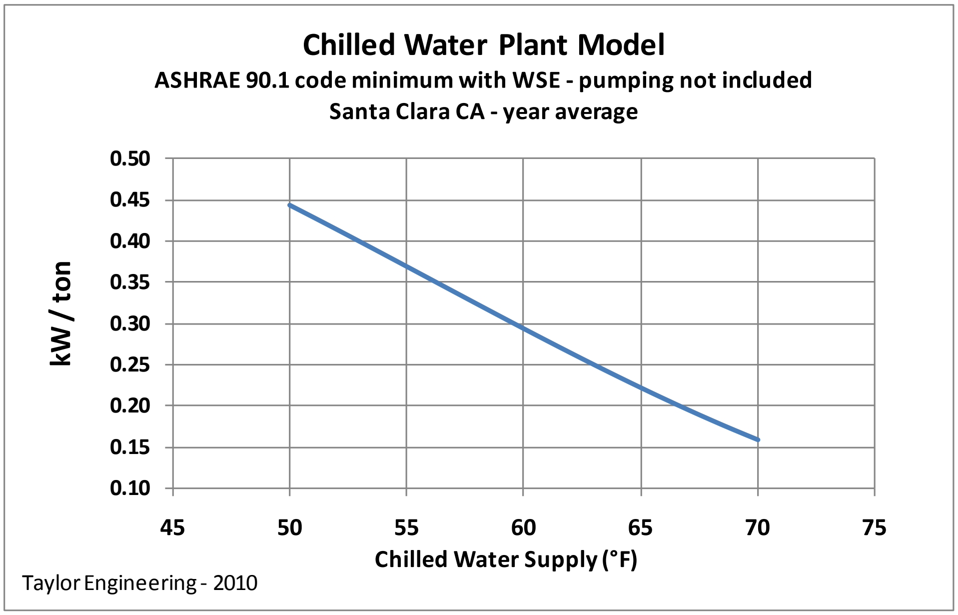

Figure 8: Graph of Chilled Water Plant Power as a Function of Chilled Water Supply Temperature

Chilled Water Plant Model Information

3/17/2010 – Taylor Engineering, Alameda CA 94501

To the extent possible ASHRAE 90.1 Chapter 11 (ECB) Rules are followed.

Note: Chilled water plant models that included chilled water distribution pumping were made but not used in this report.

Chillers

Type:	water cooled chillers meeting 90.1-2007 Addendum M Path B (chillers with VSD) minimum efficiencies: COP of 0.6 and IPLV of 0.4 at ARI 550/590 rating conditions
Quantity:	three chillers in the plant, n+1 design (one redundant) each sized for 330 tons to serve an actual 600 ton load (660 ton design load, 600 ton actual load 10% over sizing)
Evaporator Flow:	790 gpm/chiller evaporator
Chiller Condenser Flow:	920 gpm/chiller condenser
Performance:	0.58 kW per ton at design conditions of 44°F chws and 80°F cws.

Cooling Tower

Efficiency: 38.2 gpm/hp at 95°F CWR, 85°F CWS, 75°F Twb (90.1 minimum efficiency)

Quantity: 3 cells one redundant each sized for 330 tons of chiller (10% over sizing) Selected for design flow of 925 gpm per cell (10°F DT)

Pumps

Rules: from 90.1-2008 Chapter 11 rules

Chilled water pump power: 0.019 kW/gpm

Condenser water pump power: 0.022 kW/gpm

Water-Side Economizer

Rules: criteria in 90.1-2007 Addendum BU

Size: 100% of the design load (660 tons) at 35°F Twb.

CHW Flow: 1580 gpm

CHWR: 62°F

CHWS: 52°F

CW Flow: 1580 gpm

CWS: 48°F

CWR: 58°F

WSE Heat Exchanger 4°F approach on the water side economizer heat exchanger

Climate

San Jose Airport TMY 3 File

10 Appendix C: Diagram for PUE* Calculations

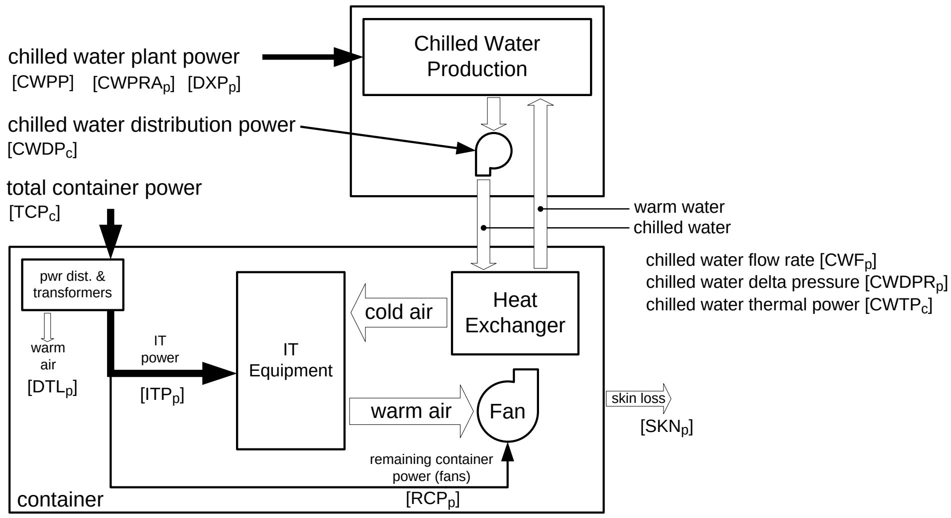

Figure 9: Diagram Representing PUE* Derivation Model

11 Appendix D: Calculation Details

Definitions designated with a “p” represent data supplied by equipment manufacturers; those designated with a “c” have been derived or calculated.

The data for chilled water plant power [CWPP] has in some cases been provided; the balance has been calculated using a chilled water plant energy use model. PUE* is defined and meant for use in the context of this report only.

Constants:

Definition of ton: 1 ton = 3.516kW thermal power

To convert feet of water column (ft WC) to pounds per square inch delta multiply by 0.4335

Definitions:

Description	Abbreviation (units)	Reference or Calculation	Notes
IT Equipment Power	ITPp (kW)	NA - provided	
Power Distribution and Transformer Loss	DTLp (kW)	NA - provided	provided as a function of IT Equipment Power
Remaining Container Power	RCPp (kW)	NA - provided	typically fan power
Total Container Power	TCPc (kW)	TCPc=ITPp+DTLp+RCPp	
Skin Loss	SKNp (kW)	NA - provided	
Chilled Water Thermal Power Required	CWTPc (tons)	CWTPc=(TCPc-SKNp)/3.516	
Chilled Water Plant Power per Ton	CWPRc (kW/ton)	Reference Chilled Water Plant Performance Graph	for water cooled chiller plants
Chilled Water Plant Power	CWPPc (kW/electrical)	CWPPc=CWTPc x CWPRc	for water cooled chiller plants

Description	Abbreviation (units)	Reference or Calculation	Notes
Chilled Water Plant Power Rate per Ton - Air Cooled Chiller	CWPRAp (kW/ton)	NA - provided	for air cooled chiller plants
Chilled Water Plant Power	CWPPc (kW electrical)	CWPPc=CWTPc x CWPRAp	for air cooled chiller plants
Chilled Water Flow Rate	CWFp (gpm)	NA - provided	
Chilled Water Delta Pressure	CWDPRp (ft WC)	NA - provided	
Chilled Water Distribution Pumping Power	CWDPc (kW)	CWDPc= ((CWDPRp x 0.4335) x CWFp x 0.000435) / 0.65	total pump efficiency = 0.65 per ASHRAE 90.1
Refrigerant Only Cooling aka DX	DXPp (kW)	NA - provided	for refrigerant cooling
Power Utilization Effectiveness*	PUE* (dimensionless)	PUE*= (TCPc+CWDPc+CWPPc)/ ITPp	for water and air cooled chiller plants
Power Utilization Effectiveness*	PUE* (dimensionless)	PUE*= (TCPc+DXPp)/ ITPp	for refrigerant (aka DX) cooling
Power Utilization Effectiveness*	PUE* (dimensionless)	PUE*= TCPc/ ITPp	for air side economizer cooling

12 Appendix E: Vendor Supplied Thermal Performance Information

Data Provided by Company Listed								
Company	**Cooling Type Server Air Inlet Temp.(F) Chilled Water Supply Temp.(F) Server Air Flow (cfm/kW)**	**IT Power [ITPp] (kW)**	**Distribution and Transformer Loss [DTLp] (kW)**	**Skin Loss [SKNp] (kW)**	**Chilled Water Flow [CWFp] (gpm)**	**Chilled Water Delta Pressure [CWDPp] (ft. WC)**	**Chilled Water Plant Performance [CWPRp] (kW/ton)**	**DX Cooling [DXPp] (kW)**
HP	Water-WC, 72, 62, 112	580	5.8	10	240	75	0.265	NA
HP	Water-WC, 80, 70, 91	580	5.8	10	240	75	0.158	NA
HP	Outside Air, 72, NA, 112	1520	15.2	NA	NA	NA	NA	NA
i/o Data Centers	Water-WC, 80, 60, 120	200	8.0	0	126	18	0.294	NA
i/o Data Centers	Water-WC, 80, 60, 120	1000	41.0	0	630	22	0.294	NA
i/o Data Centers	Water-WC, 80, 60, 120	3200	132.0	0	2016	27	0.294	NA
i/o Data Centers	Water-WC, 80, 60, 120	6400	265.0	0	4032	34	0.294	NA
Liebert	Water-WC/DX, 75, 55, 120	300	15.0	0	280	39	0.370	NA
Liebert	Water-AC/DX, 75, 55, 120	300	15.0	0	280	39	*0.980*	NA
Liebert	DX, 75, NA, 120	200	10.0	0	NA	NA	NA	72.0
Liebert	Water-WC/DX, 80, 60, 120	300	15.0	0	280	39	0.294	NA
Liebert	Water-AC/DX, 80, 60, 120	300	15.0	0	280	39	*0.900*	NA

Data Provided by Company Listed								
Company	**Cooling Type Server Air Inlet Temp.(F) Chilled Water Supply Temp.(F) Server Air Flow (cfm/kW)**	**IT Power [ITPp] (kW)**	**Distribution and Transformer Loss [DTLp] (kW)**	**Skin Loss [SKNp] (kW)**	**Chilled Water Flow [CWFp] (gpm)**	**Chilled Water Delta Pressure [CWDPp] (ft. WC)**	**Chilled Water Plant Performance [CWPRp] (kW/ton)**	**DX Cooling [DXPp] (kW)**
Liebert	DX, 80, NA, 120	200	10.0	0	NA	NA	NA	66.9
SGI	Outside Air, 77, NA, 120	280	2.8	NA	NA	NA	NA	NA
SGI	Water-WC, 77, 65, 120	750	7.5	0	525	15	0.223	0
PVD	Water-WC, 72, 58, 100	400	0.0	0	300	45	0.324	NA
PVD	Water-WC, 80, 68, 100	400	0.0	0	300	45	0.184	NA
PVD	Water-AC, 72, 58, 100	400	0.0	0	300	45	*0.128*	NA
PVD	Water-AC, 80, 68, 100	400	0.0	0	300	45	*0.128*	NA
EMS	DX, 75, NA, 120	12	0.6	0	NA	NA	NA	6.5
EMS	Water-WC, 80, 68, 120	16	0.7	0	2	6	0.184	NA
EMS	Water-WC, 72, 55, 120	20	1.0	0	12	7.5	0.370	NA
EMS	Water-WC, 72, 55, 120	40	2.0	0	15	14	0.370	NA

Abbreviations:
PV&D (Pacific Voice & Data)
EMS (Elliptical Mobile Solutions)

13 Appendix F: Calculated Results

	Description	Provided	Calculated	Calculated	Calculated	Calculated	Provided	Calculated
Company	**Cooling Type Server Air Inlet Temp.(F) Chilled Water Supply Temp.(F) Server Air Flow (cfm/kW)**	**IT Power [ITPp] (kW)**	**Remaining Container Power [RCPc] (kW)**	**Total Container Power [TCPc] (kW)**	**Chilled Water Pump Power [CWDPc] (kW)**	**Chilled Water Plant Power [CWPPc] (kW)**	**DX Power [DXPPp] (kW)**	**PUE***
HP	Water-WC, 72, 62, 112	580	17.4	603	5.20	44.7	NA	1.13
HP	Water-WC, 80, 70, 91	580	17.4	603	5.20	26.7	NA	1.09
HP	Outside Air, 72, NA, 112	1520	45.6	1581	NA	NA	NA	1.04
i/o Data Centers	Water-WC, 80, 60, 120	200	7.0	215	0.42	18.0	NA	1.17
i/o Data Centers	Water-WC, 80, 60, 120	1000	35.0	1076	2.55	90.0	NA	1.17
i/o Data Centers	Water-WC, 80, 60, 120	3200	112.0	3444	10.01	288.0	NA	1.17
i/o Data Centers	Water-WC, 80, 60, 120	6400	224.0	6889	25.22	576.0	NA	1.17
Liebert	Water-WC/DX, 75, 55, 120	300	2.1	317	0.02	33.4	NA	1.18
Liebert	Water-AC/DX, 75, 55, 120	300	2.1	317	0.02	88.4	NA	1.36
Liebert	DX, 75, NA, 120	200	2.1	212	NA	NA	72.0	1.42

Company	Description Cooling Type Server Air Inlet Temp.(F) Chilled Water Supply Temp.(F) Server Air Flow (cfm/kW)	Provided IT Power [ITPp] (kW)	Calculated Remaining Container Power [RCPc] (kW)	Calculated Total Container Power [TCPc] (kW)	Calculated Chilled Water Pump Power [CWDPc] (kW)	Calculated Chilled Water Plant Power [CWPPc] (kW)	Provided DX Power [DXPPp] (kW)	Calculated PUE*
Liebert	Water-WC/DX, 80, 60, 120	300	2.1	317	0.02	26.6	NA	1.16
Liebert	Water-AC/DX, 80, 60, 120	300	2.1	317	0.02	81.2	NA	1.34
Liebert	DX, 80, NA, 120	200	2.1	212	NA	NA	66.9	1.40
SGI	Outside Air, 77, NA, 120	280	4.0	287	NA	NA	NA	1.02
SGI	Water-WC, 77, 65, 120	750	9.5	767	2.29	48.58	0	1.09
PVD	Water-WC, 72, 58, 100	400	17.3	417	3.91	38.46	NA	1.15
PVD	Water-WC, 80, 68, 100	400	17.3	417	3.91	21.84	NA	1.11
PVD	Water-AC, 72, 58, 100	400	17.3	417	3.91	15.19	NA	1.09
PVD	Water-AC, 80, 68, 100	400	17.3	417	3.91	15.19	NA	1.09
EMS	DX, 75, NA, 120	12	0.4	13	NA	NA	6.5	1.63
EMS	Water-WC, 80, 68, 120	16	0.3	17	0.003	0.887	NA	1.12
EMS	Water-WC, 72, 55, 120	20	0.7	22	0.026	2.314	NA	1.20
EMS	Water-WC, 72, 55, 120	40	1.4	44	0.061	4.628	NA	1.20

14 Appendix G: Table – Summary of Results

Unit Type	Sample Size (# of vendors)	Average PUE*	Best PUE*
Water-WC No air-side economizer; coil and fan cooling units served by water-side economizer equipped chilled water plant	5	1.13	1.09
Water-WC/DX No air-side economizer; air to low pressure refrigerant fluid heat exchangers. Refrigerant cooled with chilled water	1	1.17	1.16
Water-AC No air-side economizer; same as "Water WC" except chilled water plant uses air-cooled chillers	1	1.09	1.09
Water-AC/DX No air-side economizer; same as "Water WC/DX" except chiller plant uses air-cooled chillers	1	1.35	1.36
DX No air-side economizer; on-board direct expansion cooling units served by air-to-refrigerant heat exchangers	1	1.41	1.40
Outside-Air Unit cooled entirely through air-side economizer with no supplemental cooling system	2	1.03	1.02

15 Appendix H: Utility Energy Efficiency Program Applicability

Utility Program Offerings – New Construction Incentives

Some utilities offer "new construction" incentive programs that reward customers for building new facilities that exceed mandated energy efficiency standards.

For modular data centers, air-side economizers for chilled water plants could be rewarded with incentives under typical program designs. Because modular/container units are likely less costly than traditional data center designs, it is unlikely that utilities could provide incentives for the units themselves.

Utilities will require an accurate energy use model for a water-side economizer-equipped central plant. This should be a fairly straightforward analysis based on local weather conditions. (The Green Grid offers an on-line tool to estimate savings for air- and water-side economizers.)

Most utilities should recognize that a water-side economizer-equipped central plant exceeds energy efficiency codes, however, energy efficiency regulations vary by state.

Generally speaking, building energy efficiency standards **do not apply** to data centers; consulting with your local utility regarding the applicability of their new construction program to a modular data center installation is highly recommended.

For example, in California the California Energy Commission develops its own building energy efficiency standards (called Title 24), which are acknowledged to be the most stringent in the nation. (Most other states use the International Energy Conservation Code, though there is variance on which version of the code applies in each state.)

However, the code in California does not apply to data centers, so the investor-owned utilities have established their own set of baseline standards that forms the basis for new construction incentives. These standards recognize that air-side and water-side economizers are not a current design standard, and are therefore eligible for incentives.

Note however that a project is underway, sponsored by utility Southern California Edison, to extend Title 24 regulation to data centers, with a likely mandate for the use of air-side economizers. It is unclear how modular data centers would be treated under the code, especially given that most current product offerings do not feature air-side economizer capability.

New construction incentive programs are designed to pay for a portion of the marginal cost of energy efficiency improvements that lead to performance above and beyond current standards.

Applications must be filed and approval secured prior to project execution; there is generally a proscribed incentive amount per kilowatt-hour of projected annual energy savings; most utilities establish an incentive cap at some proportion of the incremental project cost (generally 50%); incentives are paid after project completion.

Utility Program Offerings – Retrofit Incentives

Customers who might choose to replace existing data center infrastructure with modular units might also be able to apply for utility energy efficiency retrofit incentive programs, perhaps claiming savings from reduced airflow energy requirements, but certainly if an existing chilled water plant was retrofitted for water-side economizing.

Accurately modeling the energy savings from improved airflow management would likely be quite difficult, however, at least in part because utilities would require a calculation that specifically modeled conditions in the existing facility.

Conceivably, the actual energy use of fans for airflow in the center could be measured; measuring (and modeling) losses from airflow mixing would be exceedingly difficult to determine.

Putting airflow management energy savings aside, modeling the energy savings for serving the modular data center with a water-side economizer equipped central plant is exactly the same as for the new construction case.

Retrofit energy efficiency incentive programs generally have very similar requirements to new construction programs.

16 Appendix I: Modular Deployment Scenarios

Through discussions with modular data center providers and other industry participants, we have identified six potential scenarios where modular data center deployments might be considered in place of traditional brick and mortar data center construction.

16.1 Scenario 1: Transition Retrofit

While retrofitting an existing data center to recapture power and/or cooling system capacity, modular units could be deployed on a temporary basis so that IT equipment can be removed while retrofit work is undertaken.

In most cases, airflow management and containment retrofits can be accomplished while leaving IT equipment in place, but the use of temporary modular units could be required for more ambitious retrofit projects.

Recommendation: First generation modular units could be used in this scenario if existing chilled water plant capacity can be redirected from the existing data center to the units. Second generation units could be deployed without incurring the costs of connecting to a chilled water distribution system, or if chilled water plant capacity is unavailable.

16.2 Scenario 2: Adding Capacity to "Brick and Mortar" Data Center

There are a variety of reasons that an existing brick and mortar data center may reach a capacity limit, with physical space, available power, and cooling system performance likely candidates.

Although the lack of physical space for additional IT equipment may be a theoretical capacity limitation, it rarely appears to be so in practice. As IT equipment power density has increased, existing data centers tend to reach power and/or cooling capacity shortfalls rather than physical space limitations.

Recommendation: Second generation units may be used for power limited scenarios if the reduced power consumption resolves the power shortfall. Further, if a center has limited cooling capacity, especially if that limitation is due to chilled water plant capacity, first-generation units cannot be deployed absent a capacity increase.

16.3 Scenario 3: Greenfield Deployment

Whether at utility- or enterprise-scale, modular units could be considered for any new data center development. In this case, the deployment costs of modular infrastructure, as well as project construction timelines, should compare favorably to traditional data center designs.

Note, however, that many of the inherent energy efficiency advantages of modular units can be incorporated in traditional brick and mortar centers, such as air-side economizers (perhaps supplemented with water-side economizers), airflow isolation and management, and close-coupled cooling.

Recommendation: The specification of second-generation units for a greenfield data center should result in the lowest capital and operating cost. This assumes the modular data center is not housed inside a conventional type data center building.

16.4 Scenario 4: Deployment at Co-location Providers

There is an increasing likelihood that co-location data center operators will offer support infrastructure and hosting services to customers wishing to deploy modular infrastructure:

- i/o Data Centers is a co-location operator offering modular units that can be installed at their centers or at customer locations.
- Pelio and Associates is opening a co-location data center in Santa Clara, CA in 2011 specifically designed to accommodate modular units, with provisions for power, connectivity, and chilled water supply.

The advantages of locating units at a hosting site are essentially the same as those for locating IT infrastructure in a more traditional co-location center. There may however be a cost advantage if co-location operators are able to reduce facility development and operating costs compared to traditional co-location facility designs. The use of second-generation units would increase these potential cost advantages.

Recommendation: Consult with modular data center co-location providers to obtain cost comparison.

16.5 Scenario 5: Emergency and Temporary Deployments

Some vendors are offering modular units specifically designed for mobility, although any unit in a shipping container form factor is nominally portable.

Perhaps the more important consideration is the availability of power and chilled water plant capacity in an emergency or temporary deployment. While vendors do offer power generation and chilled water plant units that are modular, second-generation units obviate the need for the latter and should be considered for this use scenario.

Recommendation: Assuming power is available a modular data center should be considered if rapid deployment is required.

16.6 Scenario 6: Utility-Scale Data Centers

As noted in the introduction, the first use of modular units has been by utility-scale data center operators, and this trend is expected to continue.

While the primary driver for this deployment scenario may be energy efficiency, modular units also provide a different operations and management paradigm in this scenario.

For example, utility-scale data center operators may deploy containers because they allow for wholesale IT equipment refresh – containers are simply shipped back to IT equipment vendors for refurbishment. Modular units also allow for a continuum of capacity additions that may allow operators to add support infrastructure in increments rather than all at once.

While there are no known utility-scale data centers using second-generation units, Microsoft has been an open proponent of their development.

The sole disadvantage of second-generation units comes into play in this scenario: because they require outside air supply as well as an exhaust air pathway, second-generation units cannot be packed tightly together in the densities that have been used in early utility-scale deployments.