Energy and Cost Analysis of Rittal Corporation Liquid Cooled Package

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1. Executive Summary

Rittal Corporation Liquid Cooled Package was analyzed and compared to a conventionally cooled data center using legacy raised floor forced air cooling. The analysis presented here was based on a 2,000 ft^2 and 10,000 ft^2 legacy data centers and the comparable LCP cooled data centers. The total area of the data center to package a given number of IT equipment is calculated based on an equal total IT power consumption. It was determined that data centers using LCP can achieve 35-45% savings in required real estate depending on the load. In case of LCP data center, this translates to a higher heat flux (higher density) per rack and per square foot.

When comparing the initial costs, the construction cost of data centers using LCP can be 15-30% lower than comparable data centers that use conventional cooling method. However, the cooling equipment cost can be any where from 40-60% higher than conventionally cooled data centers based on number. Looking at the total initial costs, and according to the numbers above, It appears that LCP cooled data centers may be slightly higher when starting a new data center. It seems fair to consider such a system specially when planning on building a new data center. Real estate market analysis reveals that for a small data center, if it can be housed in an office space, savings on the order of 30% should be expected. For a larger data center, where one would need to consider industrial parks, an expected savings around 40% can be achieved in the same city

It is clear that LCP cooled data centers can save about 10-20% on total annual fan power consumption. Similarly, and due to smaller foot print, there is an associated saving in envelope and light load, that is translated to total annual cost reduction of about 30-45% in light related cost. In this calculation, it was assumed that lights are not activated by a motion sensor. In all energy calculations, $0.10/kWh was assumed as the cost from the utility company.

In developing the central chilled water plant power consumption, Power Usage Effectiveness (PUE) criteria was used as the analysis approach. PUE, which is the total power delivered to site divided by the IT power, was assumed to be 1.5 for an excellent or efficient data center, 2 for average, and 3 for poor or least efficient. The data reveals that 12-14% reduction in power delivered to mechanical chilled water plant can be expected. This is considered an interesting result since it definitely impacts the owner directly and yet reduces the environmental impact of data center through reduction of CO_2 emissions. One can also conclude that even further augmented savings are expected from less efficient data centers. For a small data center with average efficiency, annual savings are expected to be on the order of $30,000. This number may double or guardable depending on the size and efficiency of the data center. Lesser energy savings should be expected from an efficient data centers.

When considering the overall savings for a given data center size, apparently the chilled water savings, fan power savings, as well as envelope and lighting savings need to be added. For an average efficiency data center, one would quickly calculate an annual savings of $45,000 and $160,000 for the small and large data centers considered in this study, respectively.

2. Introduction

Legacy data centers have relied on a forced cooled air via chilled water in a raised floor environment where the entire data hall is cooled to a designed average temperature and the entire room used as a return air flow path. In low heat density environments, raised floor forced air cooling performed as designed without apparent performance issues. Apparently, at medium heat density loads, those systems and associated air management issues such as recirculation and bypass have resulted in the "hot spot" phenomena due to uneven air distribution at which data center facility managers react by reducing the set point of air supply temperature or by increasing the capacity of CRAH units or by a combination of both, either method resulted in an increase of 10-20% in cooling costs. Beaty et al (2005) and Hannaford (2006) presented several approaches to achieve better air distribution when retrofitting medium and high density loads into existing facilities. A useful air management metrics have been discussed by Tozer (2006) where recirculation, by-pass and negative pressure flow parameters have been derived based on energy conservation equations. Those parameters once calculated can be used to improve air distribution in existing facilities and reduce the overall cooling load.

The reliability and ability of raised floor systems to handle high density heat loads is becoming questionable and debatable amongst specialists who are finding it necessary to use alternative approaches such water cooled cabinets or rack based cooling methodology. Water cooled mainframes and computer systems have been utilized in the past by equipment manufacturers but since then abandoned for several reasons in favor of forced air cooling systems.

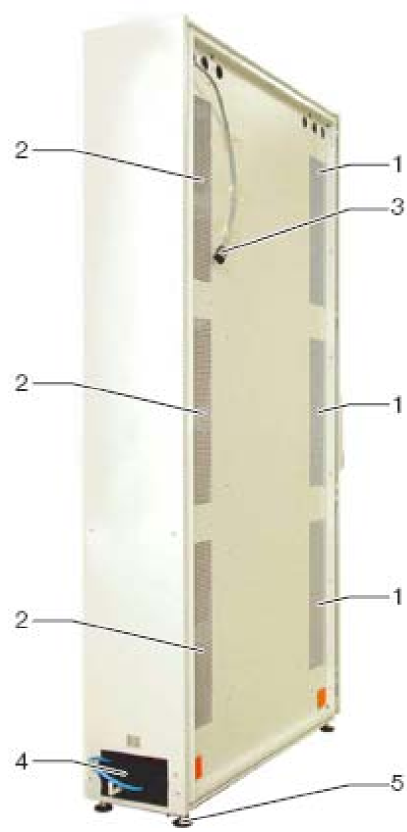
Data center cooling industry will be facing tremendous challenges in the several years to come mainly due to the introduction of high technology servers and mainframes that reject more waste heat albeit their smaller real estate such as blade servers. One example of a high density cabinet is a blade server installation consisting of 6-7U blade frames in a 42U rack. This arrangement results in a total power requirement of 18 kW, which in turn requires equal cooling effect to remove it away. In light of the fact of the exponentially rising power density of data centers, several alternative cooling techniques have been developed and introduced in response to that growth such as in-cabinet, closed-loop air cooled via a fan-coil module that can be sandwiched between IT cabinets.

Albeit the fact that reliability and redundancy of cooling systems will continue to be a vital aspect of the overall data center cooling industry, several initiatives recently have focused on the effectiveness of cooling systems driven mainly by energy conservation and environmental pressures. Major equipment manufacturers are driving resources that aim at reducing the overall power consumption and associated green house emissions of data centers. Of the total power input to the data center, the mechanical cooling systems account for a large portion and consume as much power or more as consumed by the IT equipment (Rasmussen 2003, Kosik 2007).

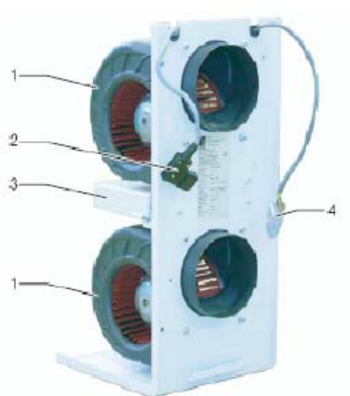
3. Rittal Liquid Cooled Package

Rittal Corporation LCP package utilizes 3 modules (air/water heat exchanger and fan) sandwiched between IT enclosures, Figure 1 below shows front, rear, cooling module, and fan module details of the liquid cooling package.

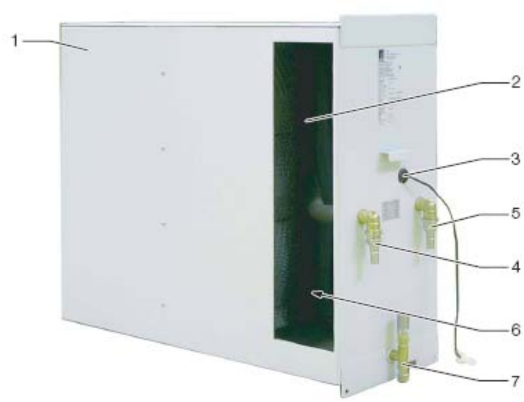
1. LCP control unit
2. Shelf for module plug-in
3. Installation space for LCP module
4. Rack (2000 H x 300 mm W x 1000 D)
5. LCP module
6. Return/outlet cooling water hose
7. Flow/inlet cooling water hose
8. water module
9. Leveling foot



1. Air outlet (cold air)
2. Air inlet (warm inlet)
3. Mains connection cable
4. Connection for cooling water and condensate
5. Leveling foor



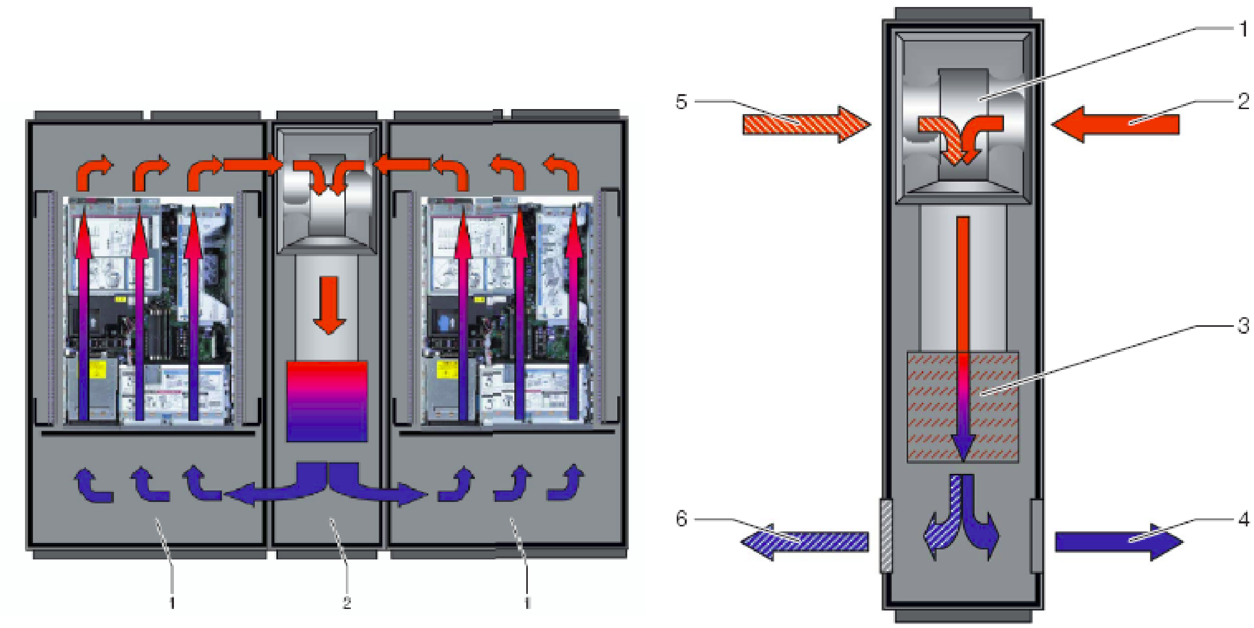
1. Fans.
2. Connector for power supply
3. Control unit for fan module
4. Connection for control unit



1. Enclosure
2. Air/Water heat exchanger
3. Control cable for temperature sensor
4. Cooling water connection flow-inlet
5. Cooling water connection return-outlet
6. Air outlet-cold air
7. Condensate connection

Figure 1: Front, rear, cooling module, and fan module details of Rittal's LCP

Air outlet openings are punched into the wall plates in the front and rear at the height of the module plug-ins to ensure air circulation from and to the server enclosure. The water module components and condensate management are built into the lowest space of the rack. Any generated condensate is collected in each LCP module and led to a condensate collecting tray which is integrated to the water module. Upon reaching a defined condensate level, a condensate pump is activated by a level sensor routing the condensate either back to the return chilled water piping or to the drain collection. In case of a defective level sensor and/or condensate pump, the unit is equipped with a condensate over flow hose leads the condensate outside of the tray A top view that shows air inlet and outlet paths and air routing to a two bayed servers are shown in Figure 2



1. Server enclosure
2. LCP

1. Fan module
2. Air inlet
3. Heat exchanger module
4. Air outlet
5. 2nd air inlet (optional)
6. 2nd air outlet (optional)

Figure 2: Top view of air inlet/outlet paths

The combined system of LCP and server should be sealed well to prevent loss of cold air, to ensure proper seal, the enclosure is equipped with side panels, roof and gland plates. Cable entries should also be sealed with a gasket or brush strips. To ensure targeted air routing in the system, the server enclosure is divided into cold and warm sections in the front section using foam strips.

The temperature control of LCP discharge air is accomplished by continuous comparison of actual air temperature to set point in the LCP control unit (20-40 ^{o}C). If the set point is exceeded, a magnetic valve opens the chilled water supply to the cooling coil. Temperature difference of discharge air to supply air is used to set the fan speed. Control attempts to maintain a constant temperature through opening and closing of the valve. The magnetic valve is fully closed only when the actual air temperature falls below the set point in the LCP control unit.

4. Analysis and Discussion

a. Design Basis

The goal of this paper is to compare a Liquid Cooled Package (Rittal Corporation) to a legacy raised floor hot aisle/cold aisle arrangement uses typical CRAH units that. In the analysis to follow, a design basis for comparison was established, initial cost based on construction circumstances as well as equipment selection was concluded, real estate comparison based on several market values and different cities, and finally a total mechanical cooling system operating expense presented on an average basis. Table 1 below shows the design parameters that were established for the purpose of comparison

DESIGN COMPARISON

		SCHEME 1A	SCHEME 1B	SCHEME 2A	SCHEME 2B
		Hot/Cold Aisle	Rittal LCP Rack	Hot/Cold Aisle	Rittal LCP Rack
Data Center Power Load	Total Power (KW)	470		2,160	
Physical Data	Length (Ft)	46	36	125	70
	Width (Ft)	46	38	80	78
	Area (Sqft)	2,116	1,368	10,000	5,460
	Average Area Loading (W / Sqft)	222	344	216	396
Computer Density	Number of Racks	56	30	405	144
	Average Rack Loading (KW / Rack)	8.39	15.67	5.33	15.00
Computer Cooling Requirements	Equipment Capacity (KW)	118	15	118	15
	Minimum Cooling Unit (Qty)	3.97	31.33	18.25	144.00
	Total Required Cooling Unit (Qty)	4	32	19	144
	Redundancy	N+1	N+1	N+1	N+1
	Redundant Unit (Qty)	1	4	1	18
	Total Cooling Unit (Qty)	5	36	20	162

Table 1. Design comparison parameters between the LCP and conventional cooling method

The total area of the data center to package a given number of IT equipment is calculated based on an equal total IT power consumption. Table 1 shows clearly that LCP provides the benefits of a smaller foot print when compared to legacy cooled data centers. Data centers using LCP can achieve 35-45% savings in required real estate depending on the size which translates to a higher heat flux (higher density) per rack and per square foot. Considering an N+1 system, the total numbers of CRAH units and LCP racks were calculated for both sizes of data centers as presented above. Figures 4-7 show the layout of the equipment for both conventional and LCP for the two different data center sizes.

b. Initial Costs

The principal cost associated with LCP as compared to a conventional raised floor cooling system is shown in Table 2 below. The Table details various architectural, mechanical, and electrical construction costs and based on an average market price. In developing Table 2 below, several assumption were made, those are:

- The construction cost is based on $150/ft^2$
- Legacy data center raised floor is based on 36" while that of the LCP is based on 12" height. Raised floor is based on 6000 lbs concentrated load and zero seismic design criteria. Although raised floor may not be necessary for data centers with LCP. A trade study has to be conducted to evaluate if overhead chilled water plumbing can provide cost benefits. Although that can be risky as condensate may generate on the outer surface of the plumbing and even riskier in case of a leakage or ruptured pipe

- Legacy data center is assumed to have a drop ceiling and return air grills installed, although many are operating with out this and rely on the fact rising warm air will find its way back to the CRAH return plenums. In this calculation, a separate return duct was not accounted for assuming that the space above the drop ceiling can be used as a return plenum

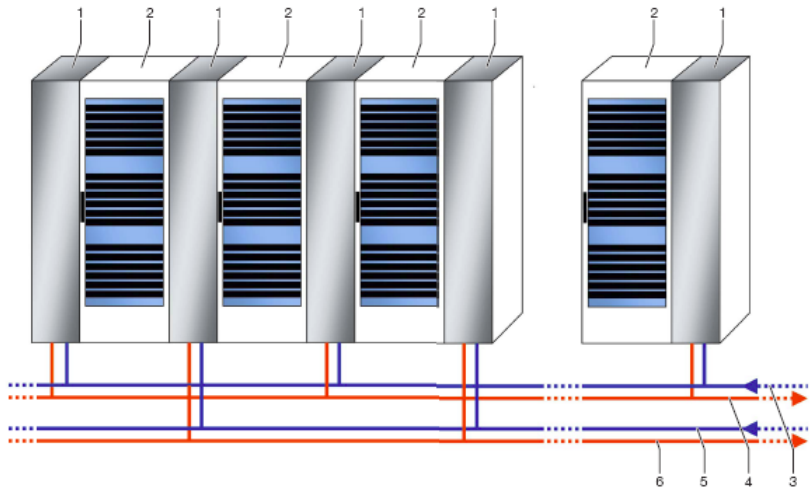
- Mechanical construction numbers were established for the chilled water layout shown in Figures 4-7 for the different models considered. The cost include chilled water and condensate drain pipes and fittings, pipe insulation, high performance butterfly valves, system fill, flush, and equipment start up for N+1 system. It doesn't include any premium time labor, commissioning, power wiring, leak detection, or drain pans under piping or CRAH units
- Electrical construction costs are based on engineering estimates associated with required wiring from the distribution panels to the CRAHs and LCPs. It includes feedboxes, circuit breakers, panels, and labor. Upstream electrical costs were not included and are considered to be similar.
- Cabinet/rack cost is based on numbers provided by Rittal and installation cost is assumed to be the same as conventional cabinets. Other sources have listed the cost of Rittal LCP at 2.5 time the cost accounted for in this study.
- Perforated tile cost was captured in the conventional data center cooling methodology

INITIAL COST ANALYSIS

Criteria		SCHEME 1A	SCHEME 1B	SCHEME 2A	SCHEME 2B
		Hot/Cold Aisle	Rittal LCP Rack	Hot/Cold Aisle	Rittal LCP Rack
Construction Cost	Construction	$317,400.00	$205,200.00	$1,500,000.00	$819,000.00
	Raised Floor Construction	$31,740.00	$16,416.00	$150,000.00	$65,520.00
	Drop ceiling cost (plenum)	$11,638.00	-	$55,000.00	-
	Drop ceiling return grills	$250.00	-	$1,250.00	-
	Perforated tile cost	$3,200.00	-	$12,000.00	-
	Mechanical Construction	$98,091.00	$173,632.00	$310,000.00	$610,585.00
	Electrical wiring	7,100	19,900	18,500	84,000
	Total Construction Cost	469,419	415,148	2,046,750	1,579,105
Cooling Equipment cost	CRAH	100,000	-	400,000	-
	CRAH Installation	50,000	-	200,000	-
	LCP Cabinet cost	-	360,000	-	1,728,000
	LCP cabinet installation	-	15,000	-	72,000
	CDU	-	not required		not required
	CDU installation	-	not required	-	not required
	cabinet/rack cost	61,600	-	445,500	-
	cabinet/rack installation	28,000	-	202,500	-
	Total Cooling Equipment Cost	239,600.00	375,000.00	1,248,000.00	1,800,000.00
	Total Initial Cost	709,019.00	790,148.00	3,294,750.00	3,379,105.00

Table 2. Initial cost analysis

It appears that the smaller foot print that was mentioned earlier reflects on many of the associated construction costs. The construction cost of data centers using LCP can be 15-30% lower than comparable data centers that use conventional cooling method. However, the cooling equipment cost can be any where from 40-60% higher than conventionally cooled data centers. It should be noted here that chilled water distribution units (CDU) cost was not included and not required per Rittal. Typical installation assumes that for every 2 rows of LCP cabinets can be served by one supply CDU and one return CDU. Rittal mentioned that CDS may not be necessary and instead a 2" manifold can run between the aisles and feed 8 LCPs, redundant manifolds would also be required as shown in Figure 3. It should be emphasized here that the redundancy scheme presented in Figure 3 was determined to be not resilient enough and alternative approach that is suitable to the mission critical facilities has been selected as shown in Figures 4-7. Looking at the total initial costs, and according to the numbers above, It appears that LCP cooled data centers may be slightly higher if starting a new data center. It seems logical to consider such a system specially when planning on building a new data center.



1. LCP
2. Server enclosure
3. Inlet cold water system 1
4. Return cold water system 1
5. Inlet cold water system 2
6. return cold water system 2

Figure 3. Redundant cooling and doubled, alternating water supply

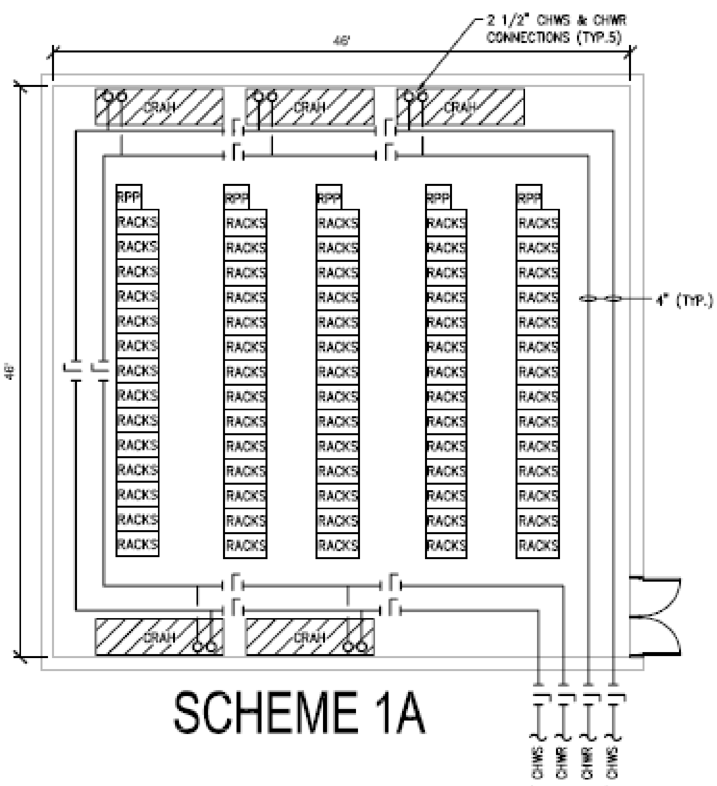


Figure 4: Layout of Legacy 2,100 ft^2 data center

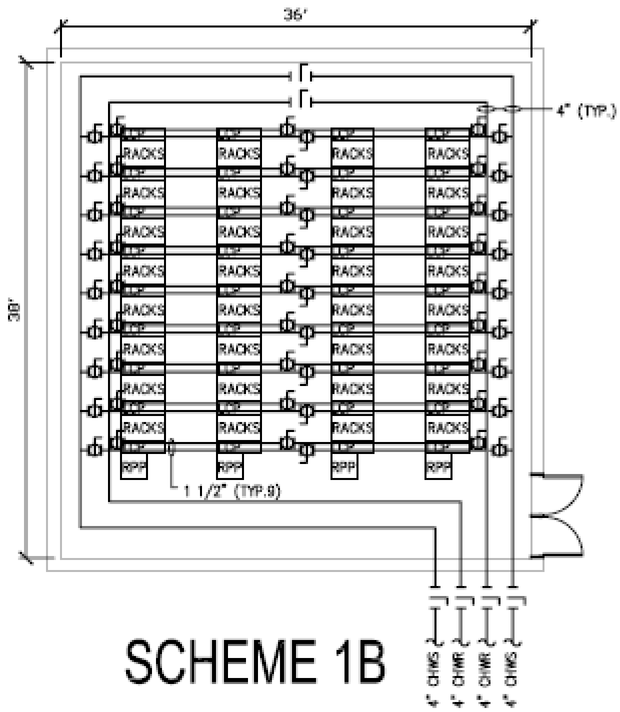


Figure 5: Layout of LCP 1,400 ft^2 data center

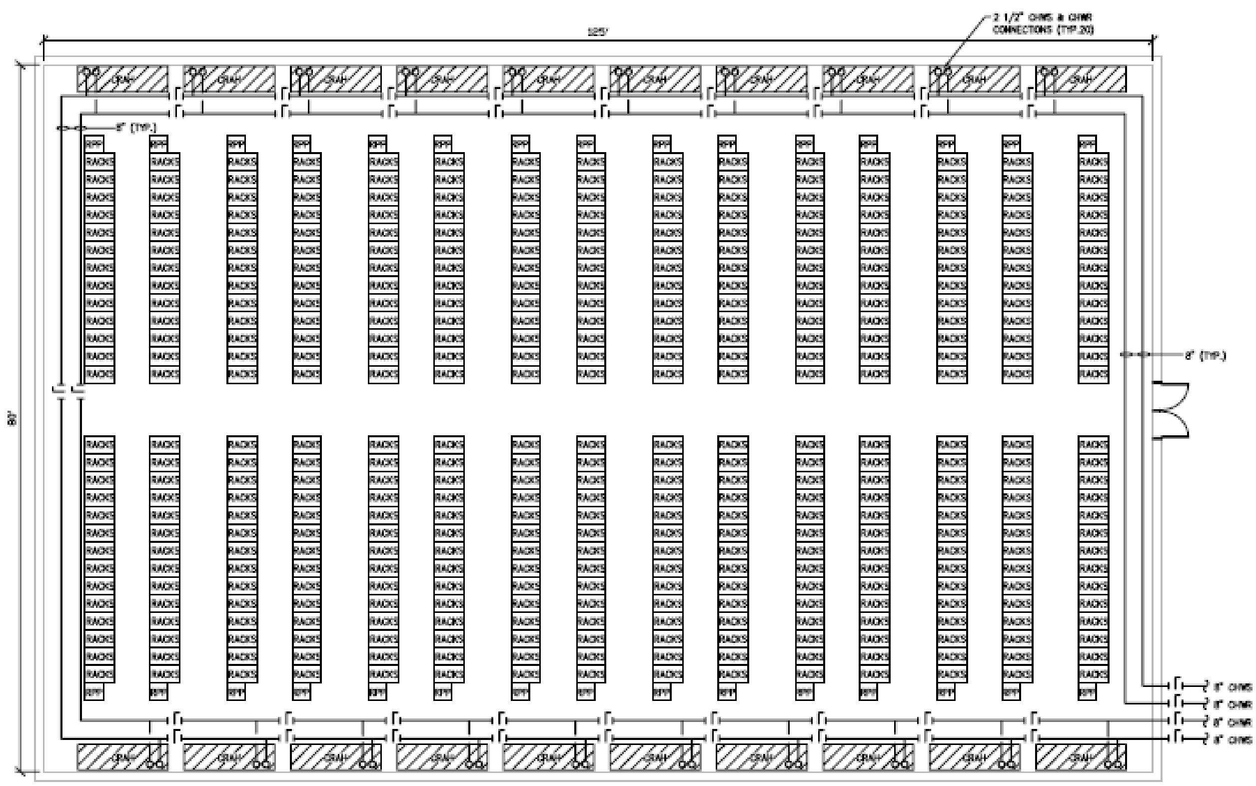


Figure 6: Layout of Legacy 10,000 ft^2 data center

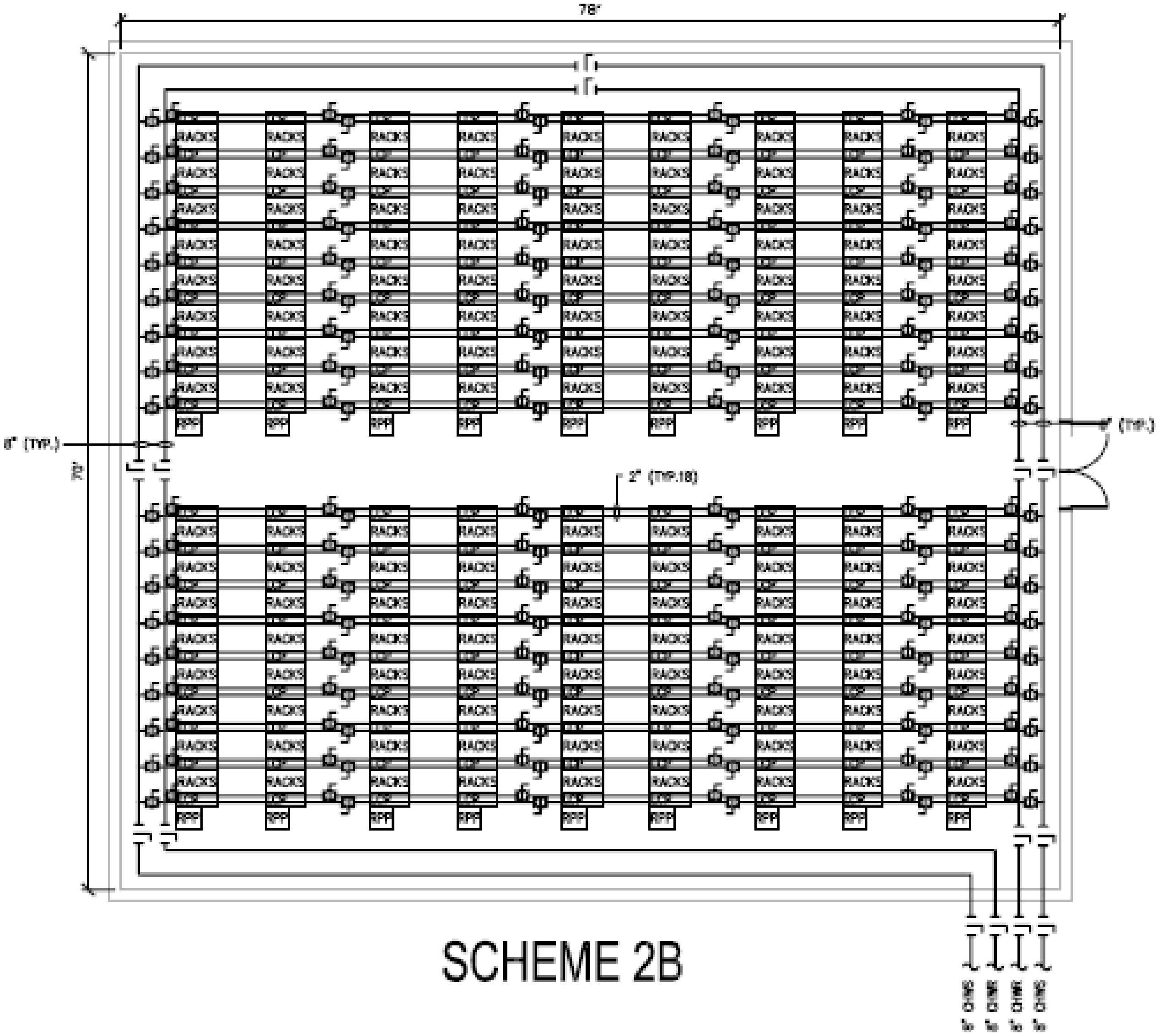


Figure 7: Layout of LCP 5,500 ft^2 data center

c. Real Estate Analysis

REAL ESTATE ANALYSIS

	Averaged Office Lease Rate		SCHEME 1A	SCHEME 1B
	US $ / sqft / Year		Hot/Cold Aisle	Rittal LCP Rack
Physical Data	Length (Ft)		46	36
	Width (Ft)		46	38
	Area (Sqft)		2,116	1,368
Annual Real Estate Cost	Chicago, US (Note 1)	$28.6	$60,412	$39,056
	Boston, US (Note 1)	$43.2	$91,327	$59,043
	Frankford, Gemany (Note 2)	$50.5	$106,767	$69,025
	Hong Kong, China (Note 1)	$55.2	$116,712	$75,455
Annual Real Estate Saving	Chicago, US		$21,355	
	Boston, US		$32,284	
	Frankford, Gemany		$37,742	
	Hong Kong, China		$41,257	

	Averaged Industrial Park / Warehouse Lease Rate		SCHEME 1A	SCHEME 1B
	US $ / sqft / Year		Hot/Cold Aisle	Rittal LCP Rack
Physical Data	Length (Ft)		125	70
	Width (Ft)		80	78
	Area (Sqft)		10,000	5,460
Annual Real Estate Cost	Chicago, US (Note 1)	$4.4	$285,500	$155,883
	Boston, US (Note 1)	$6.9	$431,600	$235,654
	Frankfort, Gemany (Note 2)	$9.3	$504,571	$275,496
	Hong Kong, China (Note 1)	$13.7	$551,568	$301,156
Annual Real Estate Saving	Chicago, US		$129,617	
	Boston, US		$195,946	
	Frankfort, Gemany		$229,075	
	Hong Kong, China		$250,412	

1. Averaged lease rate is based on CB Richard Ellis, Market View, First Quarter 2007.
2. Averaged lease rate is based on CB Richard Ellis, Market View, Third Quarter 2006.

Table 3. Real estate analysis

Table 3 compares the real estate cost associated with leasing a space in office or industrial park areas amongst four different cities based on the required foot print as depicted in Table 1. Evidently, one can observe, that for a small data center, where it can be housed in an office space, savings on the order of 30% should be expected. For a larger data center, where one would need to consider industrial parks, an expected savings around 40% can be achieved in the same city. It should be mentioned that the data above were referenced based on CBRE market review (2006, 2007)

d. Energy Analysis

ENERGY ANALYSIS - UNIT, ENVELOPE & LIGHTS

		SCHEME 1A	SCHEME 1B	SCHEME 2A	SCHEME 2B
		Hot/cold Aisle	Rittal LCP Rack	Hot/Cold Aisle	Rittal LCP Rack
Unit Fan Power Consumption	Unit Fan Power Consumption (KW)	11	1.2	11	1.2
	Total Cooling Unit (Qty)	5	36	20	162
	Total Fan Power consumption (KW)	56	43	224	194
Fan Energy Use	Per year (KWHr/Year)	489,924.90	378,432.00	1,959,699.60	1,702,944.00
Fan Energy Cost	Per year ($/Year)	$48,992.49	$37,843.20	$195,969.96	$170,294.40
Fan Energy Saving	Per year ($/Year)	$11,149.29		$25,675.56	
Lighting Power Consumption	1.8 KW/sqft (KW)	3830.0	2476.1	18100.0	9882.6
Lighting Energy Use	Per year (KWHr/Year)	33550.4	21690.5	158556.0	86571.6
Lighting Energy Cost	Per year ($/Year)	$3,355.04	$2,169.05	$15,855.60	$8,657.16
Lighting Energy Saving	Per year ($/Year)	$1,186.00		$7,198.44	

ENERGY ANALYSIS - CENTRAL PLANT

		SCHEME 1A	SCHEME 1B	SCHEME 2A	SCHEME 2B
		Hot/Cold Aisle	Rittal LCP Rack	Hot/Cold Aisle	Rittal LCP Rack
Data Center Power Load	Tower Power (KW)	470		2,160	
Unit Flow Rate	Flow Rate (GPM)	79.0	11.0	79.0	9.8
	Total Cooling Unit (Qty)	5	36	20	162
	Total Chilled Water Plant Flow Rate (GPM)	395.0	395.0	1,580.0	1,580.0
Chilled Water	Entering Chilled Water Temperature (Deg F)	48.0	56.3	48.0	55.4
	Entering Chilled Water Temperature (Deg K)	282.0	286.7	282.0	286.1
	Differential Chilled Water Temperature (Deg K)	4.6		4.1	
Center Plant Power	Excellent (KW)	141.0	121.3	648.0	568.3
	Average (KW)	258.5	222.4	1,188.0	1,041.9
	Poor (KW)	611.0	525.8	2,808.0	2,462.6
Center Plant Energy Use	Excellent (KWHr/Year)	1,235,160.0	1,062,855.2	5,676,480.0	4,978,273.0
	Average (KWHr/Year)	2,264,460.0	1,948,567.8	10,406,880.0	9,126,833.8
	Poor (KWHr/Year)	5,352,360.0	4,605,705.8	24,598,080.0	21,572,516.2
Center Plant Energy Cost	Excellent ($/Year)	$123,516.00	$106,285.52	$567,648.00	$497,827.30
	Average ($/Year)	$226,446.00	$194,856.78	$1,040,688.00	$912,683.38
	Poor ($/Year)	$535,236.00	$460,570.58	$2,459,808.00	$2,157,251.62
Center Plant Energy Saving	Excellent ($/Year)	$17,230.48		$69,820.70	
	Average ($/Year)	$31,589.22		$128,004.62	
	Poor ($/Year)	$74,665.42		$302,556.38	

Table 4. Energy Analysis

The first portion of Table 4 shows the total fan power consumption associated with the conventionally CRAH cooled data centers compared to total fan power used in LCP cooled data centers. Fans are assumed at full load and at rated power consumption for both systems. It is clear that LCP cooled data centers can save about 10-20% on total annual kWh and its cost. Similarly, and due to smaller foot print, there is an associated saving in envelope and light load, that is translated to total annual cost reduction of about 30-45% in light related cost. In this calculation, it was assumed that lights are not activated by a motion sensor. In all energy calculations, $0.10/kWh was assumed as the cost from the utility company.

In determining the impact on the central chilled water plant, Figure 8 was consulted to provide a supply chilled water temperature that is needed to meet the cooling load of 15 kW as was demonstrated in Table 1. The supply chilled water temperature for the LCP data center was compared to that of the conventional data center for both sizes. An increase of 4 K (4 ^{o}C) is possible to achieve the demand.

Calculations were conducted to evaluate the impact of increased chilled water set point as that directly impact the energy efficiency usage of data centers. It was concluded that for every 1 K increase, there is about 1-1.5% reduction in fixed speed chiller power consumption (kW/TON) and about 3-3.5% for a variable speed chiller. This was confirmed by Pavey (2003) and ASHRAE (2005). The analysis in Table 4 assumes VSD chiller with 3% chiller power reduction for every 1 K.

In calculating the central plant power consumption, which includes all the components in the mechanical cooling system such as pumps, the analysis considered a holistic approach that looks at the overall power consumption of a given data center. This holistic approach is termed a burden factor or power usage factor (PUE) and resultant global warming impact.

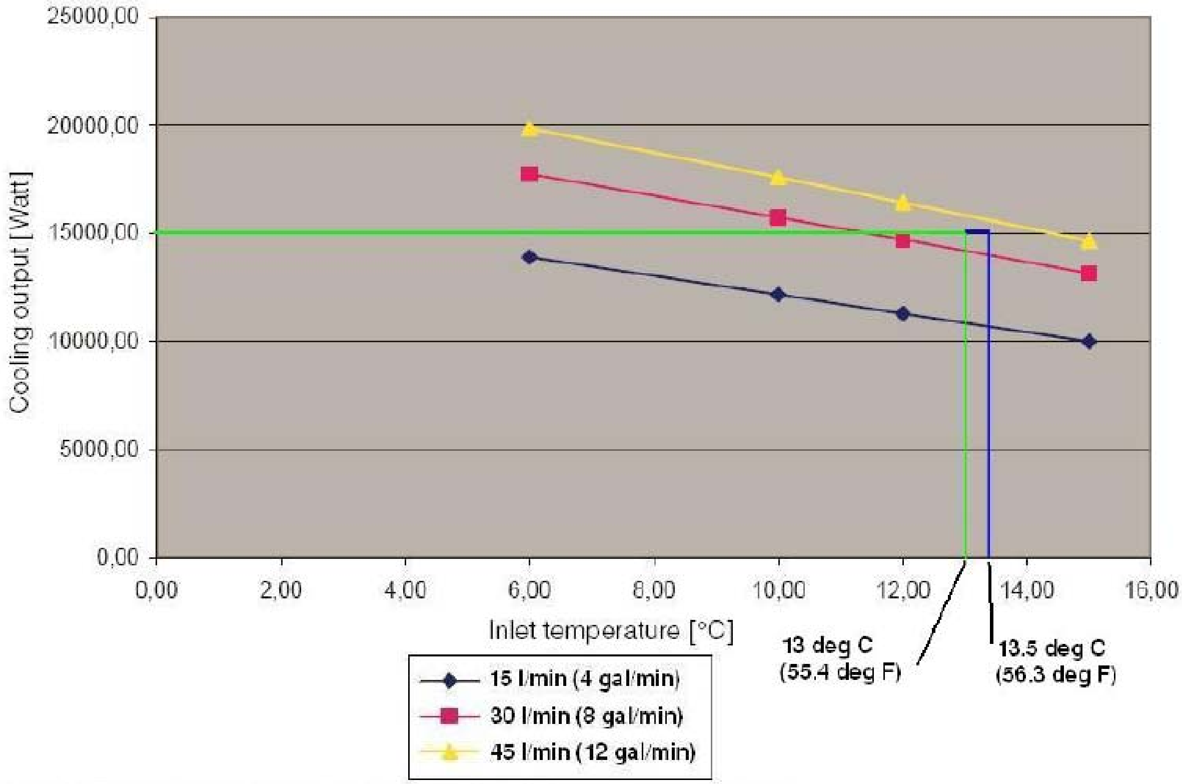


Figure 8: Cooling output of the LCP equipped with three cooling modules

The PUE categorizes data centers based on total IT power consumption, mechanical power consumption, electrical power support from utility mains down to the PDUs, RPPs, and also other power consuming systems such as fire/smoke protection system, BMS, and EPMS. A high level block diagram is shown in Figure 9.

PUE is defined as the total power delivered to site divided by the IT equipment power. The total power is the sum of mechanical, electrical, and other systems. The PUE captures the efficiency of all components starting from the mains though the UPS to the RPP level. In an equation format:

$$PUE = (P_{mechanical} + P_{electrical} + P_{others}) / P_{IT}$$

The objective is to minimize PUE by minimizing the numerator in the above equation. To achieve a low PUE value, reduction in mechanical power consumption by implementing more efficient components and reduce power consumption in chillers via sophisticated control algorithms is necessary. Similarly, more efficient electrical transformation and distribution is necessary especially in the UPS. PUE can have several values ranging from above 1 to over 3 depending on the circumstances of a given data center. EYP MCF long involvement in data center design and improvement established a criterion for different values of the PUE based on climatic zones, central chilled water plant type, and electrical components' efficiencies. Generally speaking, PUE can assume the following values

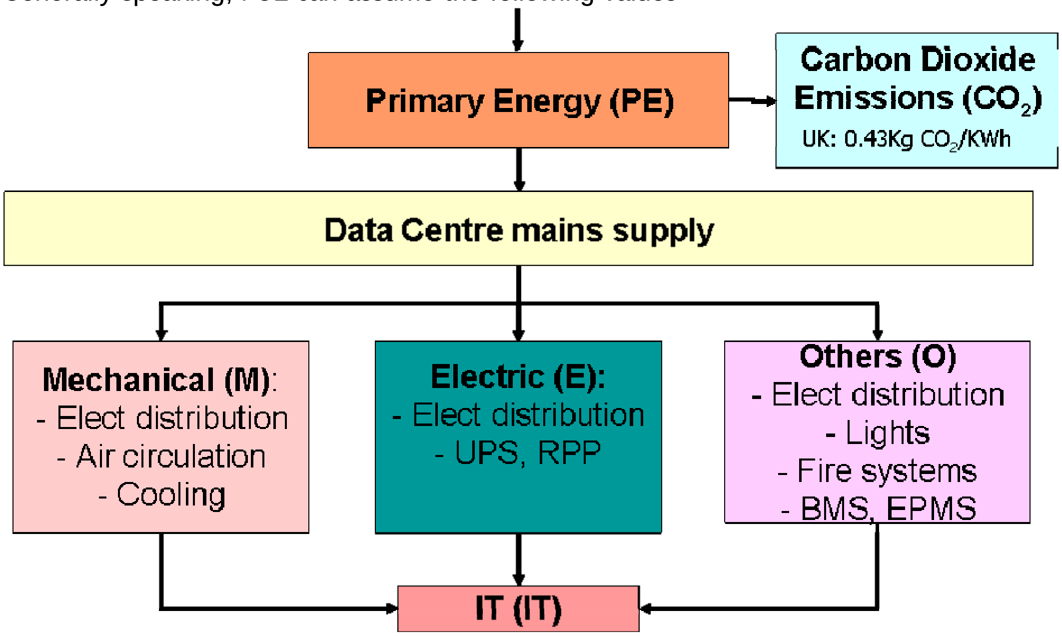


Figure 9. Data center energy block diagram

PUE < 1.5 ; Excellent
1.5 < PUE < 2 ; good
2 < PUE < 3 ; Poor

In the analysis of Table 4, PUE was selected for an excellent, 2 for average, and 3 for poor or least efficient. The data reveals that 12-14% reduction in power delivered to mechanical chilled water plant can be expected. This is considered an interesting result that definitely impact the owner directly and yet reduces the environmental impact of data center power consumption through reduction of CO_2 emissions. One can also conclude that more savings are expected from a less efficient data center. For a small data center with average efficiency, annual savings are expected to be on the order of $30,000. This number may double or guardable depending on the size and efficiency of the data center. Lesser energy savings should be expected from an efficient data centers.

When considering the overall savings for a given data center size, apparently the chilled water savings, fan power savings, as well as envelope and lighting savings need to be added. For an average efficiency data center, one would quickly calculate an annual savings of $45,000 and $160,000 for the small and large data centers considered in this study, respectively.

It should be pointed out that increased chilled water temperature has positive impact on the water side economizer if the central chilled water plant is equipped with such technology. For a traditional water side economizer system, the number of economizer hours depends on the number of hours that the out side wet bulb temperature is less than chilled water set point. The exact impact depends on the climatic zone of the city of interest. The conclusion is that the energy savings mentioned above can be enhanced even further.

5. Conclusions

The following trade study matrix summarizes the general aspects of comparison between conventional versus LCP cooled data centers.

General Comparison

Attribute	LCP cooled data center	Conventional data center
Raised floor height	Minimum just enough for chilled water network, no perforated tiles. Potentially, can be eliminated	Dictated by best practices and ASHRAE recommendations. Perforated tiles required
Aisle width	Irrelevant resulting in a smaller foot print	Dictated by best practices and ASHRAE recommendations
Air bypass	If properly engineered, shouldn't be an issue	Considered an issue and requires CFD and trial and error to minimize
Air recirculation	If properly engineered, shouldn't be an issue. Hot spots are not a concern	Considered an issue and requires CFD and trial and error to minimize. Hot spots are a concern
Negative pressure flow	Not an issue	Considered an issue and requires CFD and trial and error to minimize
Changing power density	Loads can be added as long as it with rack cooling capacity, other wise servers would have to be moved to another rack	perforated tiles can be interchanged to meet newly added loads (low-med density)
Configuration/Layout	Rack layout maybe arbitrary, cooling performance is independent	Computational fluid dynamics (CFD) analysis needed to develop air flow paths
Power density	Removes heat at source suits high density applications	Suitable for low to medium density applications
Power consumption	Lower due to higher chilled water temperature and lower fan consumption	Higher
Redundancy	Must provide 2N dual path since no sharing of cooling between racks	Can use N+1
Total Cost Ownership	Lower	Higher
Liquid leakage	Exhaust temperatures are higher to eliminate moisture, condensate management is integrated. However, If leakage happens; it can be problematic	Not an issue
Serviceability	Facility people can perform many service tasks	Requires trained technicians for the CRAH/CRAC units
Data center ambient conditions	Can accept higher temperature and humidity levels	Temperature & Humidity ranges are defined per ASHRAE
Air side economizer-Free cooling	Can't benefit from air economizer	Can use air economizer
Water side economizer-Free cooling	Increased chilled water temperature enables increased window of water economizer usage	Can use water economizer

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