ARCE 453 Report
Chandler Morehardt

Team 6: balanced design

Client: BROCADE

Project: Cal Poly Brocade Challenge 2013

06.06.2013

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Introduction

For the third year in a row, Brocade (a technology company specializing in data and storage networking products) has presented Cal Poly students with a challenging project. This project benefits both the students' knowledge and exposure to industry as well as helping Brocade scout for top talent and receive innovative ideas from college students. The project changes yearly, depending on Brocade's most pressing need. This year, the project presented the opportunity for a bigger structural focus than in years past, and Al Estes volunteered to advise three ARCE seniors on their senior project. As one of those ARCE seniors, this paper reports my experience with the project during Winter Quarter, 2013.

Problem Statement

Brocade's second largest site is located in Broomfield, CO. The site is rapidly running out of infrastructure as business grows, particularly in the data center type labs where Brocade develops and tests its products. The goal of this project is to help Brocade decide the best way and what technologies to use in the infrastructure for a new building.

The project mission was to plan and design a new building to support Brocade R&D and product testing rack labs. This space should use innovative ideas to lower both initial construction costs and operating costs while being highly efficient and best in class Power Utilization Effectiveness (PUE). The building needs to be designed with scalability and flexibility allowing for racks to be added, growth of density in the racks, as well as designed to allow for redundancy to be incorporated or added through its life. The building must also be financially feasible, taking into consideration all associated costs.

Division of Responsibilities – Team 6

Architectural/Structural Engineering: Chandler Morehardt (4th yr ARCE)
Mechanical: Alexa Coburn (1st yr ME), Juan Silva (4th yr ME), Kerry Sun (3rd yr AERO)
Electrical: Greg Wang (4th yr EE), Raul Chagoya (2nd yr CPE)
Financial: JD Torres (2nd yr BUS)

Interdisciplinary Experience

I learned a lot of lessons in professionalism and communication during this project and am a better student because of it. A major factor of our team's success is that we held group meetings <u>early and often</u>. We met three times a week to share ideas with each other and discuss different angles for the solution. One challenge of being in an interdisciplinary team was that we had to work on how we each translate what we know about our field into a language that another team member can understand.

It is important to have open communication with the Brocade representatives, Nathan and Victor. When I needed to know the weights of the racks, Victor was quick to give me a detailed response. Going to office hours was always beneficial and helped steer our group in the right direction after each meeting. One week I went to the office hours and asked a question about the structural design that sparked a 45 minute conversation with Victor about what exactly he does as a civil engineering graduate at Brocade. He went on to explain to me how he is basically a translator between Brocade and the contractor building their new buildings. I was very interested in what he does and was grateful that I decided to go to the office hours that day. Brocade also made themselves available through conference calls and email correspondence. They would pick a time that anyone could call in and ask questions. The constant communication was important to the progress of our work

An area where our team could have improved was time management. While Al had me list my deliverables and schedule their completion, our team did not have intermediate deadlines throughout the project. This scheduling of activities helped me with time management. It would have been helpful to set deadlines as a team, rather than wait until the last weekend before the project is due. We spent late nights in the library trying to piece everything together. We spent the first six weeks of the project on research. At that point, we had to take what we had and finish the project. It would have been beneficial if we had held each other more accountable for what we were expected to contribute to the team.

I valued the opportunity to work with other disciplines on this project. It was especially interesting to work with a Business major to learn the financial side of the project and how it applies to my field of study. There were many challenging, yet rewarding moments where I had to translate my work in order for someone else on the team to be able to understand it. For example, there was one time I used to whiteboard to illustrate tributary area to another teammate. I also had to ask the other disciplines questions about their design that might pertain to my design. These questions usually pertained to the dimensions of the systems that they were trying to put into a building that had already been given fixed dimensions. Throughout the project, I needed to be very flexible with the input I was receiving from my teammates. Overall, I had a positive experience working with other majors and look forward to applying what I learned to my future career.

Overview of Design

The building will be a structural steel frame building with space for 152 racks per phase. This 4-phase construction process will occur over a 9 year period and be able to hold 608 racks by completion. Our cooling system consists of three main components: a rear-door heat exchanger, coolant distribution unit (CDU), and an air-cooled chiller. The rear-door heat exchanger attaches to the back of each individual rack and neutralizes the heat directly at the source, maximizing energy efficiency. The second essential component of our design is the CDU unit, which consists of a heat exchanger, pumps, controls, and a piping distribution manifold. The third component of our design is an air-cooled chiller that is located outside and utilizes Broomfield's cold weather to incorporate free-cooling into our system. In our data center design, we decided to use overhead flexible piping rather than the traditional under-floor hard piping. Additionally, we will have two cooling accessories: a negative pressure ventilation fan to remove excess heat from the data center and one AC unit located in the meeting room. The electrical distribution will be accomplished through a 480 to 208 V AC system, versus other AC or DC-DC distributions. The electrical system will mainly be powered by utility, however in the event of a power failure, backup diesel generators will supply the required power. All of our electrical components are running off a dual-branch design, providing N+1, and for our case, also 2N redundancy. Having 2N redundancy means that maintenance can be provided without shutting down any critical loads. In our design we utilize uninterruptible power supplies (UPS), load banks, power distribution units (PDU), and switchgears. These components provided by Schneider Electric are easily scalable which gives this system great flexibility. All these components work in unison to accommodate the needs of powering and monitoring this data center.

Structural Recommendation

One of the main architectural concerns is to maximize the floor space for rack layout. The chosen structural material is steel because of how long steel can span without needing columns. The chosen joist system of open-web trusses can typically span 60 feet. Concrete and timber buildings require more supports throughout the framing plan and take more construction time. Although steel can be slightly more expensive, it minimizes the area occupied by columns, allows for changes in the building over time and minimizes on-site erection time.

Another important requirement for the mechanical design of this building is to prevent the racks from overheating. From an architectural standpoint, this means choosing an exterior material that minimally absorbs the suns heat. Dark colored materials absorb 70-90% of the radiant energy from the sun. A solution to this is to use a lighter colored exterior material in addition to radiant barrier insulation. Radiant barriers can reduce heat gains on the roof/walls of the building by 25% and can also double as insulation.

When it comes to foundation design, there are some important soil characteristics about the Broomfield area to take into account. Bentonite, a highly expansive clayey soil is prevalent throughout the Denver area. This soil expands and contracts depending on water levels and can cause unwanted settlement of the foundation, leading to extra cost. The recommended foundation design is to drill caissons or piers down to the bedrock. When the foundation is anchored in the bedrock, the soil above no longer becomes an issue because of how stable the bedrock is. Fortunate for this project, bedrock is typically shallower in mountainous regions like Broomfield, Colorado.

For more information, see the Architectural Engineering Work Package and Appendix.

Architectural Engineering Work Package

Project: Brocade Data Center

Location: 4 Brocade Parkway, Broomfield, CO

Owner: Brocade

Building Description: Brocade's second largest site, located in Broomfield, CO, is rapidly running out of infrastructure as the business grows, particularly in the data center labs. This building will primarily provide more room for data racks and secondarily provide space for engineers to work. The space should be designed to initially hold 150 racks and be scalable to house 600 racks total. The layout should maximize usable space and should be designed to have 50 engineers working within the lab. Story height is 15 feet for the one story building. The primary structure of the building is structural steel beams and columns with metal deck and open web trusses. The recommended lateral force resisting system is concrete shear walls and moment frames.

Site location: The Broomfield, CO branch of Brocade has plenty of available land, so finding space for this additional server rack lab was no problem. The initial 150 rack space was chosen to be across the street in the north direction from the existing structure so that the parking lot can be shared and the engineers can easily walk over to the rack lab. The expansion of the building will occur along the main road into the property in the west direction so that all points of the rack lab are equally accessible from the existing structure. There is plenty of space for additional parking on either end of the fully scaled rack lab. Several options were considered in the site selection process. Option 3 was eliminated because of its lack of accessibility from the current parking lot and existing structure. The recommended location is a mix of Option 1 and 2 for its ease of accessibility from the parking lot and existing building. The site selection research can be seen in the Appendix.

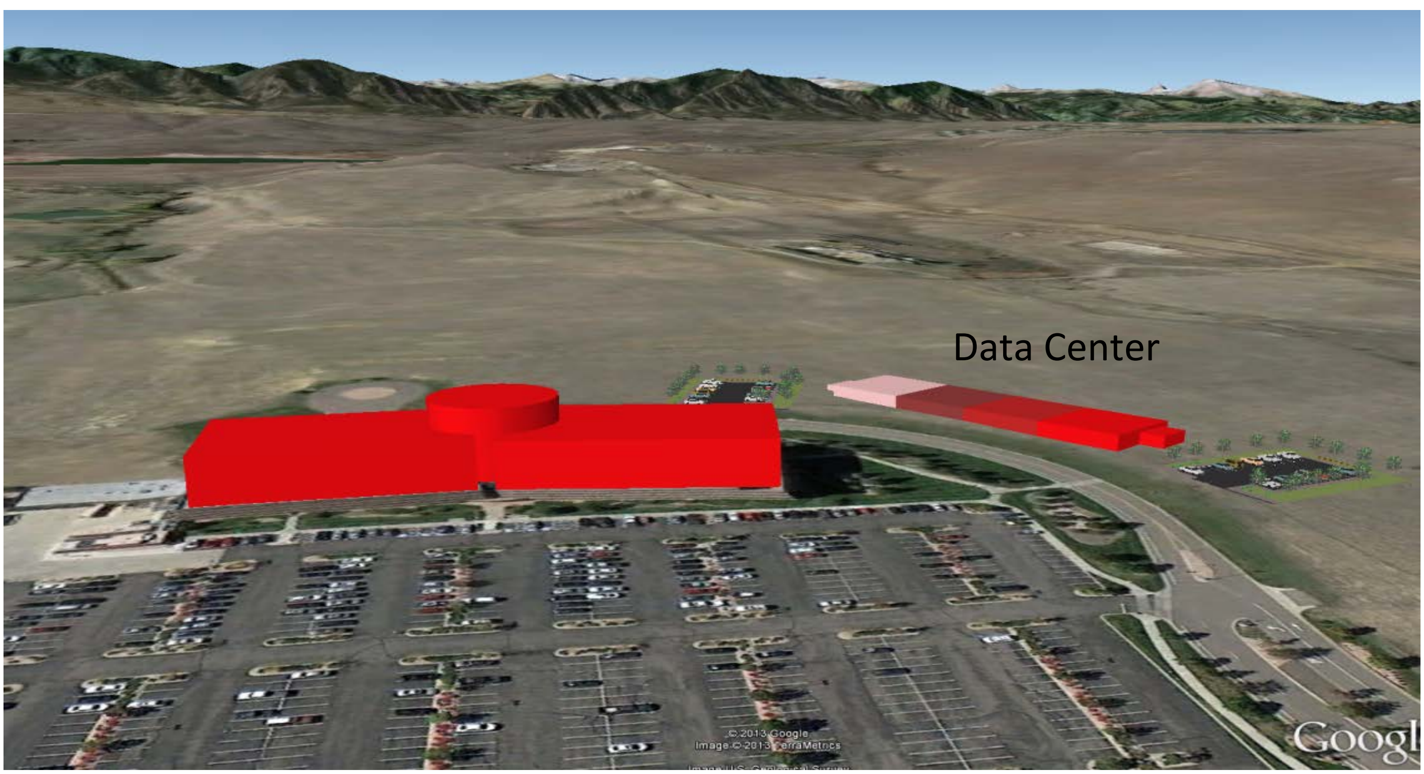


Figure 1: Site location in Broomfield, CO

Structural Design

Building Code:	2012 International Building Code	
References:	Loads:	ASCE 7-10
	Steel:	AISC 360-10
	Concrete:	ACI 318-05

Weights:

Slab on Grade	Live Load = 250 psf (rack weight)	
	Dead Load = Slab self-weight	
Roof	Live Load = 20 psf	
	Snow Load = 20 psf	

Material Selection: The recommended material selection is structural steel. The reasons for selection steel as opposed to concrete or timber/masonry are that steel minimizes area occupied by the columns which maximized the floor plan for rack space. Steel is easy to install and uninstall which allows for changes in the building over time. This building will undergo four phases over twelve years (one phase every 3 years). Steel construction also has minimal on-site erection time and construction time. These are important characteristics for a phased construction. By nature, data center floor plans are repetitive and simple. A more complicated framing layout might call for timber or concrete as the structural material.

Practical Span Ranges: Steel beams can span anywhere from 10 to 75 feet and are typically spanned 30 feet. Open-Web Joists typically span 60 feet and metal decking can span anywhere from 10 to 20 feet.

Exterior Architectural Materials

A radiant barrier on the underside of the roof will allow for the exterior materials to use methods of natural cooling (Figure 2). The primary source of heat build-up is sunlight absorbed through the roof, walls and windows. A radiant barrier (Figure 3) can reduce heat gains on the roof by 25% and will also double as insulation for this project. Dark colored exterior materials absorb 70-90% of the radiant energy from the sun while light colored surfaces effectively reflect most of the heat away. The recommended exterior architectural material for the rack lab is a light colored surface with radiant barriers as the primary insulation.

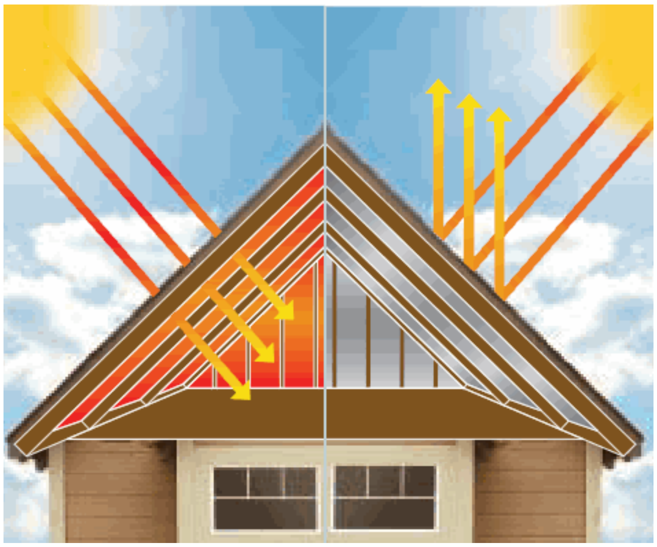
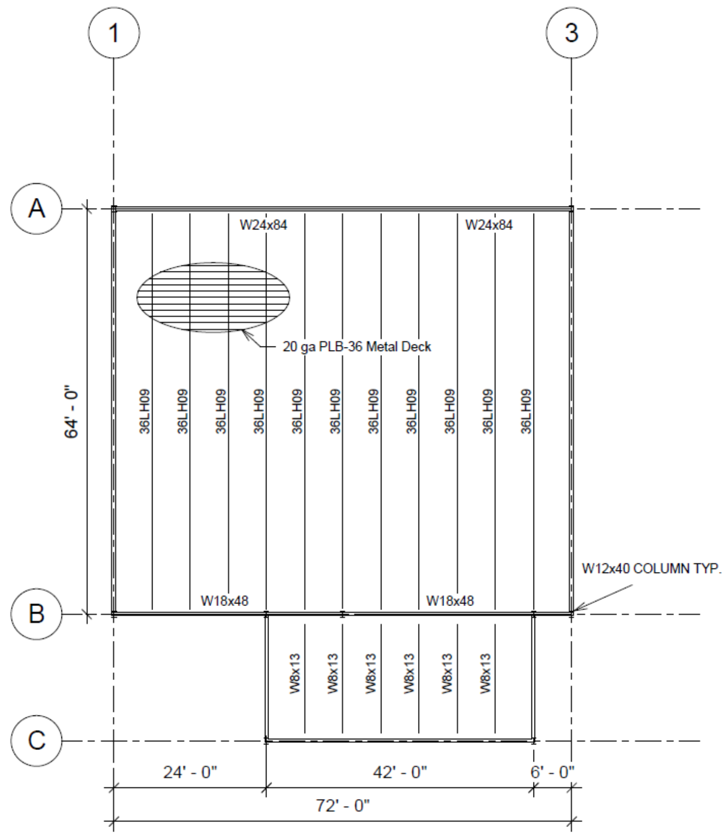


Figure 2: Radiant Barrier demonstration

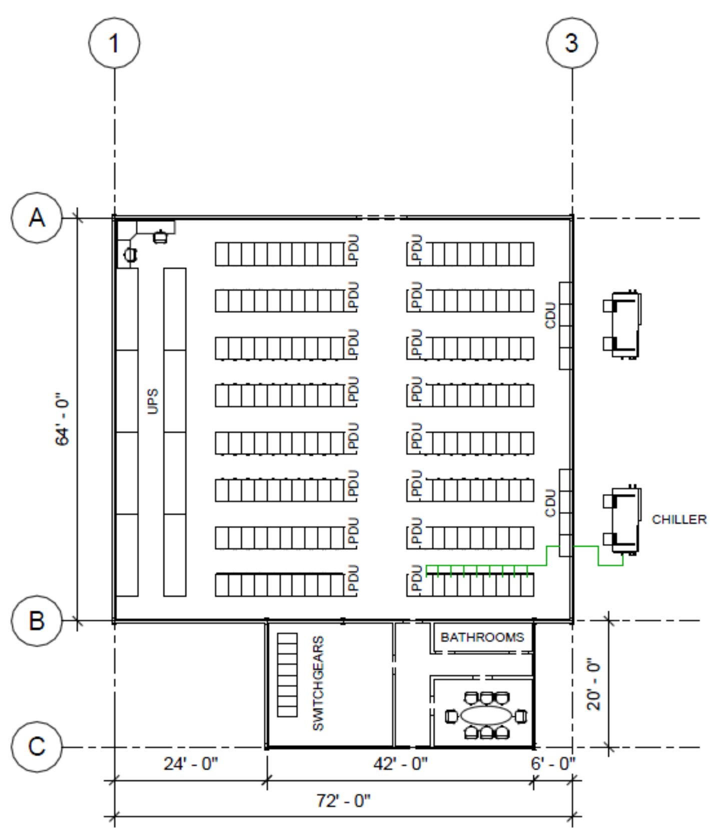
Figure 3: Radiant Barrier sheet

Rack Layout: The rack layout will include 9-10 racks per row. Racks are typically laid out with 8-12 per row. The more racks that are next to each other without interruption, the more efficient the system is. For example, a row length of 1 rack would be the least efficient, while a row length of infinite racks would be the most efficient. Having more than 12 racks per row is not feasible due to means of egress and fire codes. For reference, see the phase 1 rack layout in Figure 4.

Framing Options: The chosen framing option was to run the joists in the long direction and the beams in the short direction. This layout was chosen in order to eliminate the need for columns in the server room. The 6-foot on center joist layout was chosen based on optimizing the metal deck span. For more information, see the structural calculations in the Appendix.



1 FRAMING PLAN PHASE 1
1/16" = 1'-0"



1 RACK LAYOUT
1/16" = 1'-0"

Figure 4: Rack Layout

Phase Construction: This building will be built initially to hold 152 server racks and will be scalable to house 608 racks. This growth will be done through a 4-phase process, adding 4600 ft^2 of space (room for 152 racks) every 3 years. This process is recommended to eliminate wasted space. If the entire 20,000 ft^2 were built up front and only a portion of that used, there would be an unnecessary cost to maintain the unused portion. The phased construction will minimally interfere with operations in the data center by simply adding on to the building and opening a doorway when the addition is complete.

Foundations: The foundation design for this project will need to account for expansive soil. Bentonite, a highly expansive soil, expands when saturated with water and shrinks during drought periods, causing settlement of the foundation. One way to avoid this is to drill caissons (or piers) into the bedrock (Figure 5), which will not settle. Bedrock depths can range from 10 feet to 150 feet below the ground surface but are typically shallower in mountainous or high elevation areas such as Broomfield, CO. The Broomfield Building Department also stated that drilled piers to the bedrock are a common foundation design for the area.

The benefits of drilled piers are that they don't have alignment problems and the larger diameters allow them to support more load. Drilled piers also require lighter construction equipment than other foundation systems and therefore, less vibration during installment. When drilling the hole for the pier, the soil type can be verified to check the accuracy of the soil report. Some problems with drilled piers are that there is the possibility of running into large cobbles or boulders which require much effort to move. If the soil is cohesionless, there is the possibility of caving. Also, inspection of the hole can be dangerous.

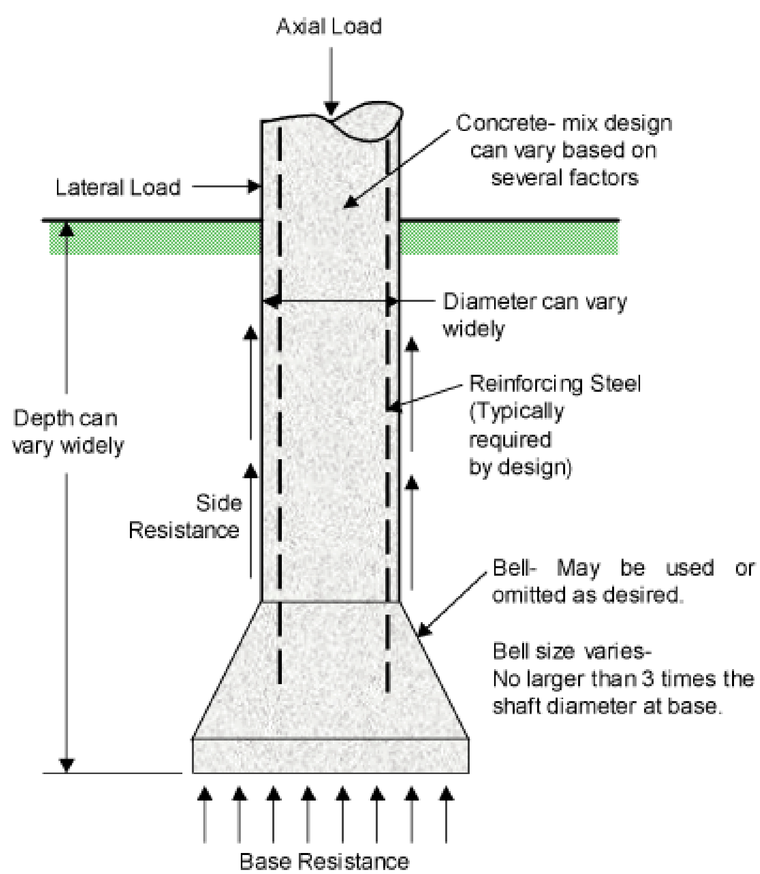


Figure 5: Drilled Pier to Bedrock

Conclusion

On Tuesday, March 5th, 2013, Brocade representatives travelled to Cal Poly for the preliminary presentations. From these presentations, the top teams would be selected to present again at Brocade's headquarters in San Jose, CA on Friday, March 8th, 2013. My group was asked to present again in San Jose, along with 2 other groups. Only one group was not asked to present again. The day in San Jose was spent presenting in the morning, followed by networking with Brocade employees in the afternoon and a tour of the facilities. Later in April, Brocade came down to San Luis Obispo one final time to host a reception dinner for all teams involved and announce the winning teams. The reception was held at Novo on Higuera Street. The night began with catching up with our teammates and then talking with the Brocade representatives. After a five course meal, the winners were announced. Our team was awarded second place. Initially, there was disappointment among our team, but we were all happy with the experience and grateful to be walking away with our $400 per person prize money.

I would definitely do this project again and would recommend it for other ARCE's to get involved in. That being said, because the project changes yearly, it is important to make sure there is an opportunity for a structural element of the project before committing to do it. The Brocade Challenge gave me exposure to an experience that I would not have found in any other class at Cal Poly.

balanced design

JOB
SHEET NO OF
CALCULATED BY DATE
CHECKED BY DATE
SCALE

REF

Steel Deck Design

64' x 36' bays, deck parallel to 36' side

Roof Load take-off

DL = 26.5 psf
LL = 20 psf

D+L = 46.5 psf ASD

Deck Span

Options:
1) 2 double spans (9' each)
2) 1 double, 1 triple (7.2' each)
3) 2 triple (6' each) ← optimizes

options:
20 ga PLB-36 80 psf ← Cheaper
20 ga PLN-24 170 psf
ASD

VERCO CATALOG

Use 20 ga PLB-36 1 1/2" deep roof deck

with Primer painted finish to fire-proof the deck.

balanced
design

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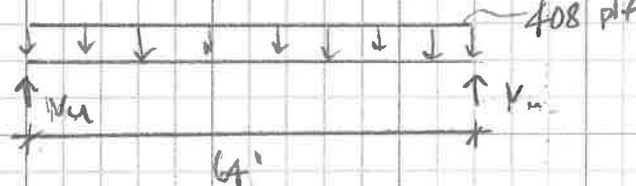
Steel open Web Joist Design

f_u = actual/req'd stress
F_n = nominal stress
ϕ = resistance factor
ϕF_n = design stress

LRFD

Trusses span 64' and are 6' o.c.



LC $1.4D = 1.4(30) = 42$ psf
$1.2D + 1.6L_r = 1.2(30) + 1.6(20) = 68$ psf ←

Vulcraft catalog

Sand $L_r = 20$ psf

68 psf (6') = 408 plf

use 36LH09 $\phi F_n = 513$ plf > 408 plf ✓

36" depth

LRFD

STANDARD LOAD TABLE FOR LONGSPAN STEEL JOISTS, LH-SERIES

Based on a 50 ksi Maximum Yield Strength - Loads Shown In Pounds Per Linear Foot (plf)

Joist Designation	Approx. Wt in Lbs. Per Linear Ft. (Joists only)	Depth in inches	Max Load (plf)	SAFELOAD* in Lbs. Between		SPAN IN FEET														
			< 29	29-33		34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
24LH03	11	24	601	17430		513	508	504	484	460	439	418	400	382	366	351	336	322	310	298
						235	226	218	204	188	175	162	152	141	132	124	116	109	102	96
24LH04	12	24	737	21360		628	597	568	540	514	490	468	447	427	409	393	376	361	346	333
						288	265	246	227	210	195	182	169	158	148	138	130	122	114	107
24LH05	13	24	789	22890		673	669	660	628	598	570	544	520	496	475	456	436	420	403	387
						306	297	285	264	244	226	210	196	182	171	160	150	141	132	124
24LH06	16	24	1061	30780		906	868	832	795	756	720	685	655	625	598	571	546	522	501	480
						411	382	356	331	306	284	263	245	228	211	197	184	172	161	152
24LH07	17	24	1166	33810		997	957	919	882	847	811	774	736	702	669	639	610	583	559	535
						452	421	393	367	343	320	297	275	257	239	223	208	195	182	171
24LH08	18	24	1243	36060		1060	1015	973	933	895	858	817	780	745	712	682	652	625	600	576
						480	447	416	388	362	338	314	292	272	254	238	222	208	196	184
24LH09	21	24	1464	42450		1248	1212	1177	1146	1096	1044	994	948	903	861	822	786	751	720	690
						562	530	501	460	424	393	363	337	313	292	272	254	238	223	209
24LH10	23	24	1547	44850		1323	1284	1248	1213	1182	1152	1105	1053	1002	955	912	873	834	799	766
						596	559	528	500	474	439	406	378	351	326	304	285	266	249	234
24LH11	25	24	1630	47280		1390	1350	1312	1276	1243	1210	1180	1152	1101	1051	1006	963	924	885	850
						624	588	555	525	498	472	449	418	388	361	337	315	294	276	259
			< 34	34-41		42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
28LH05	13	28	623	21180		505	484	465	445	429	412	397	382	367	355	342	330	319	309	298
						219	205	192	180	169	159	150	142	133	126	119	113	107	102	97
28LH06	16	28	828	28140		672	643	618	592	568	546	525	505	486	469	451	436	421	406	393
						289	270	253	238	223	209	197	186	175	166	156	148	140	133	126
28LH07	17	28	934	31770		757	726	696	667	640	615	591	568	547	528	508	490	474	457	442
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28LH08	18	28	1001	34020		810	775	744	712	684	657	630	604	580	556	535	516	496	478	462
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28LH09	21	28	1232	41880		1000	958	918	879	844	810	778	748	721	694	669	645	622	601	580
						428	400	375	351	329	309	291	274	258	243	228	216	204	193	183
28LH10	23	28	1347	45810		1093	1056	1018	976	937	900	864	831	799	769	742	715	690	666	643
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28LH11	25	28	1445	49140		1170	1143	1104	1066	1023	982	943	907	873	841	810	781	753	727	702
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32LH08	17	32	790	30810	30810	616	595	574	553	535	517	499	483	468	453	439	426	412	400	388
						255	242	229	216	205	194	184	175	167	159	151	144	137	131	125
32LH09	21	32	992	38670	38670	774	747	720	694	670	648	627	606	586	568	550	534	517	502	487
						319	302	285	270	256	243	230	219	208	198	189	180	172	164	157
32LH10	21	32	1096	42750	42750	856	825	798	768	742	717	693	667	645	624	603	583	564	546	529
						352	332	315	297	282	267	254	240	228	217	206	196	186	178	169
32LH11	24	32	1201	46830	46830	937	903	870	840	811	783	757	732	709	687	664	643	624	604	585
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36LH12	25	36	1197	51450	51450	889	862	835	810	784	762	739	717	696	675	655	636	618	600	583
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						415	395	376	359	342	327	312	298	285	273	262	251	240	231	222
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36LH15	36	36	1635	70320	70320	1213	1192	1171	1153	1116	1081	1047	1015	984	955	927	900	874	850	826
						480	464	448	434	413	394	375	358	342	327	312	299	286	274	263

STEEL JOIST SJI INSTITUTE

balanced
design

JOB
SHEET NO ______ OF ______
CALCULATED BY ______ DATE ______
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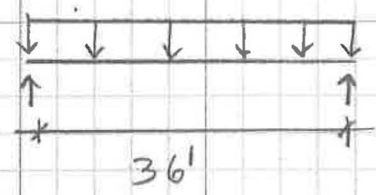
SCALE

REF	
	STEEL BEAM DESIGN
worst case for interior beam at full phase	 analyze as distributed load $A_t = 64' \times 36' = 2304 \text{ ft}^2$
	Lr reduction
ASCE 7-10 4.8.2	$R_1 = 0.6$ for $A_t > 600 \text{ ft}^2$
	$0.6(20) = 12$ so, snow load governs = 20 psf
LOAD TABLES	$1.2D + 1.6S = 1.2(34) + 1.6(20) = 72.8$ psf
	$72.8 \times 64' = 4660$ plf
	$V_u = \frac{wl}{2} = 84^K$
	$M_u = \frac{wl^2}{8} = 755$ k-ft
	Check deflection
IBC Table 1604.3	$\Delta_{allow} = l/240$ for supporting non-plaster ceiling $= 1.5"$ LL only
Table 3-23 AISC	$\Delta_{actual} = \frac{5wl^4}{384EI}$ $I_{req'd} = \frac{5(2050 \frac{lb}{ft} \frac{1 ft}{12 in})(36 \times 12)^4}{384(29000000 \text{ psi})(1.5 \text{ in})} = 1780 \text{ in}^4$
Table 3-3	Options: W24X68 W21x83 W24x84

balanced design

JOB

SHEET NO. OF

CALCULATED BY DATE

CHECKED BY DATE

SCALE

Check ϕM_n / ϕV_n

	I_x (in^4)	ϕM_n (k-ft)	ϕV_n (k)	Weight
W24x68	1830	~~664~~		
W21x83	1830	~~735~~		
W24x84	2370	840	340	84 plf ←

Use W24x84

for exterior beams W18X48 satisfies req'm

balanced design

JOB ______________________

SHEET NO ________ OF ________

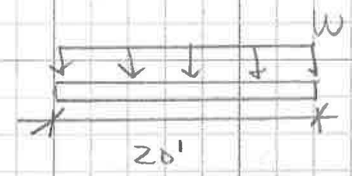
CALCULATED BY ________________ DATE ________

CHECKED BY ________________ DATE ________

SCALE ______________________

REF

Beam 2 Design



6' o.c.

$A_t = 20 \times 6 = 120\ ft^2$

$1.2D + 1.6S = 1.2(34) + 1.6(20) = 72.8\ psf$

$72.8\ psf \times 6 = 436.8\ plf = w$

$V_u = \frac{wl}{2} = 4.37^{K}$

$M_u = \frac{wl^2}{8} = 21.8^{k\text{-}ft}$

Check Defl

$\Delta_{allow} = l/240 = 1''$

$$E_{req'd} = \frac{5\left(192\ plf\ \frac{ft}{12\ in}\right)(20 \times 12)^4}{384\,(29 \times 10^6\ psi)(1'')} = 23.8$$

options: W8x10* ← satisfies I, ϕM_n, ϕV_n

W8x13

balanced design

JOB
SHEET NO ____ OF ____
CALCULATED BY ____ DATE ____
CHECKED BY ____ DATE ____
SCALE

REF

Column Design

$A_t = 36' \times 32' = 1152 ft^2$

34 psf DL
20 psf Snow

$1.2D + 1.6L = 72.8 psf$

$72.8 \times 1152 = 84^K$

$K = 1.0$ $KL = 15$ feet

Options

AISC Steel Manual Table 4-1

W8x31 $\phi P_n = 230^K$
W10x33 $\phi P_n = 233^K$
W12x40 $\phi P_n = 281^K$ ← Use min W12 for columns

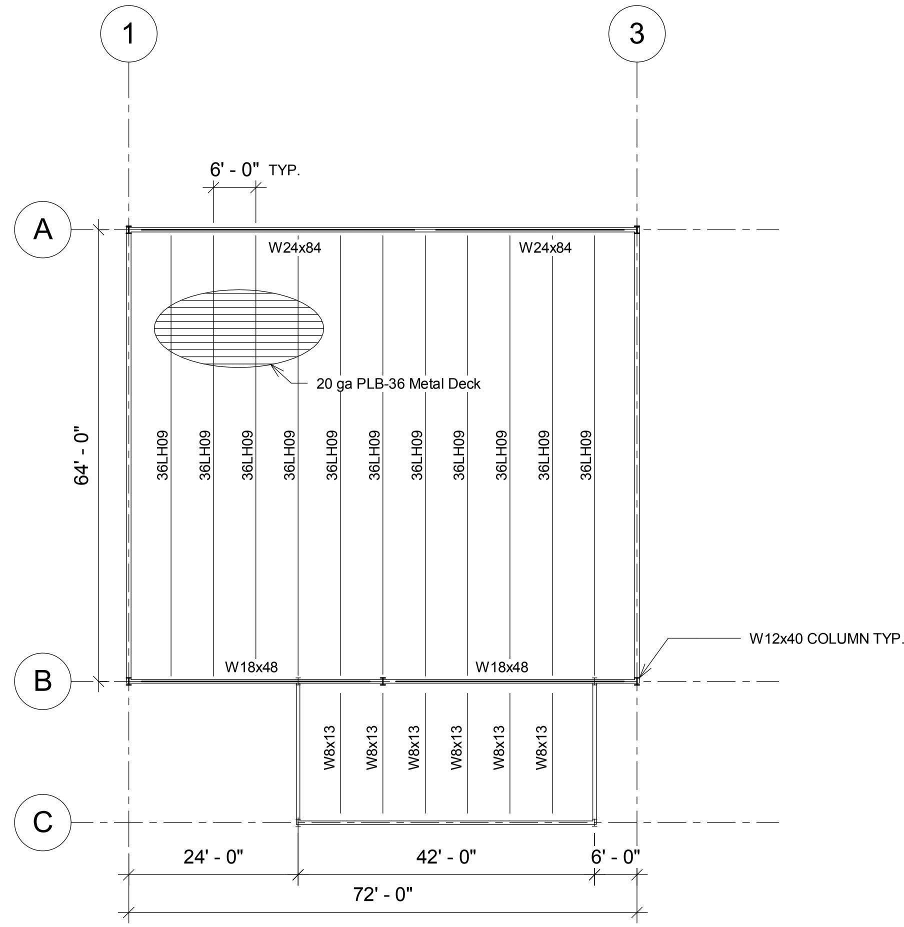
SITE LOCATION RESEARCH

prevailing wind

building footprint

property line

optional new parking areas



1 FRAMING PLAN PHASE 1
1/16" = 1'-0"

balanced design

BROCADE

DATA CENTER

No.	Description	Date

ROOF FRAMING PLAN

Project number	031301
Date	03.05.13
Drawn by	C. MOREHARDT
Checked by	TEAM 6

S.1

Scale 1/16" = 1'-0"

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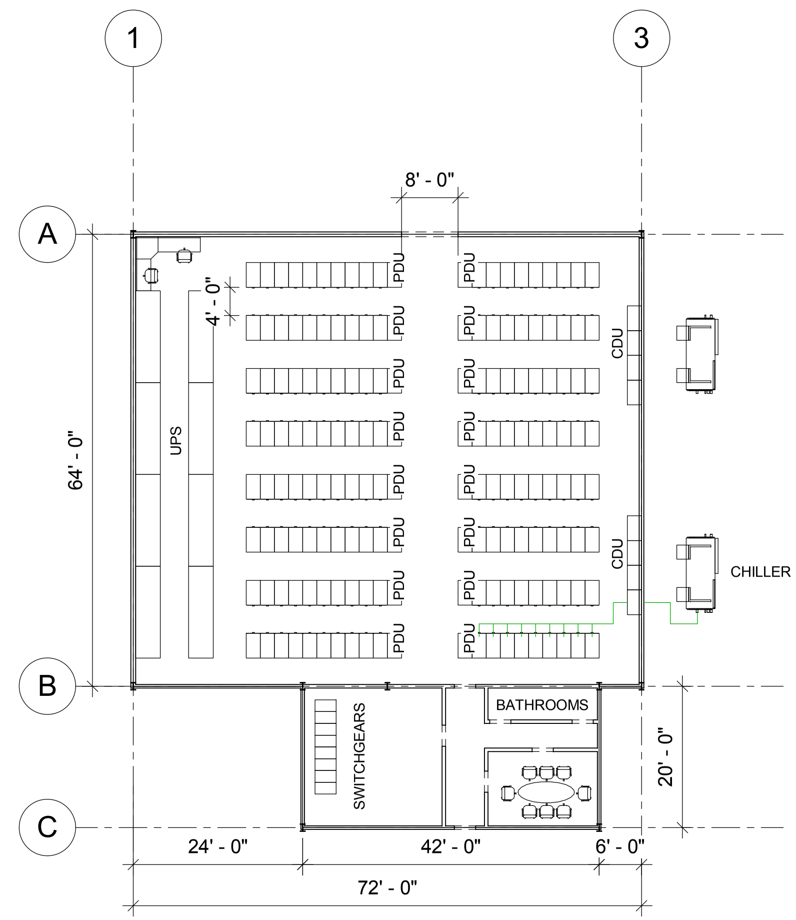

1 RACK LAYOUT
1/16" = 1'-0"

balanced design

BROCADE

DATA CENTER

No.	Description	Date

RACK LAYOUT

Project number 031301
Date 03.05.13
Drawn by C. Morehardt
Checked by Team 6

S.2

Scale 1/16" = 1'-0"

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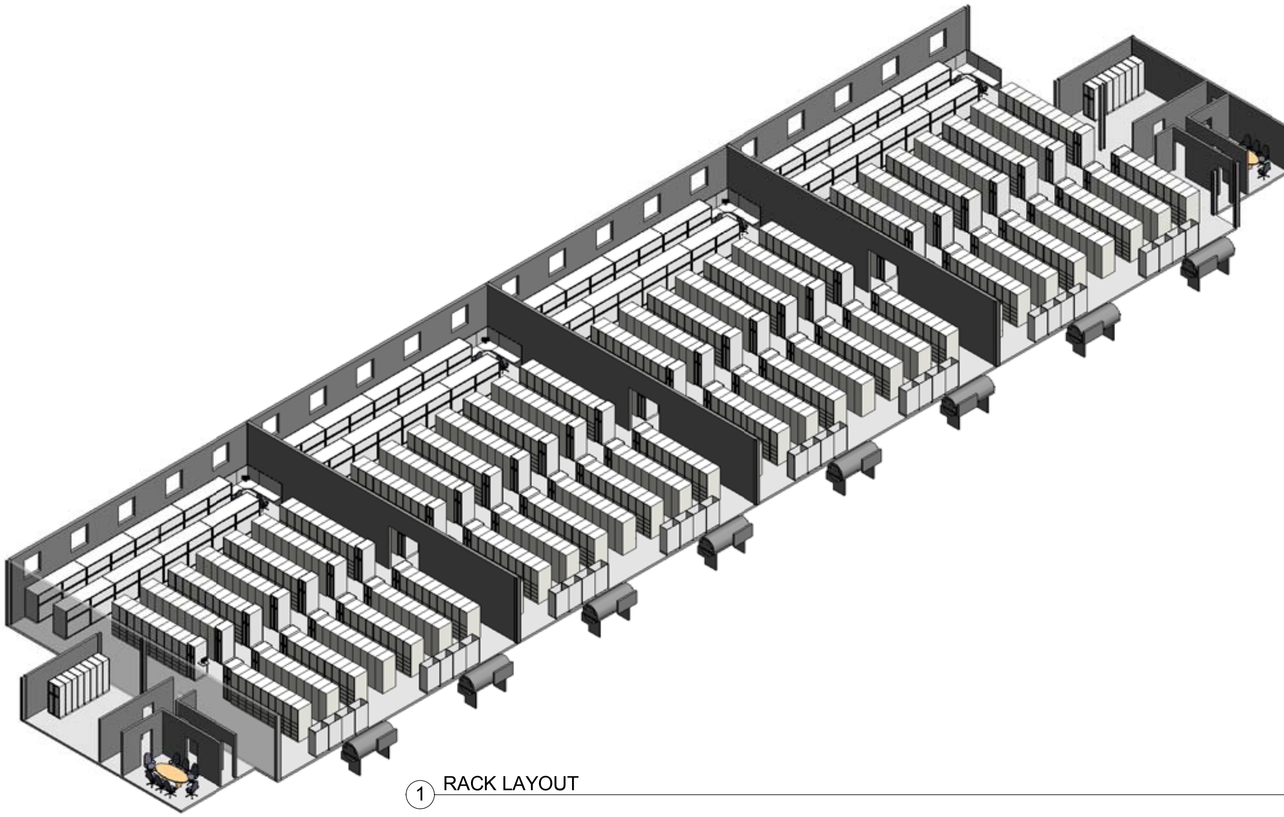

1 RACK LAYOUT

balanced 6 design

BROCADE

DATA CENTER

No.	Description	Date

RACK LAYOUT 3D

Project number	031301	S.3
Date	03.05.13	
Drawn by	C. Morehardt	
Checked by	Team 6	Scale

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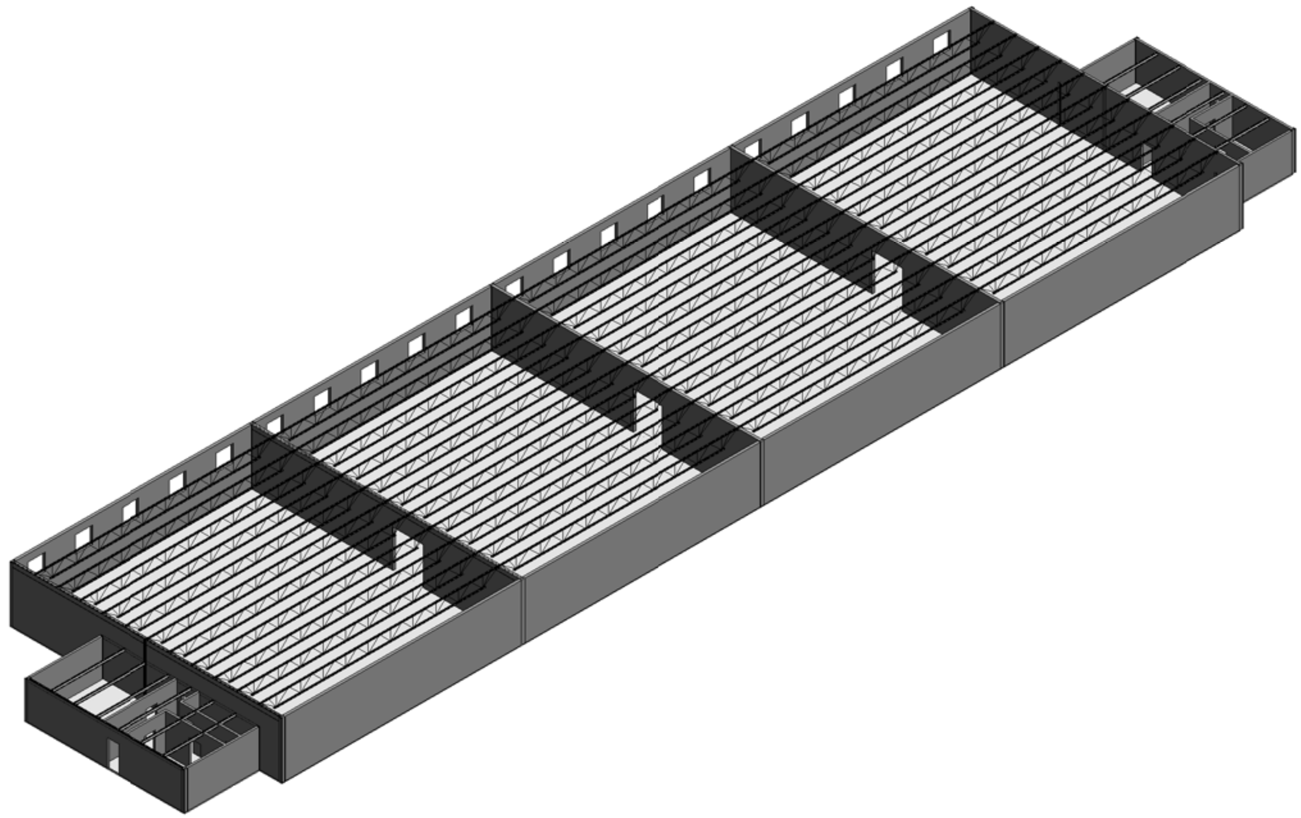


1 STRUCTURAL 3D VIEW

balanced
design

BROCADE

DATA CENTER

No.	Description	Date

STRUCTURAL 3D VIEW

Project number	031301	S.4
Date	03.05.13	
Drawn by	C. Morehardt	
Checked by	Team 6	Scale

3/5/2013 4:39:29 PM

Senior Project Record of Meeting

Date/Time/Location: 1/24/13

Participants: Andy / Kevin / Chandler

What was worked on – activities:

Attended Brocade meeting

What was discussed

Reports due 5 March

Senior project will be full package (required / optional) for ARCH / Civil

What should be completed prior to next meeting

- Milestones ✓
- RFI ✓
- Tues 4:00 pm ??

Time spent on project since last meeting:

Andy: 3 hrs
Chandler: 5 hrs
Kevin: 4 hrs

Senior Project Record of Meeting

Date/Time/Location: 1/31/13

Participants: Andy / Kevin / Chandler

What was worked on – activities:

Attended group meeting

What was discussed

new people added to teams -- made things less productive

covered individual milestone documents

discussed RFI results

What should be completed prior to next meeting

See milestone sheet

next meeting 14 Feb ♡ Valentines Day

Time spent on project since last meeting:

Andy: 9 hrs

Chandler: 6 hrs

Kevin: 6 hrs

Senior Project Record of Meeting

Date/Time/Location: 2/14/13

Participants: Andy | Kevin | Chandler

What was worked on – activities:

Report due in three weeks.

What was discussed

(Kevin) Changed milestones
needs info from others
working on finishes -- doesn't need others

Chandler: group meetings less productive
working more on own

Andy: not meeting as group as much - just w/ individuals

What losing sleep over? Biggest worry

- coordination
- computer stuff
- time
- need stuff from group members

What should be completed prior to next meeting

Bring some actual work
- calcs
- drawings
- ~~[illegible]~~

Time spent on project since last meeting:

Kevin 16 hrs
Chandler 12 hrs
Andy 15 hrs

Senior Project Record of Meeting

Date/Time/Location: 21 Feb 4:00 pm

Participants: Andy | Kevin | Chandler | Ali

What was worked on – activities:

Report due in two week
Meeting more often – crunch time

What was discussed

2 weeks remaining what's left

- Modelling
- site civil
-

} Andy

3-D model
Calc for bldg
Documentation

} Kevin

Calcs – columns | Slab
Const cost
3-D modeling
Animations

} Chandler

What should be completed prior to next meeting

Show: cost estimate
· site civil
· 3D model

Time spent on project since last meeting:

Andy 12 hrs
Kevin 10 hrs
Chandler 15 hrs

Senior Project Record of Meeting

Date/Time/Location: 2/29/13

Participants: Chandler / Kevin / Al

What was worked on – activities:

Foundation
Cost
modelling

What was discussed

Chandler – called Bldg dept – asked about Betonite
3-D model, going well

Presentation Due Tues: Borderson 104
3-4 Chandler 20-30 minutes
2-3 Kevin

Kevin: has to revise structure
team changed to 2 story model w/Mech Equip on 2nd floor

What should be completed prior to next meeting

– Presentation + work package

– Slides

Time spent on project since last meeting:

Kevin: 12 hrs
Chandler: 15 hrs

P. 34 – 42

Senior Project Record of Meeting

Date/Time/Location: 3/14/13

Participants: Andy | Kevin | Chandler

What was worked on – activities:

Actual competition
Cal Poly
San Jose

What was discussed

- Summary of trip
- Organization of Report
  - Overall project result ✓
  - Interdisciplinary interaction ✓
    - what constitutes a good team ✓
    - where did your team fall ✓
    - What did you learn ✓
  - Structural report ✓

What should be completed prior to next meeting

Before spring break
- turn in draft report

- Digital commons Submission
- Projects day presentation

Photos

Time spent on project since last meeting:

Chandler: 40 hrs
Andy: 37.5 hrs
Kevin: 35 hrs

Time Sheet	
Week	Hours
1	5
2	6
3	6
4	6
5	15
6	15
7	20
8	20
Total	**93**

balanced design

Team 6

Chandler Morehardt

Alexa Coburn

Kerry Sun

Juan Silva

Greg Wang

Raul Chagoya

JD Torres

Client: BROCADE

Project Name: Brocade Cal Poly Challenge 2013

03.05.2013

Table of Contents

Problem Statement

Brocade's second largest site is located in Broomfield, CO. The site is rapidly running out of infrastructure as business grows, particularly in the data center type labs where Brocade develops and tests it products. The goal of this project is to help Brocade decide the best way and what technologies to use in the infrastructure for a new building.

Plan and design a new building to support Brocade R&D and product testing rack labs. This space should use innovative ideas to both lower initial construction costs and operating costs while being highly efficient or best in class Power Utilization Effectiveness (PUE). The building needs to be designed with scalability and flexibility allowing for racks to be added, growth of density in the racks, as well as designed to allow for redundancy to be incorporated or added through its life. The building must also be financially feasible, taking into consideration all associated costs.

Division of Responsibilities

Architectural/Structural Engineering Work Package: Chandler Morehardt
Mechanical Work Package: Alexa Coburn, Juan Silva, Kerry Sun
Electrical Work Package: Greg Wang, Raul Chagoya
Financial Package: JD Torres

Overview of Design

The building will be a structural steel frame building with space for 152 racks per phase. This 4-phase construction process will occur over a 9 year period and be able to hold 608 racks by completion. Our cooling system consists of three main components: a rear-door heat exchanger, coolant distribution unit (CDU), and an air-cooled chiller. The rear-door heat exchanger attaches to the back of each individual rack and neutralizes the heat directly at the source, maximizing energy efficiency. The second essential component of our design is the CDU unit, which consists of a heat exchanger, pumps, controls, and a piping distribution manifold. The third component of our design is an air-cooled chiller that is located outside and utilizes Broomfield's cold weather to incorporate free-cooling into our system. In our data center design, we decided to use overhead flexible piping rather than the traditional under-floor hard piping. Additionally, we will have two cooling accessories: a negative pressure ventilation fan to remove excess heat from the data center and one AC unit located in the meeting room. The electrical distribution will be accomplished through a 480 to 208 V AC system, versus other AC or DC-DC distributions. The electrical system will mainly be powered by utility, however in the event of a power failure, backup diesel generators will supply the required power. All of our electrical components are running off a dual-branch design, providing N+1, and for our case, also 2N redundancy. Having 2N redundancy means that maintenance can be provided without shutting down any critical loads. In our design we utilize uninterruptible power supplies (UPS), load banks, power distribution units (PDU), and switchgears. These components provided by Schneider Electric are easily scalable which gives this system great flexibility. All these components work in unison to accommodate the needs of powering and monitoring this data center.

FInancial Analysis

The estimated capital cost of constructing the data center with all of its components is $4,028,411. Under favorable circumstances, Brocade could build the data center and profit $500,000 from the sale of the building within the first year of the project. The money earned through this scenario has more value than the money that would be profited from selling the building after a ten year build to own scenario.

When looking at our project versus conventional data center designs, we have found that ours is more efficient and therefore economical. Although the capital cost of our data center is slightly larger per square foot than typical data centers, the savings in operational costs is a benefit that makes the higher capital cost negligible.

	Avg. Enterprise Class Data Center	Team 6 Design
Annual Power Consumed (kWh)	42,905,400 kWh	34,669,200 kWh
Cost per Rack at $.07/kW	$5005.63	$4044.74
Cost after 10 years	$22,243,052	$17,973,234
Savings after 10 Years	$4,269,818	

Three scenarios were run (see appendix for Discounted Cash Flow Models): build to suit, build to own and build and lease back. Based on the numbers run through our discounted cash flow model, our recommendation is for Brocade to pursue the Build and Lease Back financial model.

Under a build to own scenario, even if the building's value went up 5% per year, its NPV would be worth less than 4 times the amount it took to construct the building even after taking account the increased value of the building after Phase 4 of construction. Even after escalating the building value 5% per year, the discounted cash flow model shows that the building would be worth $1,971,000, which is significantly smaller than the $4,031,000 it will take to initially construct and run the building.

Build and Lease Back shows similar operating cost to Build to Suit. The difference will obviously be the initial capital gains. Project revenue from these two scenarios will come from the sale of the land and/or building. Our finance model shows that it will be much more financially viable to construct and subsequently sell the building under the Build and Lease Back scenario. A Build and Lease Back scenario would be ideal because of the initial revenue in year zero it provides while allowing for an exit strategy that simply involves ending the 10-year lease and selling off assets.

Recommendation

Structural:

One of the main structural concerns is to maximize the floor space for rack layout. The chosen structural material is steel because of how long steel can span without needing columns. The chosen joist system of open-web trusses typically span 60 feet. Concrete and timber buildings require more supports throughout the framing plan and take more construction time. Although steel can be slightly more expensive, it minimizes the area occupied by columns, allows for changes in the building over time and minimizes on-site erection time.

Another important requirement for the architectural design of this building is to prevent the racks from overheating. From a structural standpoint, this means choosing an exterior material that minimally absorbs the suns heat. Dark colored materials absorb 70-90% of the radiant energy from the sun. A solution to this is to use a lighter colored exterior material as well as radiant barrier insulation. Radiant barriers can reduce heat gains on the roof/walls of the building by 25% and can also double as insulation.

When it comes to foundation design, there are some important soil characteristics about the Broomfield area to take into account. Bentonite, a highly expansive clayey soil is prevalent throughout the Denver area. This soil expands and contracts depending on water levels and can cause unwanted settlement of the foundation, leading to extra cost. The recommended foundation design is to drill caissons or piers down to the bedrock. When the foundation is anchored in the bedrock, the soil above no longer becomes an issue because of how stable the bedrock is. Fortunate for this project, bedrock is typically shallower in mountainous regions like Broomfield, Colorado.

For more information, see the Architectural Engineering Work Package and Appendix.

Mechanical:

Our cooling system consists of three main components: a Rear Door Heat Exchanger (RDHx) that attaches onto the back of each rack, a Coolant Distribution Unit (CDU), and an air-cooled chiller. The RDHx is a passive liquid-cooled heat exchanger that attaches directly to the back of each rack. By close-coupling the heat exchanger to the heat source, a “mini” hot aisle is confined in the space between the servers and the rear door, providing an ultimate containment solution. By using RDHx’s, a hot-cold aisle arrangement of racks is no longer necessary; the air entering the front of the rack has the same temperature as the air exiting through the back door. As opposed to typical CRAH cooling systems, which require fans to move the air from the heat source to the cooling unit, RDHx’s do not use fans since they neutralize the hot air directly at the heat source.

The CDU unit is composed of a heat exchanger, pumps, controls, and a piping distribution manifold. The CDU distributes cooled water to the RDHx’s, creating an isolated secondary loop separate from the primary chilled water system loop, which enables precise control of the water supply and pressure. Heat removed by the RDHx’s is then returned to the chilled water supply by means of the heat exchanger in the CDU. Additionally, our system addresses redundancy by incorporating redundant pumps, actuators, and valves in case the initial components fail.

The third component in our design is the air-cooled chiller. We chose to use an air-cooled chiller rather than a water-cooled chiller for several reasons. First, water-cooled chillers require a mechanical room and a cooling tower (which would raise capital cost) while air-cooled chillers utilize free, open space outside, which we have plenty of. Secondly, since the temperature of Broomfield, CO is generally cold, using an air-cooled chiller is a great way to take advantage of cold air as free cooling resource and implement free-cooling into our design.

The piping we decided to go with is overhead, flexible piping. This flexible piping eliminates the use of intermediate fittings, which reduces the potential for water leakage and raises the reliability of the pipes.

Lastly, we included negative pressure ventilation fans to help extract additional heat in the data center. Although our primary cooling system composed of the RDHx, CDU, and chiller will neutralize the heat produced by the server equipment, we want to include extra fans to extract any extra heat produced. Additionally, we are including an AC wall-mount unit in the meeting room to cool the engineers while they work.

Electrical:

For our electrical distribution we chose the traditional 480 V to 208 V system. However, our other ideas included DC-DC and running higher AC voltages. The problem with the conceptual idea of running 380 V DC to the racks, which provides the highest efficiency over any system, is the lack of compatibility. In order for server racks to handle 380 V there would need to be a new generation of IT and power equipment. IT vendors would only proceed with this revolutionary change if there's a compelling economic advantage for their customers, which there isn't really at the moment.

The main problem with running higher AC voltages as they do everywhere else in the world besides North America is the higher potential for fault currents. Without a primary transformer in this distribution, the fault current levels are dangerously high around all the electrical components. This creates a major safety hazard for a data center environment such as Brocade's, where there will constantly be engineers working on powered equipment. Higher potential for fault currents also raises the Personal Protection Equipment level, which makes it more difficult to operate and make changes to equipment.

The standard 480 V to 208 V best suits our application. Schneider Electric's new product line of UPSs and PDUs offer efficiencies closely comparable to DC systems, monitoring at all levels, scalability options, and easy installation and maintenance. The actual voltage distribution from the utility to the server racks follows a dual-branch layout, ensuring N+1 redundancy which also turns out to be 2N. Our main power sources are backed up by diesel generators. This design is outlined in our single-line drawing attached in the electrical work package.

Lessons Learned

We learned a lot of lessons in professionalism and communication during this project and are all better students because of it. A major factor of our teams success is that we held group meetings early and often. We met 3 times a week to share ideas with each other and discuss different angles for the solution. One challenge of being in an interdisciplinary team was that we had to work on how we each translate what we know about our specialty into a language that another team member can understand.

Another key lesson learned was that it is important to have open communication with the Brocade representatives, Nathan and Victor. Going to office hours was always beneficial and helped steer our group in the right direction after each meeting. The fact that Brocade made themselves available through conference calls and email correspondence was largely important to the progress of our groups work.

Architectural Engineering Work Package

Chandler Morehardt

Project: Brocade Data Center

Location: 4 Brocade Parkway, Broomfield, CO

Owner: Brocade

Building Description: Brocade's second largest site, located in Broomfield, CO, is rapidly running out of infrastructure as the business grows, particularly in the data center labs. This building will primarily provide more room for data racks and secondarily provide space for engineers to work. The space should be designed to initially hold 150 racks and be scalable to house 600 racks total. The layout should maximize usable space and should be designed to have 50 engineers working within the lab. Story height is 15 feet for the one story building. The primary structure of the building is structural steel with metal deck and open web trusses. The recommended lateral force resisting system is concrete shear walls and moment frames.

Site location: The Broomfield, CO branch of Brocade has plenty of land to build on, so finding space for this additional server rack lab was no problem. The initial 150 rack space was chosen to be across the street in the north direction from the existing structure so that the parking lot can be shared and the engineers can easily walk over to the rack lab. The expansion of the building will occur along the main road into the property in the west direction so that all points of the rack lab are equally accessible from the existing structure. There is plenty of space for additional parking on either end of the fully scaled rack lab. Several options were considered in the site selection process. Option 3 was eliminated because of its lack of accessibility from the current parking lot and existing structure. The recommended location is a mix of Option 1 and 2 for its ease of accessibility from the parking lot and existing building. The site selection research can be seen in the Appendix.

Figure 1: Location on site

Building Code:	2012 International Building Code	
References:	Loads:	ASCE 7-10
	Steel:	AISC 360-10
	Concrete:	ACI 318-05

Structural Criteria

Lateral	Shear Walls and Moment Frames
Slab on Grade	Live Load = 250 psf (rack weight)
	Dead Load = Slab self weight
Roof	Live Load = 20 psf
	Snow Load = 20 psf

Material Selection: The recommended material selection is structural steel. The reasons for selection steel as opposed to concrete or timber/masonry can be seen below. By nature, data center floor plans are repetitive and simple. A more complicated framing layout might call for timber or concrete as the structural material.

Reasons for Selecting Structural Steel

- Minimizes area occupied by columns
  - This maximizes the floor plan for rack space.
- Allows for changes in the building over time
  - Building will undergo 4 phases over 12 years (1 phase/3 years)
- Minimizes on-site erection time
- Minimizes construction time
  - Important for phase construction

Practical Span Ranges

Steel Beams	10-75’ (typically 30’)
Open-Web Joists	10’-150’ (typically 60’)
Metal Decking	10’-20’ (typically 10’)

Exterior Architectural Materials

A radiant barrier on the underside of the roof will allow for the exterior materials to use methods of natural cooling. The primary source of heat build-up is sunlight absorbed through the roof, walls and windows. A radiant barrier can reduce heat gains on the roof by 25% and will also double as insulation for this project. Dark colored exterior materials absorb 70-90% of the radiant energy from the sun while light colored surfaces effectively reflect most of the heat away. The recommended exterior architectural material for the rack lab is a light colored surface with radiant barriers as the primary insulation.

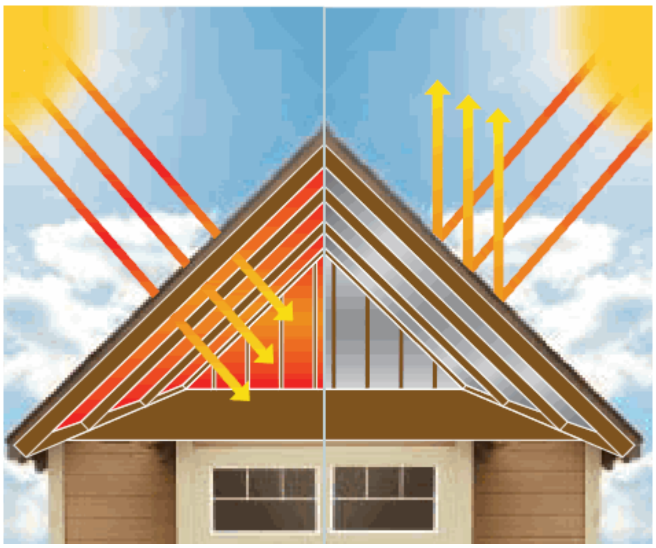
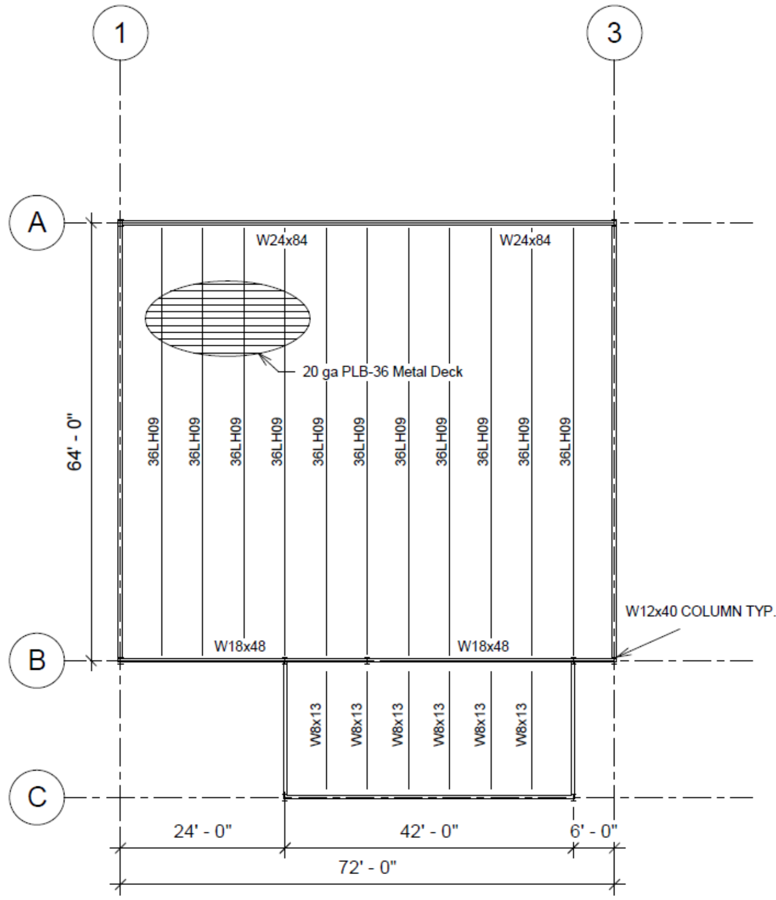


Figure 2: Radiant Barrier demonstration

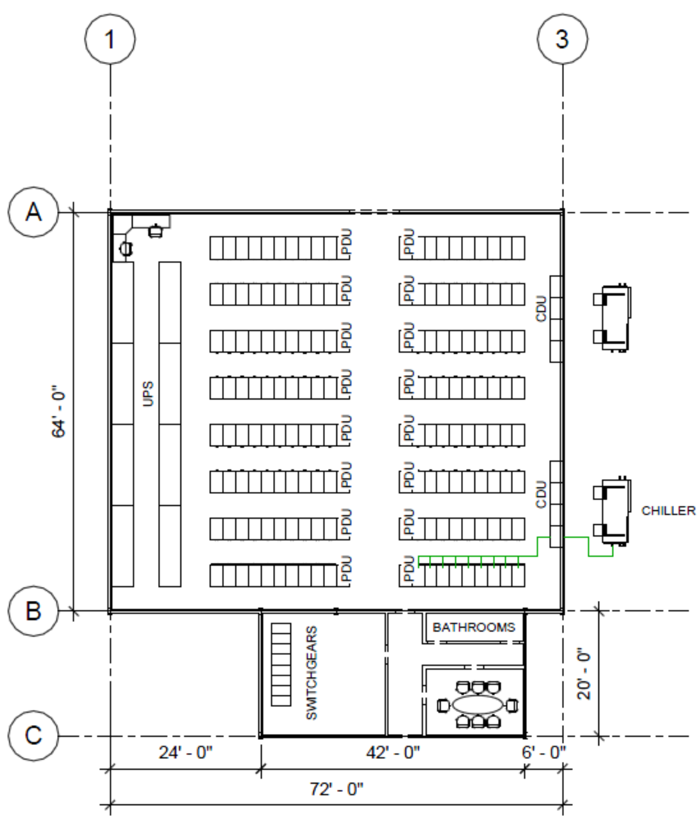
Figure 3: Radiant Barrier sheet

Rack Layout: The rack layout will include 9-10 racks per row. Racks are typically layed out with 8-12 per row. The more racks that are next to each other without interruption, the more efficient the system is. For example, a row length of 1 rack would be the least efficient, while a row length of infinite racks would be the most efficient. Having more than 12 racks per row is not feasible due to means of egress and fire codes. For reference, see the phase 1 rack layout below.

Framing Options: The framing option was chosen to run the joists in the long direction and the beams in the short direction. This layout allows for there to be no columns in the server room. The 6-foot on center joist layout was chosen based on optimizing the metal deck span. For more information, see the structural calculations in the Appendix.



1 FRAMING PLAN PHASE 1
1/16" = 1'-0"



1 RACK LAYOUT
1/16" = 1'-0"

Phase Construction: This building will be built initially to hold 152 server racks and will be scalable to house 608 racks. This growth will be done through a 4-phase process, adding 4600 ft^2 of space (room for 152 racks) every 3 years. This process is recommended to minimize wasted space, which would occur from building the entire 20,000 ft^2 building up front. The phase construction will minimally interfere with operations in the data center by simply adding on to the building and opening a doorway when the addition is complete.

Underground: There are many data centers around the world that occupy abandoned bunkers or the side of mountains to form an underground data center. Some benefits to having an underground data center are added security and protection from the sun. Some underground data centers, like the one in Helsinki, uses seawater to cool the racks. However, unless there is already an underground space to occupy or a nearby mountain to dig in to, excavation costs make building underground very costly and not worth the return on investment from energy savings. I believe that there is more to be gained by building above ground in a cool climate such as Colorado because of free cooling.

Foundations: The foundation design for this project will need to take into account the hazard of expansive soil. Bentonite, a highly expansive soil, expands when saturated with water and shrinks during drought periods, causing settlement of the foundation. One way to avoid this is to drill caissons (or piers) into the bedrock, which will not settle. Bedrock depths can range from 10 feet to 150 feet below the ground surface but is typically shallower in mountainous or high elevation areas such as Broomfield, CO. The Broomfield Building Department also stated that drilled piers to the bedrock are a common foundation design for the area.

Benefits of drilled piers:
- Lighter construction equipment
- No alignment problems
- Larger diameters
- Less ground vibration
- Verification of soil

Problems with drilled piers:
- Cobbles and boulders
- Caving (if soil is cohesionless)
- Inspection hole is dangerous

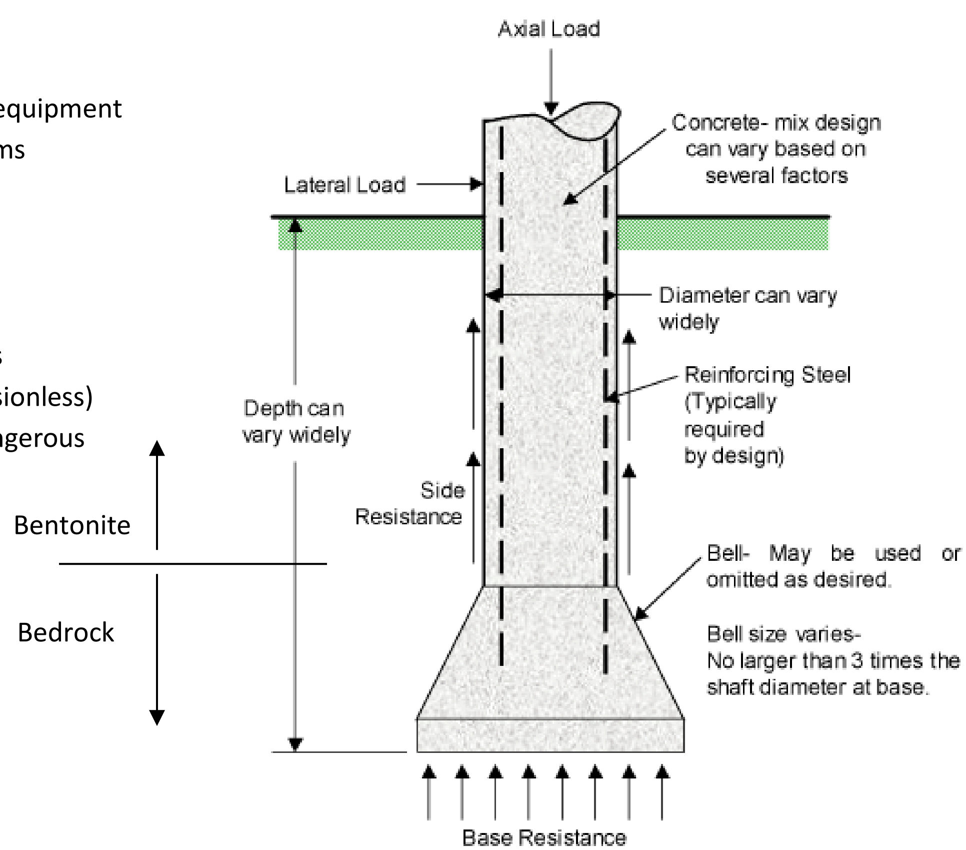


Figure 4: Drilled Pier to Bedrock

Mechanical Write-up

Alexa Coburn

Juan Silva

Kerry Sun

Cooling System Description:

Our cooling system consists of three main components: a Rear Door Heat Exchanger (RDHx), a Coolant Distribution Unit (CDU), and an air-cooled chiller. The Rear Door Heat Exchanger (RDHx) is a passive liquid-cooled heat exchanger that attaches directly to the back of each rack. The RDHx uses a water-filled coil to directly neutralize the exhaust air before its reentry into the data center. The specially designed fin and tube coils in the rear door are protected by two 79% open perforated sheets, which help maintain airflow through the rack. By close-coupling the heat exchanger to the heat source, a "mini" hot aisle is confined in the space between the servers and the rear door, providing an ultimate containment solution. By using RDHx's, a hot-cold aisle arrangement of racks is no longer necessary; the air entering the front of the rack has the same temperature as the air exiting through the back door. The function of a RDHx is demonstrated in Figure 1.

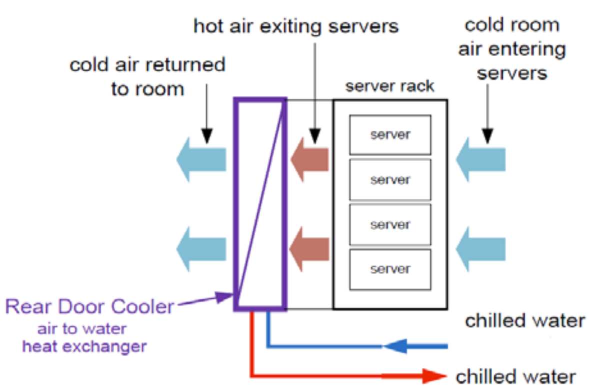


Figure 1. RDHx Function

Figure 2. RDHx-LD

Not only do Rear-Door Heat Exchangers effectively control the ambient air temperature in the data center, they also provide a significant reduction in energy required to cool the building. As opposed to typical CRAH cooling systems, which require fans to move the air from the heat source to the cooling unit, RDHx's do not use fans since they neutralize the hot air directly at the heat source. In addition, RDHx's do not require any moving parts or electrical connections, further minimizing energy consumption. The one concern we had about using RDHx's was that engineers will be opening the rack doors often to work on the servers. In this instance, the heat exchanger will not be able to cool the air directly at the source, allowing heat to escape into the room; however, we came to the conclusion that all the other racks with closed rear doors (air exiting at approximate 85 F degrees) will compensate for the couple of racks that heat is escaping from. In other words, the effect of opening a few doors at a time is minimal considering the size of the room and amount of RDHx's. As for the specific brand, we suggest "low-density" RDHx's supplied by Coolcentric This actual device is shown in Figure 2. The RDHx - LD (low density) supports low to medium rack densities of approximately 4-12kW. These heat exchangers come in a top or bottom feed configuration to support underground or overhead piping. Additional information about this specific model is provided in the appendix. Note that we suggest using overhead piping to reduce cost and increase accessibility. This piping system is explained in detail in the description of pumping and piping below.

Another essential component of our cooling system is a floor-mounted Coolant Distribution Unit (CDU), which consists of a heat exchanger, pumps, controls, and a piping distribution manifold. The CDU drawing is shown in Figure 3. The CDU distributes cooled water to the RDHx's, creating an isolated secondary loop separate from the primary chilled water system loop, which enables precise control of the water supply and pressure. Heat removed by the RDHx's is then returned to the chilled water supply by means of the heat exchanger in the CDU. In addition, the CDU maintains the secondary loop water temperature above the dew point, preventing condensation on the RDHx coils and ensuring sensible cooling. Because the CDU is designed to provide constant flow to the RDHx's, changes in heat load require modulating the primary valve and allowing more or less chilled water to flow to the heat exchangers. The CDU model we chose for our system is the CD6A floor-mount model also provided by Coolcentric. It is a versatile unit designed with redundant speed pumps. The CD6A is energy efficient, supporting 260 kW maximum cooling capacity while only consuming a maximum of 3.7kW of power. We will incorporate 8 CDU units in our design, located at side of the wall. Our design is scalable so that additional CDU units can be added as the building expands and more and more racks are included. Additionally, our system addresses redundancy by incorporating redundant pumps, actuators, and valves in case the initial components fail. The redundant pumps are shown in Figure 4.

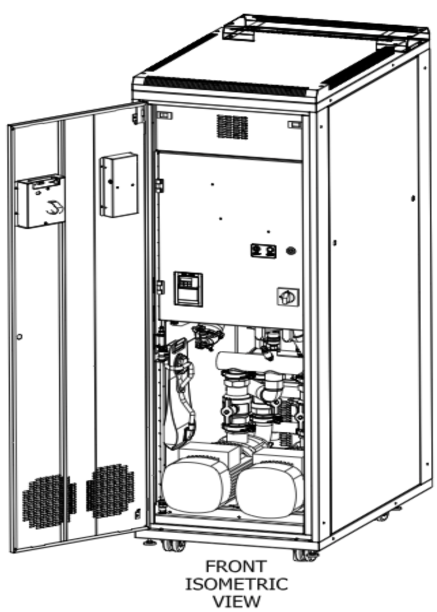


Figure 3. CDU Front View

Figure 4. Redundant Pumps in CDU

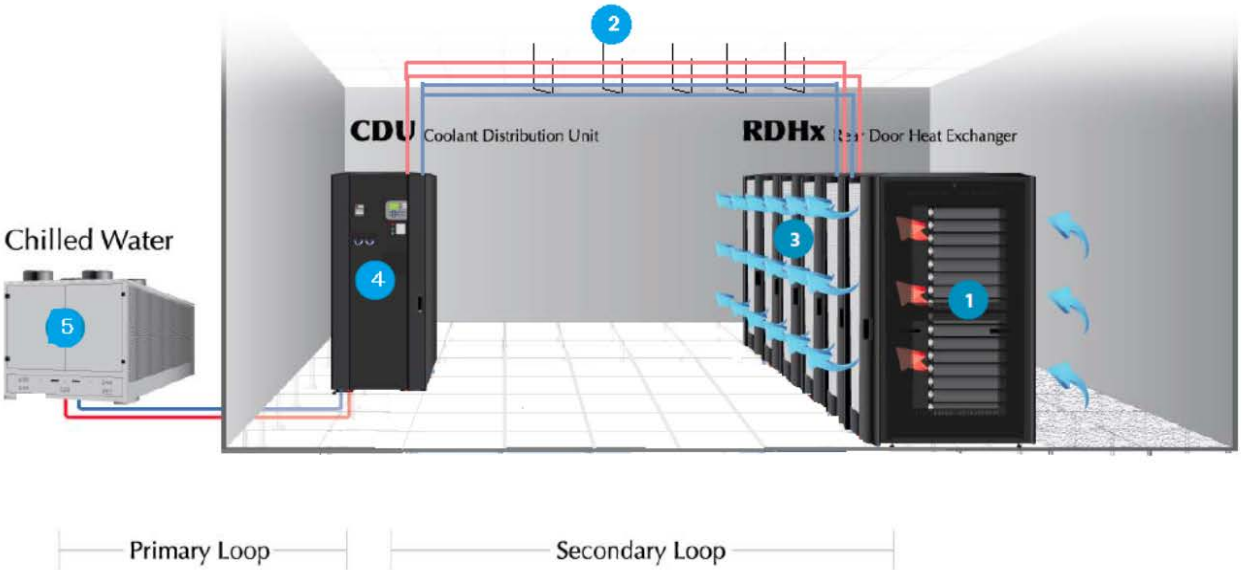


Figure 5. Basic Representation of our Design

The third component in our design is the air-cooled chiller. We chose to use an air-cooled chiller rather than a water-cooled chiller for several reasons. First, water-cooled chillers require a mechanical room and a cooling tower (which would raise capital cost) while air-cooled chillers utilize free, open space outside, which we have plenty of. Secondly, since the temperature of Broomfield, CO is generally cold, using an air-cooled chiller is a great way to take advantage of cold air as free cooling resource and implement free-cooling into our design. In Figure 6, which shows the annual temperature of Broomfield, you can see that there are only two months (July and August) that are relatively hot, allowing the air-cooled chiller to operate efficiently all but two months in the year. Some benefits of using an air-cooled chiller are that it lowers capital cost by eliminating the need for a separate mechanical room and also lowers maintenance cost with fewer components in our system.

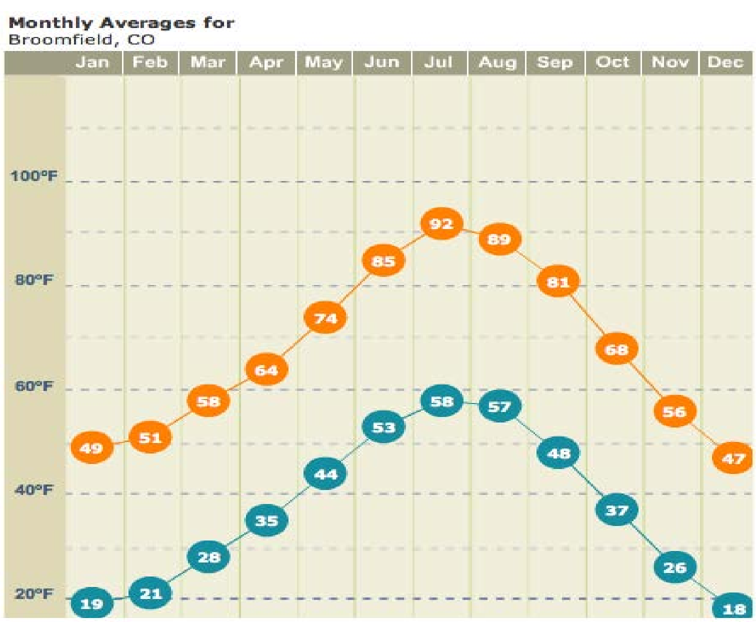


Figure 6. Monthly Average Temperature of Broomfield, CO

We chiller we suggest is the YCIV Air-Cooled Variable Speed Screw Chiller because it uses the best of modern screw compressor design and manufacturing techniques. These also offer quieter, vibration-free operation and are well known for their robustness, simplicity, and reliability. They are designed for long periods of continuous operation, needing very little maintenance. Screw compressors can overcome high lift when speed is reduced, allowing energy savings without the possibility of surge as the compressor unloads.

Piping Description:

The traditional approach to piping distribution has been to use hard copper or carbon steel piping with welded, brazed or threaded fitting for routing and branching of piping to the racks. Since leakage is always a common concern with traditional piping, the distribution is generally located under a raised floor where channels or trenches are sometimes built under the pipe to capture water in case of any leaks or rupture. For our new industrialized data center, raised flooring is not necessary because we implement flexible piping instead of hard piping. A centralized distribution system allows for multiple connections to a main distribution header above the racks. The flexible piping is routed through the aisles from the distribution header to each rack and a drip pan is placed underneath the pipes. Figure 7 illustrates the use of flexible piping overhead. Seamless flexible piping eliminates the use of intermediate fittings, such as elbows, decreasing the risk of water leaks and increasing the fundamental reliability of the piping itself. This methodology replaces all the intermediate joints in the data center with only two joints per supply and return line; one at the distribution header and one at the rack. A traditional hard piping system would have 10 to 20 joints per supply or return branch. This reduces the leak potential by 80-90% compared to hard piping. Additionally, the potential for condensation is reduced by not having intermediate fittings because it is difficult to provide insulation at the joints of a pipe, so with fewer joints, there is less chance for condensation. The flexible piping material we are using is a multi-layered composite tubing consisting of an aluminum tubing sandwiched between inner and outer layers of cross-linked polyethylene. This gives the piping flexibility to be routed through the data center with the rigidity to stay in place. The cross-linked polyethylene or PEX also offers excellent protection against corrosion and the smooth interior walls and chemical properties make it resistant to mineral buildup with hard or soft water eliminating the risk of pinholes. Table 1 shows the comparison between using hard and flexible piping.

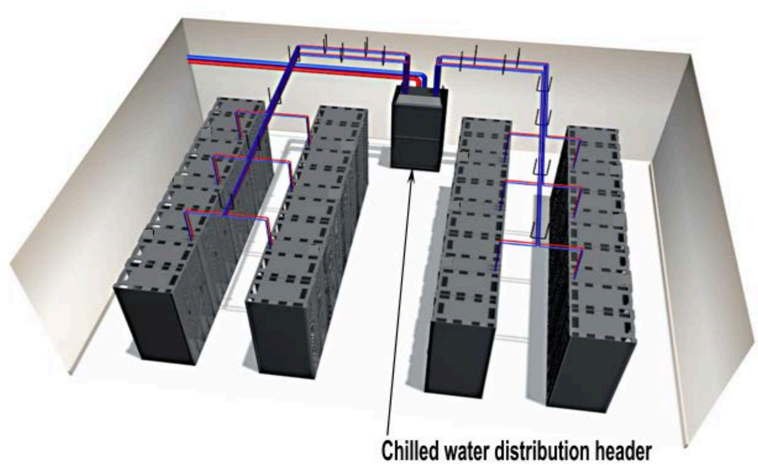


Figure 7. Demonstration of flexible piping overhead.

	Hard Piping	Flexible Piping
Reliability	Leak potential at every joint location	Eliminating intermediate joints increases reliability
Installation Cost	Higher installation cost. System balancing requires more time adding cost to start-up	Lower installation cost. System start-up and balancing is less complex with the centralized distribution system
Amount of Joints	Typical for 10-20 joints between distribution and each rack	Only 2 joints per branch
Material Cost	Hard piping has lower initial cost, but overall installation cost is higher because it takes more labor	PEX piping has a higher cost, but overall installation is lower
Earthquake/Vibration	Vibrations can cause leakage at the joints	Less susceptible to break or leak in earthquake conditions
Condensation	More potential for condensation due to difficulty to insulate multiple fittings. Small cracks or spaces left without insulation may cause condensation	Less potential for condensation due to elimination of intermediate joints between the distribution system and the racks
Mineral Buildup	Susceptible to leakage due to mineral buildup	Very resistant to mineral buildup due to smooth interior walls and chemical properties
Pressure Drop	The use of elbows for turns and mineral buildup causes additional pressure drop	Smooth interior and larger radius turns without fittings reduces the pressure drop

Table 1. Comparison of Hard Piping and Flexible Piping

Extra Fans and AC Units:

Since the temperature of the facility is designed to stay at 85 degrees Fahrenheit, we decided to use negative pressure ventilation fans to help extract any excess heat produced by from the engineers who work on the equipment. Our primary cooling system including the RDHx's , CDU's, and chiller will accomplish the task of neutralizing all the heat produced by the servers, however, we decided to add fans to make sure the data center stays cool enough to support people. We chose to use negative pressure fans over positive pressure fans due to the fact that we want more air exiting the building than entering. Additionally we are including one AC wall mount unit in the meeting room so the engineers can be in a comfortable temperature at all times.

Redundancy:

Redundancy is implemented into our cooling system to ensure system availability in the event of component failure. Our Coolant Distribution Unit (CDU) has 2 pumps internally; one of them is a redundant pump, which backs up the CDU if the first pump breaks down. Also we have decided to have N+1 redundancy for our air-cooled chiller to prevent the failure of the chiller due to the hot temperature in July and August in Broomfleid, CO.

Electrical Work Package

Raul Chagoya

Greg Wang

Electrical Distribution Description:

Power distribution to data centers can be done using either AC or DC power. AC power is typically distributed at the server rack level at voltages of 120 V, 208 V, or 230 V. DC power is typically distributed at the telecommunications standard voltage of 48 V. Throughout North America a traditional 480/277 V to 208/120 V AC step-down transformation, accomplished at the power distribution unit (PDUs), is most commonly used. Everywhere else in the world uses 400/230 V AC directly to the server racks. Only a few small data centers throughout the world are currently using a DC power distribution. The different data center power distribution methods that will be discussed are shown in **Figure 1**, **2**, and **3**.

Proposals have been made recently to move towards DC distribution in order to increase overall electrical efficiency by eliminating the unnecessary voltage transformation and AC/DC conversion stage. Additionally, without the bulk of transformers a lot of floor space and floor weight is freed up. However, several studies praising the dramatic efficiency improvement from DC systems utilize historic values for AC devices that are not representative of what is currently available. For example, a recent article assumes an AC UPS efficiency value of 74-96% versus a DC UPS efficiency value of 97%. Schneider Electric's new product line now actually offers efficiencies over 96% for their AC UPS and PDU systems.

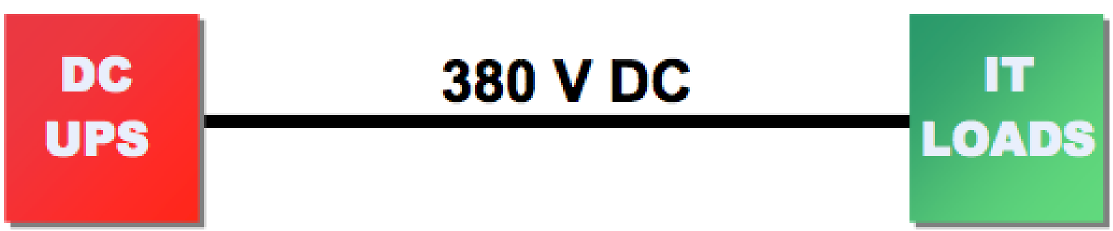


Figure 2: Hypothetical Approach for Distributing 380V DC

With that being said, the 48 V DC distribution has proven to have worse efficiency than any existing AC system. This has led to the conceptual proposals of higher DC distribution voltages, such as 380 V DC shown above in **Figure 1**, to overcome the earlier problems associated with DC power. A 380 V DC approach may offer approximately a 1% advantage in efficiency over the best AC system, which can be the difference of hundreds of dollars in energy savings a year for larger data centers. However, as mentioned earlier this is a conceptual idea. A 380 V DC distribution system would require a new generation of IT and power equipment that does not yet exist. In order for IT vendors to proceed with such a revolutionary change there needs to be a compelling economic advantage for their customers, which for most users at the moment is relatively small.

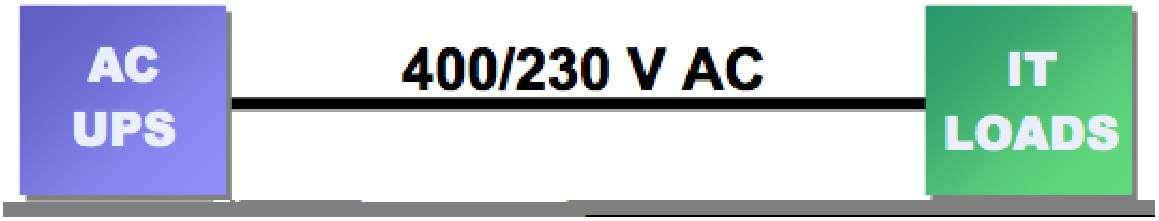


Figure 3: Common AC Distribution Outside North America

The AC system with the highest efficiency, but only by less than 1%, is the 400/230 V distribution shown in **Figure 2**. Virtually all IT equipment is designed for worldwide compatibility and can operate on a voltage range of 100 to 240 V. Running the server rack at the highest voltage supported requires less current given the same power capacity, one source of efficiency improvement. So hypothetically a 415/240 V AC distribution system would improve it even more. Eliminating the voltage transformations in the PDUs, originally required for the 480 to 208 V distribution as shown below in **Figure 3**, will remove that source of inefficiency while reducing floor weight and floor space as well. This also ends up making the component cost cheaper compared to the other AC system. However, a 400/230 V AC distribution requires running neutral conductors throughout the whole system since the 230 V output is derived from a line-neutral configuration. The extra costs required for the labor, wire, and protection devices make the overall system cost comparable to other systems.

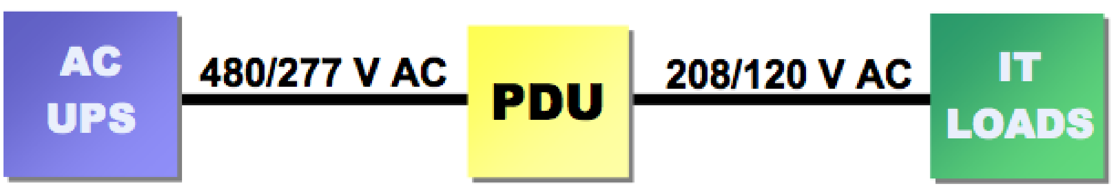


Figure 4: Common AC Distribution in North America

A negative factor of eliminating the PDU transformer is the increased potential for fault currents. A proper application needs to be carefully implemented in order to ensure that it is safe to perform maintenance and install additional IT peripherals without de-energizing the entire system. **Figure 4** on the next page outlines the concept of fault current availability for both AC systems. The arc flash potential is a major safety hazard for Brocade's data center, where there will be several engineers constantly working on the energized server racks and PDUs. Additionally, with the higher potential for arc flash, the higher the PPE (Personal Protective Equipment) level and the more difficult it will be to operate and make changes to equipment in the data center. This is another major downside for the 400/230 V AC distribution method for Brocade's data center, which needs to be easily scalable in the future.

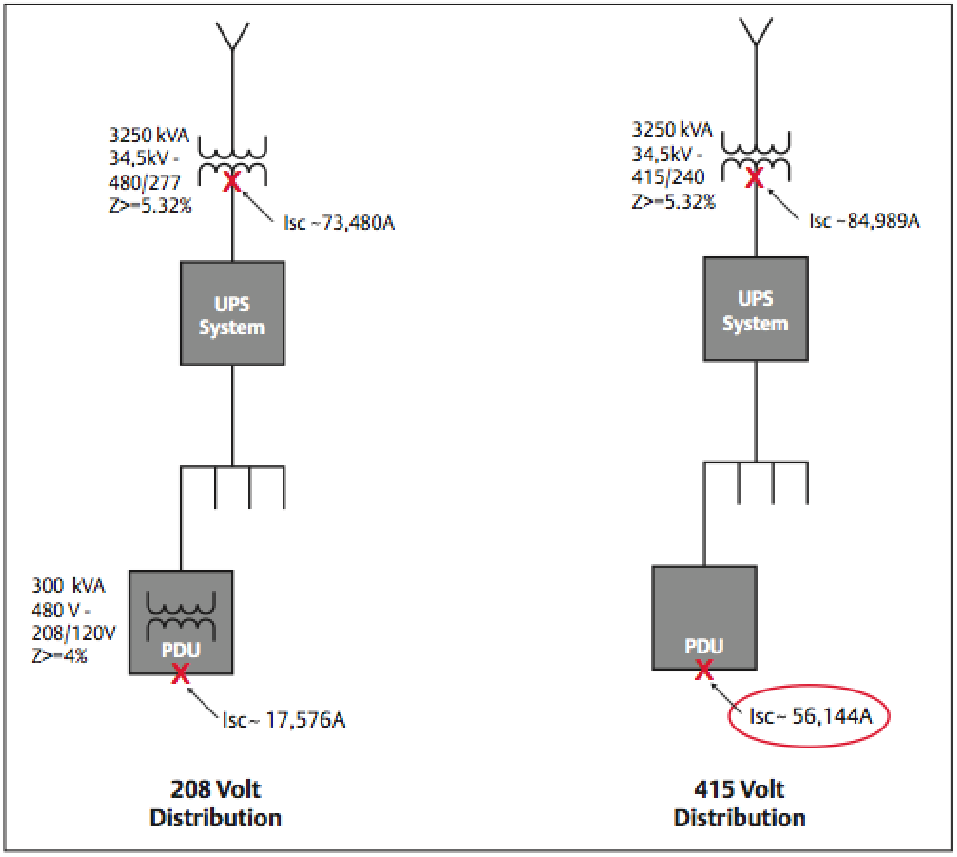


Figure 5: 208V Distribution vs. 415V Distribution Fault Current Comparison

This leads us back to the standard 480 to 208 V AC distribution system. For the size of this data center, the minuscule difference in efficiency compared to the 400/230 V AC distribution is insignificant when also taking into consideration the negative aspects of the other systems for our application. Our decision matrix shown in **Table 1** summarizes all these main points. The most attracting category for the 480 to 208 V is its compatibility. First of all, it provides 120 V AC power supply for wall outlets without any other components, unlike the other systems which require a separate transformer. Since this design is so widely used, installation is much simpler and cheaper now, also making maintenance and expansion of the equipment easier. Additionally, with a transformer in the PDU, the fault current at that level is significantly reduced.

OPTIONS	COST	RELIABILITY	EFFICIENCY	FLOOR SPACE	COMPATIBILITY	TOTAL
DC-DC (48V DC)	2	4	2	5	2	15
DC-DC (380V DC)	4	4	5	5	1	19
415/240V AC	4	4	4	3	3	18
480 to 208V AC	4	4	4	2	5	19

Table 1: Decision Matrix on Electrical Distribution System

Our 208 V electrical distribution is based off a two active power source, dual-branch system for each phase of the data center. As described in the architectural work package, each phase contains 150 racks. If you refer to the single-line drawing, which I recommend doing so throughout this entire discussion, you can see that each set of up to 80 racks is powered by two electrical branches (hence the name dual-branch) to ensure redundancy. Our design has N+1 redundancy, which turns to be a 2N redundancy system as well due to the dual-branch setup. Since we are just using one of each component, the N+1/2N redundancy comes from the other leg of the branch. The two main power sources are coming in from the utility company at 13.2 kV, which should be physically isolated in different areas in case of a catastrophe so there's no loss of both at the same time. Each source is fed into its own main service medium voltage switchgears.

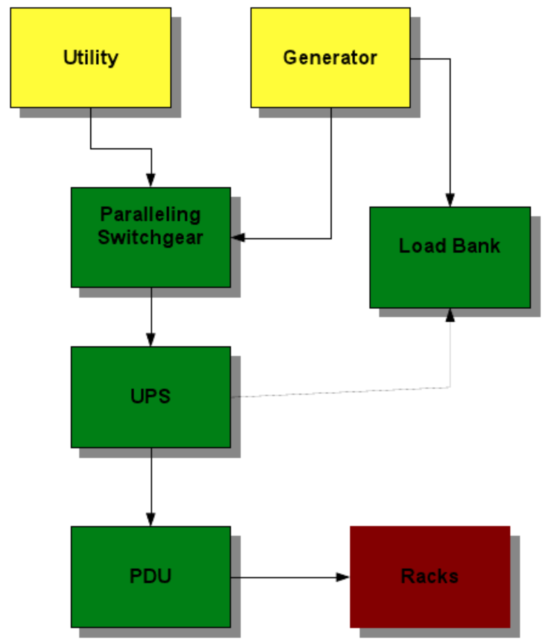


Figure 6: Electrical System Block Diagram

The main switchgears will distribute power to individual branches, along with each having a tie with a paralleling switchgear. These paralleling switchgears are responsible for switching the main power source to the backup generators in the case of a power outage. Two 3 MW diesel generators will be connected to each of the paralleling switchgears, ensuring 2N redundancy. The sizing of the generators is more than enough to support phase 1 (150 racks) at full capacity (12 kW per rack), and the electrical systems for cooling and lighting for several hours. The medium voltage coming out from the main switchgear is stepped-down to 480V through a 2 MVA transformer for each leg of each dual-branch. The transformer is sized appropriately to handle up to 80 racks at their full 12 kW capacity in each branch. This is done so because transformers are not as easily scalable compared to other components, making the total cost and convenience of installing a large transformer initially advantageous. Our single-line drawing only shows one of these dual-branch distributions; however, in the real application there would be two of these dual-branches for each phase of 150 racks. The continuing description will be for one of these branches.

Once the voltage has gone through the transformers it is sent to a low voltage switchgear for each leg of the branch. These low voltage switchgears have connections back to the paralleling switchgears so they can interchange their power source from utility to backup generators in the event of utility failure. This is also where power is distributed to the HVAC and lighting system. They are then connected to the UPS input switchgears. These input switchgears purpose is to supply power to two separate UPSs. Each UPS has a battery that is fully charged at all times, accomplished through double-conversion online technology, so if the main power source were to go out the battery will provide momentary power to critical loads until backup power can be initiated. These UPSs are connected to UPS paralleling switchgears to insure that if one UPS fails the other one can be used, this continues to keep our system at 2N redundancy. The UPS paralleling switchgears are also connected to the loadbank switchgear. The loadbank switchgear plays an important role because it allows for the proper loading in order to test equipment like the generators and UPSs. The loadbank can be used to keep the generators running at the highest efficiency possible by preventing wet-stacking. Wet-stacking occurs when unburned fuel accumulates in the exhaust system. This accumulation can foul the fuel injectors, engine valves, the exhaust system; these can all be causes of reducing operating performance. The loadbank can also be used to routinely test the UPSs. This ensures that they are performing as expected when a load is connected to them.

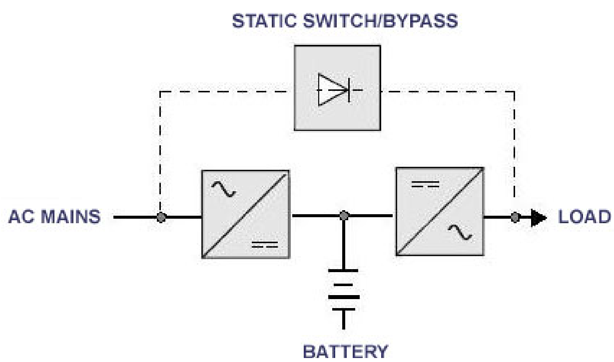


Figure 6: UPS Double-Conversion Online

From the UPS paralleling switchgears the power outputs to the UPS distribution switchboards. These switchboards send the voltage to two PDUs for each row of 19 server racks, where the voltage is stepped-down from 480 V to 204 V. This useable voltage is distributed by the Starline Power Bus system down the rows. Each server rack contains two rack PDUs, with each one powered by it's own row PDU for redundancy at this level. Additionally, the row PDUs has the potential to output 120 V to satisfy those loads throughout the data center.

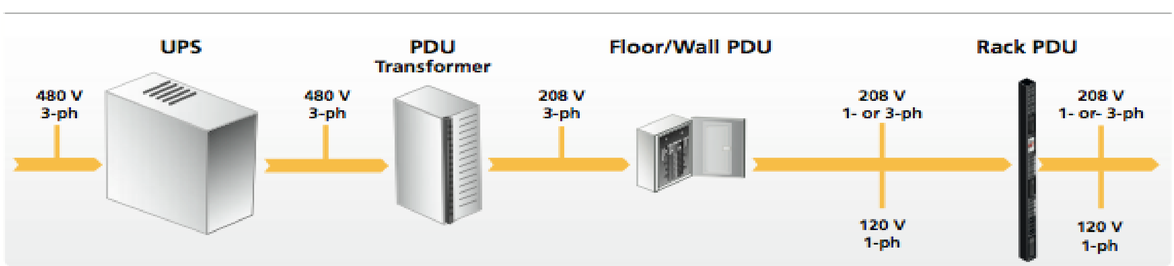


Figure 7: Low Voltage Electrical Block Diagram

The way we setup our electrical system ensures that it can be scaled up rather easily. The main service switchgears have the capacity to expand from the initial 150 racks to up to 600 racks. The future branches will just follow the same layout as the one showed in the single-line diagram. More backup diesel generators can simply be paralleled with each other to supply the desired backup power. At the branch level the UPSs can be scaled from 320kW to 960W and the PDUs from 80kW to 240kW, the range we found for powering 80 racks ranging from 4 kW to 12 kW. Schneider Electric's APC product line offers all these modular systems, completely customized for our application. A benefit from the 2N redundancy also allows for the system to be scaled and maintained without having to cease power to any critical loads.

As mentioned before, this electrical distribution setup is commonly found in data centers throughout North America. So although our design is not extremely unique, it is the best application for this data center. Current models of all the equipment provide great efficiency and reliability, power monitoring at every level, easy scalability, redundancy, and overall simple design.

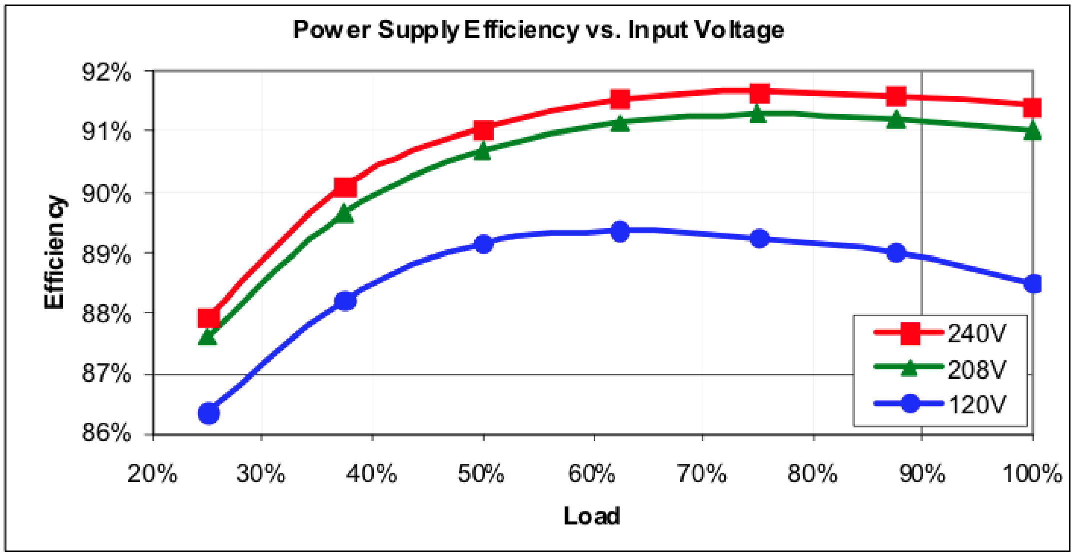


Figure 8: Efficiency Comparison for AC Distribution Options

Power Consumption:

	UPS Power Consumption (% of total power)	Lighting Power Consumption (% of total power)	Cooling Power Consumption (% of total power)	Critical Loads Power Consumption (% of total power)	Total Power
150 Racks 4kW	192 kW (19%)	9.36 kW (1%)	188.68 kW (19%)	600 kW (61%)	990.04 kW
150 Racks 12kW	576 kW (19.3%)	9.36 kW (0.3%)	597.20 kW (20%)	1800 kW (60.4%)	2982.56 kW
600 Racks 4kW	768 kW (19.4%)	40.2 kW (1%)	749.52 kW (19%)	2400 kW (60.6%)	3957.72 kW
600 Racks 12kW	2304 kW (19.3%)	40.2 kW (0.3%)	2383.60 kW (20%)	7200 kW (60.4%)	11927.8 kW

Table 2: Power Consumption at Different Phases and Capacities

- It is assumed that all switchgears have negligible inefficiencies.

- Lighting Power Consumption Sample Calculation:
  0.002 * floor area in square feet = 0.002 * 4680 sq. ft. = **9.36 kW**
  (0.002 constant comes from APC Whitepaper #3)

- Cooling Power Consumption Calculations can be found in the Mechanical Work Package.

- Critical Load Power Consumption Sample Calculation:
  150 Racks * 4 kW per Rack = **600 kW** consumed

- UPS Power Consumption Sample Calculation:
  Assuming UPS inefficiency and battery charging value is constant = 0.32
  (0.32 constant comes from APC whitepaper #3)

  UPS Power Consumption for 150 Racks at 4 kW
  = Power Consumed by Racks * 0.32 = 600 kW *.32 = **192 kW**

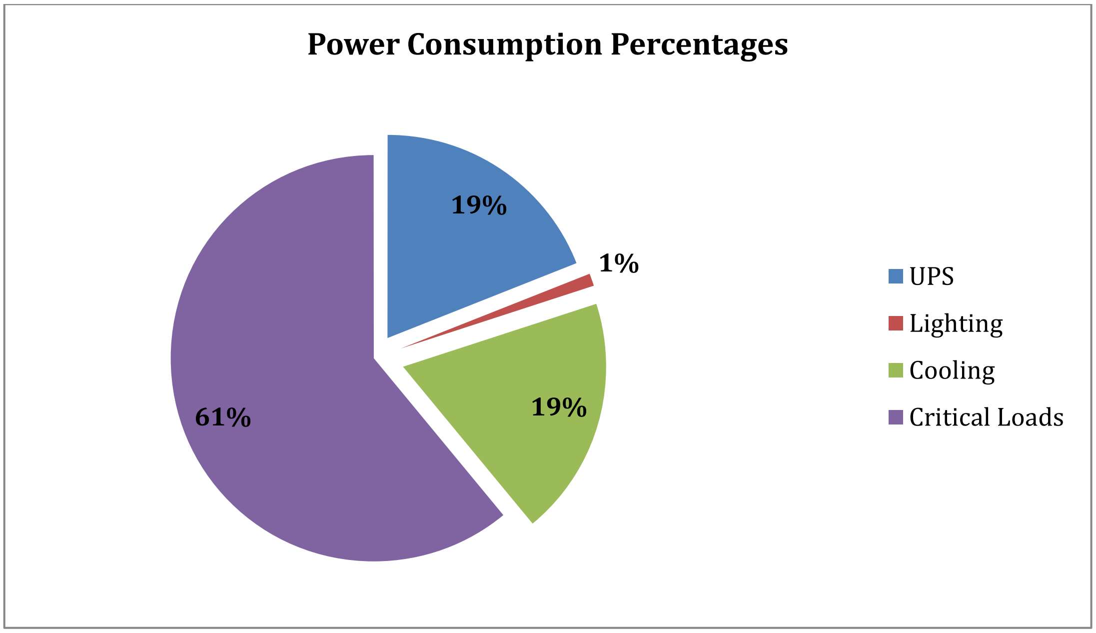


Figure 9: Power Consumption Percentages of Entire Data Center

kWh and cost for initial 150 racks at 4kW:

1 year = 365 days = 8760 hours

990.04kW * 8760hours = **86727504.4 kWh**

$0.07 per kWh * 86727504.4 kWh = **$607092.53**

kWh and cost for 150 racks at 12 kW:

2982.56kW * 8760hours = **26127225.6 kWh**

$0.07 per kWh * 26127225.6 kWh = **$1828905.88**

kWh and cost for 600 racks at 4 kW:

3957.72kW * 8760hours = **34669627.2 kWh**

$0.0826 per kWh * 34669627.2 kWh = **$2863711.25**

kWh and cost for 600 racks at 12 kW:

11927.8 * 8760hours = **104487528 kWh**

$0.0826 per kWh * 104487528 kWh = **$8630670.00**

APPENDIX: Discounted Cash Flow Model

Assumptions

Sq Ft (Phase 1)		5448	**Taxes**		
Sq Ft added per phase		4888	CO Sales Tax Rate		8.15%
Wall Sq ft		3970	Assessment Rate		29%
Value added per phase		$60,000	Tax Area	0070	
			Mill Levie		86.533
Energy & Cost Assumptions			Property Tax Rate		0.086533
kWh per rack		4	Inflation Rate		3.00%
$/kwh		0.07			
Elec. Px Escalator (%/year)		3.00%	**Depreciation**		
Service & Warranty	$	0.50	Years Depreciation (Racks)		4
Service & Warranty Increase (%/yr)		5.00%	Years Depreciation (Building)		39
Cost of New Racks	$	1.00	Salvage Value (Building)	$	1,500
Land Cost Assumptions			**WACC**		
Cost of Land ($/sq ft)	$	0.15	WACC		10.65%
Building Value Esclator (%/year)		5.00%	Cost of Equity		12.25%
Cost of Rent ($ / sq ft)	$	15.00	Assumed Tax Rate		30.00%
Rent Value Escalator (%/yr)		5.00%	Estimated Growth Rate		4.00%
Building Sale Discount		10.00%			
Reed Location Factor (Denver)		95.80%			

Estimate of Initial Data Center Costs

Raw Building Materials

Description	Quantity	Unit	Unit Price	Total	Cost/sf	RS Ref #
Steel Roof Decking	5448	SF	$ 2.59	$ 14,110.32	$ 2.59	0531-2600
Steel Joists (36LH09)	704	LF	$ 21.00	$ 14,784.00	$ 2.71	05210-2400
Radiant Barrier Insulation(Walls)	3970	SF	$ 0.30	$ 1,191.00	$ 0.22	
Radiant Barrier Insulation (Roofing)	4440	SF	$ 0.30	$ 1,332.00	$ 0.24	
Steel Beam W14x48	240	LF	$ 73.25	$ 17,580.00	$ 3.23	0512-23(30)
Steel Column W12x40	140	LF	$ 74.00	$ 10,360.00	$ 1.90	0512-7150
Concrete Slab	82	CY	$ 113.00	$ 9,266.00	$ 1.70	0331-0300
Total Cost of Raw Building Materials				**$ 68,623.32**	**$ 12.60**	
%Total Cost of Raw Building Materials	**1.46%**					

Mechanical

Description	Quantity	Unit	Unit Price	Total	Cost/sf
Coolant Distribution Units: CD6A (70 ton)	8	Ea.	$ 6,000.00	$ 48,000.00	$ 8.81
Coolcentric Rear Door Heat Exchanger	150	Ea.	$ 3,500.00	$ 525,000.00	$ 96.37
A/C Unit, Wall Mount	2	Ea.	$ 2,592.00	$ 5,184.00	$ 0.95
Negative Pressure Fans	10	Ea.	$ 5,641.00	$ 56,410.00	$ 10.35
Chiller, centrifugal, air-cool, 400 TON	4	Ea.	$ 225,508.00	$ 902,032.00	$ 165.57
Total Cost of Mechanical				**$ 1,536,626.00**	**$ 282.05**
%Total Cost of Mechanical	**32.65%**				

Electrical

Description	Quantity	Unit	Unit Price	Total	Cost/sf	RS Ref #
Diesel Engine Generators 3MW	4	Ea.	$ 500,000.00	$ 2,000,000.00	$ 367.11	
Incoming Switchboard	12	Ea.	$ 24,900.00	$ 298,800.00	$ 54.85	
Distribution Switchboard 2500 amp	8	Ea.	$ 8,250.00	$ 66,000.00	$ 12.11	2624-0800
Power Distribution Unit 240kVa	16	Ea.	$ 25,000.00	$ 400,000.00	$ 73.42	
Medium Voltage Transformer 2MVa	8	Ea.	$ 9,575.00	$ 76,600.00	$ 14.06	2622-4100
Low Voltage Circuit Breakers	100	Ea.	$ 2,000.00	$ 200,000.00	$ 36.71	
Medium Voltage Circuit Breakers	30	Ea.	$ 2,000.00	$ 60,000.00	$ 11.01	
Total Cost of Electrical				**$ 3,101,400.00**	**$ 569.27**	
% Total Cost of Electrical	**65.89%**					

Total Valuation of Work (National Avg.)	$ 4,706,649.32
Total Valuation of Work (Denver Avg.)	$ 4,508,970.05

Building Permits & Fees

Building Permit Fee	$ 22,276.36
Plan Review Fee	$ 14,479.63
Buiding Permit Use Tax	$ 93,561.13
Total Cost of Building Permits & Fees	$ 130,317.12

Build to Own Cash Flow (values in $000's USD)

Year	Zero 2014	One 2015	Two 2016	Three 2017	Four 2018	Five 2019	Six 2020	Seven 2021	Eight 2022	Nine 2023	Ten 2024
Project Revenue:											
Sale of Building:											
Value of Building & Land	$ 4,509	$ 4,734	$ 4,971	$ 5,280	$ 5,544	$ 5,821	$ 6,172	$ 6,481	$ 6,805	$ 7,205	$ 7,565
Income From Sale of Building											$ 6,808
Total Project Revenue											**$ 6,808**
Operating Costs:											
Electricity:											
Number of Racks	150	150	150	300	300	300	450	450	450	600	600
Power Consumed per Rack (kWh)		4	4	4	4	4	4	4	4	4	4
Annual Power Consumed (kWh)		600	600	1200	1200	1200	1800	1800	1800	2400	2400
Price of Electricity ($/kWh)		$ (0.070)	$ (0.072)	$ (0.074)	$ (0.076)	$ (0.079)	$ (0.081)	$ (0.084)	$ (0.086)	$ (0.089)	$ (0.091)
Cost of Electricity		$ (42)	$ (43)	$ (89)	$ (92)	$ (95)	$ (146)	$ (150)	$ (155)	$ (213)	$ (219)
Service & Warranty											
Cost of Service per Rack		$ (0.50)	$ (0.53)	$ (0.55)	$ (0.58)	$ (0.61)	$ (0.64)	$ (0.67)	$ (0.70)	$ (0.74)	$ (0.78)
Cost of Service & Warranty		$ (75)	$ (79)	$ (165)	$ (174)	$ (182)	$ (287)	$ (302)	$ (317)	$ (443)	$ (465)
Installation of New Racks:											
Number of Racks to be Installed	150			150			150			150	
Cost per Rack	$ (1.00)	$ (1.03)	$ (1.06)	$ (1.09)	$ (1.13)	$ (1.16)	$ (1.19)	$ (1.23)	$ (1.27)	$ (1.30)	$ (1.34)
Cost of Installing New Racks	$ (150)	$ -	$ -	$ (164)	$ (338)	$ -	$ (179)	$ (553)	$ -	$ (196)	$ -
Total Operating Costs	**$ (150)**	**$ (117)**	**$ (122)**	**$ (418)**	**$ (603)**	**$ (277)**	**$ (612)**	**$ (1,005)**	**$ (472)**	**$ (852)**	**$ (685)**
Operating Income:											
Total Project Revenue	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 6,808
Total Operating Costs	$ (150)	$ (117)	$ (122)	$ (418)	$ (603)	$ (277)	$ (612)	$ (1,005)	$ (472)	$ (852)	$ (685)
Total Operating Income	$ (150)	$ (117)	$ (122)	$ (418)	$ (603)	$ (277)	$ (612)	$ (1,005)	$ (472)	$ (852)	$ 6,124
Discounted Cash Flow	**$ (150)**	**$ (106)**	**$ (100)**	**$ (309)**	**$ (402)**	**$ (167)**	**$ (334)**	**$ (495)**	**$ (210)**	**$ (343)**	**$ 2,226**
Other Expenses											
Taxes:											
Property Tax		$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407
Cost of Construction	$ 4,509										

Build and Lease Back Cash Flow (values in $000's USD)

Year	Zero	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten
	2014	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*
Project Revenue:											
Sale of Building:											
Value of Building & Land	$ 4,509	$ 4,734	$ 4,971	$ 5,220	$ 5,481	$ 5,755	$ 6,042	$ 6,345	$ 6,662	$ 6,995	$ 7,345
Income From Sale of Building	$ 4,960										
Total Project Revenue	**$ 4,960**										
Operating Costs:											
Electricity:											
Number of Racks	150	150	150	300	300	300	450	450	450	600	600
Power Consumed per Rack (kWh)		4	4	4	4	4	4	4	4	4	4
Annual Power Consumed (kWh)		600	600	1200	1200	1200	1800	1800	1800	2400	2400
Price of Electricity ($/kWh)		$ (0.070)	$ (0.072)	$ (0.074)	$ (0.076)	$ (0.079)	$ (0.081)	$ (0.084)	$ (0.086)	$ (0.089)	$ (0.091)
Cost of Electricity		$ (42)	$ (43)	$ (89)	$ (92)	$ (95)	$ (146)	$ (150)	$ (155)	$ (213)	$ (219)
Service & Warranty											
Cost of Service per Rack		$ (0.50)	$ (0.53)	$ (0.55)	$ (0.58)	$ (0.61)	$ (0.64)	$ (0.67)	$ (0.70)	$ (0.74)	$ (0.78)
Cost of Service & Warranty		$ (75)	$ (79)	$ (165)	$ (174)	$ (182)	$ (287)	$ (302)	$ (317)	$ (443)	$ (465)
Installation of New Racks:											
Number of Racks to be Installed	150			150			150			150	
Cost per Rack	$ (1.00)	$ (1.03)	$ (1.06)	$ (1.09)	$ (1.13)	$ (1.16)	$ (1.19)	$ (1.23)	$ (1.27)	$ (1.30)	$ (1.34)
Cost of Installing New Racks	$ (150)	$ -	$ -	$ (164)	$ (338)	$ -	$ (179)	$ (553)	$ -	$ (196)	$ -
Cost of Rent											
Square Feet	5448	5448	5448	10336	10336	10336	15224	15224	15224	20112	20112
$/sq ft		$ (0.0150)	$ (0.0158)	$ (0.0165)	$ (0.0174)	$ (0.0182)	$ (0.0191)	$ (0.0201)	$ (0.0211)	$ (0.0222)	$ (0.0233)
Total Cost of Rent	$ -	$ (81.720)	$ (85.806)	$ (170.932)	$ (179.478)	$ (188.452)	$ (291.452)	$ (306.024)	$ (321.325)	$ (445.719)	$ (468.005)
Total Operating Costs	**$ (150)**	**$ (199)**	**$ (208)**	**$ (589)**	**$ (783)**	**$ (465)**	**$ (904)**	**$ (1,311)**	**$ (793)**	**$ (1,297)**	**$ (1,153)**
Operating Income:											
Total Project Revenue	$ 4,960	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Operating Costs	$ (150)	$ (199)	$ (208)	$ (589)	$ (783)	$ (465)	$ (904)	$ (1,311)	$ (793)	$ (1,297)	$ (1,153)
Total Operating Income	$ 5,110	$ (199)	$ (208)	$ (589)	$ (783)	$ (465)	$ (904)	$ (1,311)	$ (793)	$ (1,297)	$ (1,153)
Discounted Cash Flow	**$ 5,110**	**$ (180)**	**$ (208)**	**$ (435)**	**$ (522)**	**$ (281)**	**$ (492)**	**$ (646)**	**$ (353)**	**$ (522)**	**$ (419)**
Other Expenses											
Taxes:											
Property Tax		$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407
Cost of Construction	$ 4,509										

Build to Suit Cash Flow (values in $000's USD)

Year	Zero 2014	One 2015	Two 2016	Three 2017	Four 2018	Five 2019	Six 2020	Seven 2021	Eight 2022	Nine 2023	Ten 2024
Project Revenue:											
Sale of Land:											
Value per Sq Ft	$ 0.15										
Amount of Land Sold (Sq Ft)	5448										
Income From Sale of Land	$ 817.20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Project Revenue	**$ 817.20**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operating Costs:											
Electricity:											
Number of Racks	150	150	150	300	300	300	450	450	450	600	600
Power Consumed per Rack (kWh)		4	4	4	4	4	4	4	4	4	4
Annual Power Consumed (kWh)		600	600	1200	1200	1200	1800	1800	1800	2400	2400
Price of Electricity ($/kWh)		$ (0.070)	$ (0.072)	$ (0.074)	$ (0.076)	$ (0.079)	$ (0.081)	$ (0.084)	$ (0.086)	$ (0.089)	$ (0.091)
Cost of Electricity		$ (42)	$ (43)	$ (89)	$ (92)	$ (95)	$ (146)	$ (150)	$ (155)	$ (213)	$ (219)
Service & Warranty											
Cost of Service per Rack		$ (0.50)	$ (0.53)	$ (0.55)	$ (0.58)	$ (0.61)	$ (0.64)	$ (0.67)	$ (0.70)	$ (0.74)	$ (0.78)
Cost of Service & Warranty		$ (75)	$ (79)	$ (165)	$ (174)	$ (182)	$ (287)	$ (302)	$ (317)	$ (443)	$ (465)
Installation of New Racks:											
Number of Racks to be Installed	150			150			150			150	
Cost per Rack	$ (1.00)	$ (1.03)	$ (1.06)	$ (1.09)	$ (1.13)	$ (1.16)	$ (1.19)	$ (1.23)	$ (1.27)	$ (1.30)	$ (1.34)
Cost of Installing New Racks	$ (150)	$ -	$ -	$ (164)	$ (338)	$ -	$ (179)	$ (553)	$ -	$ (196)	$ -
Cost of Rent											
Square Feet	4888	4888	4888	8858	8858	8858	12828	12828	12828	16798	16798
$/sq ft		$ (0.0150)	$ (0.0158)	$ (0.0165)	$ (0.0174)	$ (0.0182)	$ (0.0191)	$ (0.0201)	$ (0.0211)	$ (0.0222)	$ (0.0233)
Total Cost of Rent	$ -	$ (73.320)	$ (76.986)	$ (146.489)	$ (153.814)	$ (161.504)	$ (245.582)	$ (257.861)	$ (270.754)	$ (372.274)	$ (390.888)
Total Operating Costs	**$ (150)**	**$ (190)**	**$ (199)**	**$ (565)**	**$ (757)**	**$ (438)**	**$ (858)**	**$ (1,263)**	**$ (742)**	**$ (1,224)**	**$ (1,075)**
Operating Income:											
Total Project Revenue	$ 817	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Operating Costs	$ (150)	$ (190)	$ (199)	$ (565)	$ (757)	$ (438)	$ (858)	$ (1,263)	$ (742)	$ (1,224)	$ (1,075)
Total Operating Income	$ 967	$ (190)	$ (199)	$ (565)	$ (757)	$ (438)	$ (858)	$ (1,263)	$ (742)	$ (1,224)	$ (1,075)
Discounted Cash Flow	**$ 967**	**$ (172)**	**$ (163)**	**$ (417)**	**$ (505)**	**$ (264)**	**$ (467)**	**$ (622)**	**$ (330)**	**$ (492)**	**$ (391)**
Other Expenses											
Taxes:											
Property Tax		$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407	$ 407

balanced design

JOB

SHEET NO OF

CALCULATED BY DATE

CHECKED BY DATE

SCALE

REF

Steel Deck Design

64' x 36' bays, deck parallel to 36' side

Roof Load take-off

DL = 26.5 psf
LL = 20 psf

D+L = 46.5 psf ASD

Deck Span

Options:
1) 2 double spans (9' each)
2) 1 double, 1 triple (7.2' each)
3) 2 triple (6' each) ← optimizes

options:
20 ga PLB-36 80 psf ← Cheaper
20 ga PLN-24 170 psf
ASD

VERCO CATALOG

Use 20 ga PLB-36 1 1/2" deep roof deck

with primer painted finish to fire-proof the deck.

balanced design

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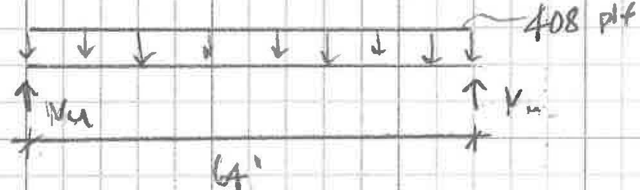
Steel open Web Joist Design

f_u = actual/req'd stress
F_n = nominal stress
ϕ = resistance factor
ϕF_n = design stress

} LRFD

Trusses span 64' and are 6' o.c.



LC $1.4D = 1.4(30) = 42$ psf

$1.2D + 1.6L_r = 1.2(30) + 1.6(20) = 68$ psf ←

Vulcraft catalog

Sand $L_r = 20$ psf

68 psf (6') = 408 plf

use 36LH09 $\phi F_n = 513$ plf > 408 plf ✓

36" depth

LRFD

STANDARD LOAD TABLE FOR LONGSPAN STEEL JOISTS, LH-SERIES
Based on a 50 ksi Maximum Yield Strength - Loads Shown In Pounds Per Linear Foot (plf)

Joist Designation	Approx. Wt in Lbs. Per Linear Ft. (Joists only)	Depth in inches	Max Load (plf)	SAFELOAD* in Lbs. Between		SPAN IN FEET														
			< 29		29-33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
24LH03	11	24	601		17430	513	508	504	484	460	439	418	400	382	366	351	336	322	310	298
						235	226	218	204	188	175	162	152	141	132	124	116	109	102	96
24LH04	12	24	737		21360	628	597	568	540	514	490	468	447	427	409	393	376	361	346	333
						288	265	246	227	210	195	182	169	158	148	138	130	122	114	107
24LH05	13	24	789		22890	673	669	660	628	598	570	544	520	496	475	456	436	420	403	387
						306	297	285	264	244	226	210	196	182	171	160	150	141	132	124
24LH06	16	24	1061		30780	906	868	832	795	756	720	685	655	625	598	571	546	522	501	480
						411	382	356	331	306	284	263	245	228	211	197	184	172	161	152
24LH07	17	24	1166		33810	997	957	919	882	847	811	774	736	702	669	639	610	583	559	535
						452	421	393	367	343	320	297	276	257	239	223	208	195	182	171
24LH08	18	24	1243		36060	1060	1015	973	933	895	858	817	780	745	712	682	652	625	600	576
						480	447	416	388	362	338	314	292	272	254	238	222	208	196	184
24LH09	21	24	1464		42450	1248	1212	1177	1146	1096	1044	894	948	903	861	822	786	751	720	690
						562	530	501	460	424	393	363	337	313	292	272	254	238	223	209
24LH10	23	24	1547		44850	1323	1284	1248	1213	1182	1152	1105	1053	1002	955	912	873	834	799	766
						596	559	528	500	474	439	406	378	351	326	304	285	266	249	234
24LH11	25	24	1630		47280	1390	1350	1312	1276	1243	1210	1180	1152	1101	1051	1006	963	924	885	850
						624	588	555	525	498	472	449	418	388	361	337	315	294	276	259
			< 34		34-41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
28LH05	13	28	623		21180	505	484	465	445	429	412	397	382	367	355	342	330	319	309	298
						219	205	192	180	169	159	150	142	133	126	119	113	107	102	97
28LH06	16	28	828		28140	672	643	618	592	568	546	525	505	486	469	451	436	421	406	393
						289	270	253	238	223	209	197	186	175	166	156	148	140	133	126
28LH07	17	28	934		31770	757	726	696	667	640	615	591	568	547	528	508	490	474	457	442
						326	305	285	267	251	236	222	209	197	186	176	166	158	150	142
28LH08	18	28	1001		34020	810	775	744	712	684	657	630	604	580	556	535	516	496	478	462
						348	325	305	285	268	252	236	222	209	196	185	175	165	156	148
28LH09	21	28	1232		41880	1000	958	918	879	844	810	778	748	721	694	669	645	622	601	580
						428	400	375	351	329	309	291	274	258	243	228	216	204	193	183
28LH10	23	28	1347		45810	1093	1056	1018	976	937	900	864	831	799	769	742	715	690	666	643
						466	439	414	388	364	342	322	303	285	269	255	241	228	215	204
28LH11	25	28	1445		49140	1170	1143	1104	1066	1023	982	943	907	873	841	810	781	753	727	702
						499	475	448	423	397	373	351	331	312	294	278	263	249	236	223
28LH12	27	28	1587		53970	1285	1255	1227	1200	1173	1149	1105	1063	1023	984	948	913	880	849	819
						545	520	496	476	454	435	408	383	361	340	321	303	285	270	256
28LH13	30	28	1654		56250	1342	1311	1281	1252	1224	1198	1173	1149	1126	1083	1041	1002	964	930	897
						569	543	518	495	472	452	433	415	396	373	352	332	314	297	281
			< 39	39-46	47-49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
32LH06	14	32	647	25230	25230	507	489	472	456	441	426	412	399	385	373	363	351	340	330	321
						211	199	189	179	169	161	153	145	136	131	125	119	114	108	104
32LH07	16	32	728	28380	28380	568	549	529	511	493	477	462	447	432	418	406	393	381	370	360
						235	223	211	200	189	179	170	162	154	146	140	133	127	121	116
32LH08	17	32	790	30810	30810	616	595	574	553	535	517	499	483	468	453	439	426	412	400	388
						255	242	229	216	205	194	184	175	167	159	151	144	137	131	125
32LH09	21	32	992	38670	38670	774	747	720	694	670	648	627	606	586	568	550	534	517	502	487
						319	302	285	270	256	243	230	219	208	198	189	180	172	164	157
32LH10	21	32	1096	42750	42750	856	825	798	768	742	717	693	667	645	624	603	583	564	546	529
						352	332	315	297	282	267	254	240	228	217	206	196	186	178	169
32LH11	24	32	1201	46830	46830	937	903	870	840	811	783	757	732	709	687	664	643	624	604	585
						385	363	343	325	308	292	277	263	251	239	227	216	206	198	187
32LH12	27	32	1409	54960	54960	1101	1068	1032	996	961	928	897	867	838	811	786	762	738	715	694
						450	428	406	384	364	345	327	311	295	281	267	255	243	232	221
32LH13	30	32	1572	61320	61320	1225	1201	1177	1156	1113	1072	1035	999	964	931	900	871	843	816	790
						500	480	461	444	420	397	376	354	336	319	304	288	275	262	249
32LH14	33	32	1618	63120	63120	1264	1239	1215	1192	1170	1149	1107	1069	1032	997	964	933	903	874	846
						515	495	476	459	440	417	395	374	355	337	321	304	290	276	264
32LH15	35	32	1673	65250	65250	1305	1279	1255	1231	1207	1186	1164	1144	1125	1087	1051	1017	984	952	924
						532	511	492	473	454	438	422	407	393	374	355	338	322	306	292
			< 43	43-46	47-56 57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
36LH07	16	36	590	25350	25350	438	424	411	399	387	376	366	355	345	336	327	318	310	301	294
						177	188	160	153	146	140	134	128	122	117	112	107	103	99	95
36LH08	18	36	649	27900	27900	481	466	453	439	426	414	402	390	379	369	358	349	340	331	322
						194	185	176	168	160	153	146	140	134	128	123	118	113	109	104
36LH09	21	36	832	35760	35760	616	597	579	561	544	528	513	499	484	471	459	445	433	423	412
						247	235	224	214	204	195	186	179	171	163	157	150	144	138	133
36LH10	21	36	916	39390	39390	681	660	639	619	601	583	567	550	535	520	507	492	480	466	454
						273	260	248	236	225	215	206	197	188	180	173	165	159	152	146
36LH11	23	36	1000	42990	42990	742	720	697	676	657	637	618	601	583	567	552	537	522	508	495
						297	283	269	257	246	234	224	214	205	196	188	180	173	166	159
36LH12	25	36	1197	51450	51450	889	862	835	810	784	762	739	717	696	675	655	636	618	600	583
						354	338	322	307	292	279	267	255	243	232	222	213	204	195	187
36LH13	30	36	1407	60510	60510	1045	1012	981	951	922	894	868	843	819	796	774	753	732	712	694
						415	395	376	359	342	327	312	298	265	273	262	251	240	231	222
36LH14	36	36	1551	66690	66690	1152	1132	1093	1059	1024	991	961	931	903	876	850	826	802	780	757
						456	434	412	392	373	356	339	323	309	295	283	270	259	247	237
36LH15	36	36	1635	70320	70320	1213	1192	1171	1153	1116	1081	1047	1015	984	955	927	900	874	850	826
						480	464	448	434	413	394	375	358	342	327	312	299	286	274	263

balanced design

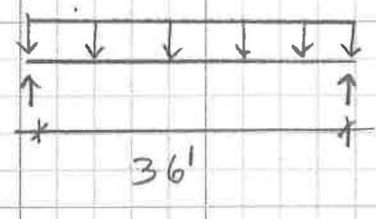
JOB

SHEET NO ____ OF ____

CALCULATED BY ____ DATE ____

CHECKED BY ____ DATE ____

SCALE

REF	
	STEEL BEAM DESIGN
worst case for interior beam at full phase	 analyze as distributed load. $A_t = 64' \times 36' = 2304\ ft^2$
	Lr reduction
ASCE 7-10 4.8.2	$R_1 = 0.6$ for $A_t > 600\ ft^2$
	$0.6(20) = 12$ so, snow load governs = 20 psf
LOAD TABLES	$1.2D + 1.6S = 1.2(34) + 1.6(20) = 72.8$ psf
	$72.8 \times 64' = 4660$ plf
	$V_u = \frac{w\ell}{2} = 84^K$
	$M_u = \frac{w\ell^2}{8} = 755$ k-ft
	Check deflection
IBC Table 1604.3	$\Delta_{allow} = \ell/240 = 1.5"$ for supporting non-plaster ceiling LL only
Table 3-23 AISC	$\Delta_{actual} = \frac{5w\ell^4}{384EI}$ $\quad I_{req'd} = \frac{5(2050 \frac{lb}{ft} \frac{1ft}{12in})(36 \times 12)^4}{384(29000000\ psi)(1.5\ in)} = 1780\ in^4$
Table 3-3	Options: W24X68, W21x83, W24x84

balanced design

JOB
SHEET NO. OF
CALCULATED BY DATE
CHECKED BY DATE
SCALE

Check ϕM_n / ϕV_n

	I_x (in⁴)	ϕM_n (k·ft)	ϕV_n (k)	Weight
W24x68	1830	~~664~~		
W21x83	1830	~~735~~		
W24x84	2370	840	340	84 plf ←

Use W24x84

for exterior beams W18X48 satisfies req'm

balanced design

JOB

SHEET NO ____ OF ____

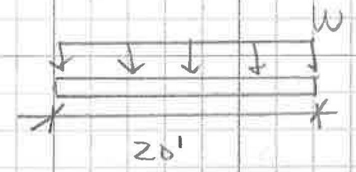
CALCULATED BY ____ DATE ____

CHECKED BY ____ DATE ____

SCALE

REF

Beam 2 Design



6' o.c.

$A_t = 20 \times 6 = 120\ ft^2$

$1.2D + 1.6S = 1.2(34) + 1.6(20) = 72.8\ psf$

$72.8\ psf \times 6 = 436.8\ plf = w$

$V_u = \frac{wl}{2} = 4.37^K$

$M_u = \frac{wl^2}{8} = 21.8^{k \cdot ft}$

Check Defl

$\Delta_{allow} = l/240 = 1''$

$E_{req'd} = \frac{5\left(192\ plf\ \frac{ft}{12\ in}\right)(20 \times 12)^4}{384\,(29 \times 10^6\ psi)(1'')} = 23.8$

options: W8x10* satisfies I, ϕM_n, ϕV_n

W8x13 ←

balanced design

JOB

SHEET NO OF

CALCULATED BY DATE

CHECKED BY DATE

SCALE

REF

Column Design

$A_t = 36' \times 32' = 1152\,ft^2$

34 psf DL
20 psf Snow

$1.2D + 1.6L = 72.8$ psf

$72.8 \times 1152 = 84^K$

$K = 1.0$ $KL = 15$ feet

Options

AISC Steel Manual Table 4-1

W8x31 $\phi P_n = 230^K$
W10x33 $\phi P_n = 233^K$
W12x40 $\phi P_n = 281^K$ ← Use min W12 for columns

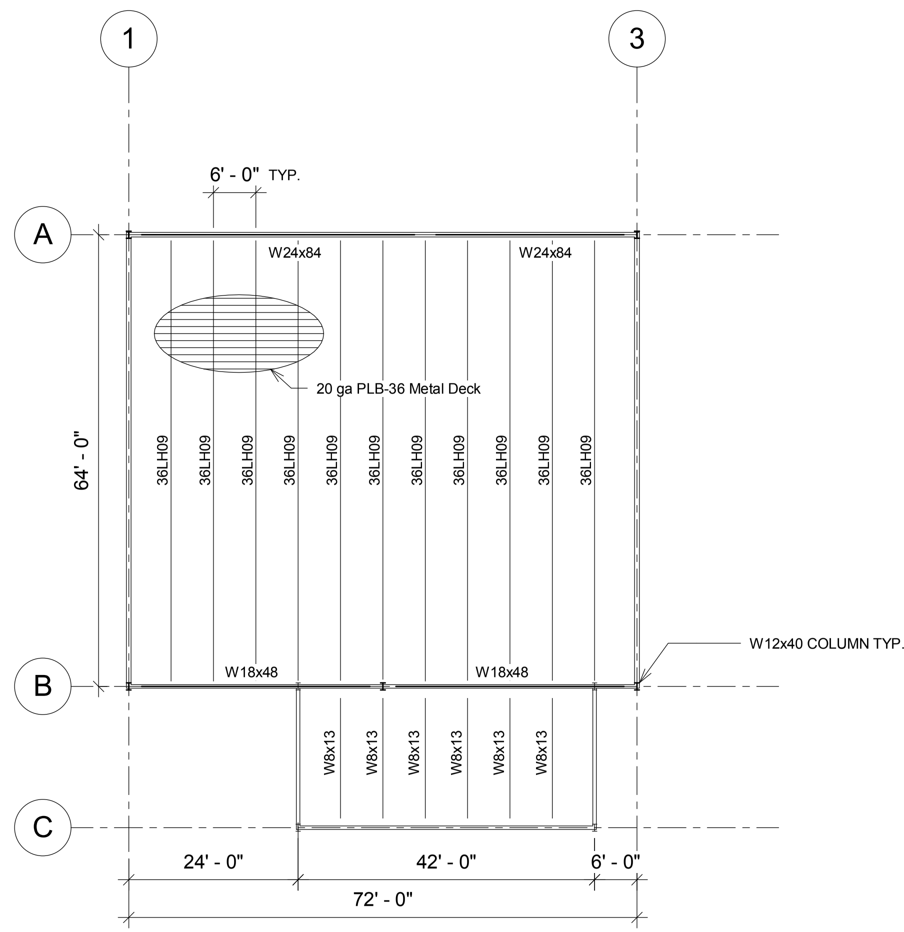
SITE LOCATION RESEARCH

prevailing wind

building footprint

property line

optional new parking areas



1 FRAMING PLAN PHASE 1
1/16" = 1'-0"

balanced design

BROCADE

DATA CENTER

No.	Description	Date

ROOF FRAMING PLAN

Project number	031301	S.1
Date	03.05.13	
Drawn by	C. MOREHARDT	
Checked by	TEAM 6	Scale 1/16" = 1'-0"

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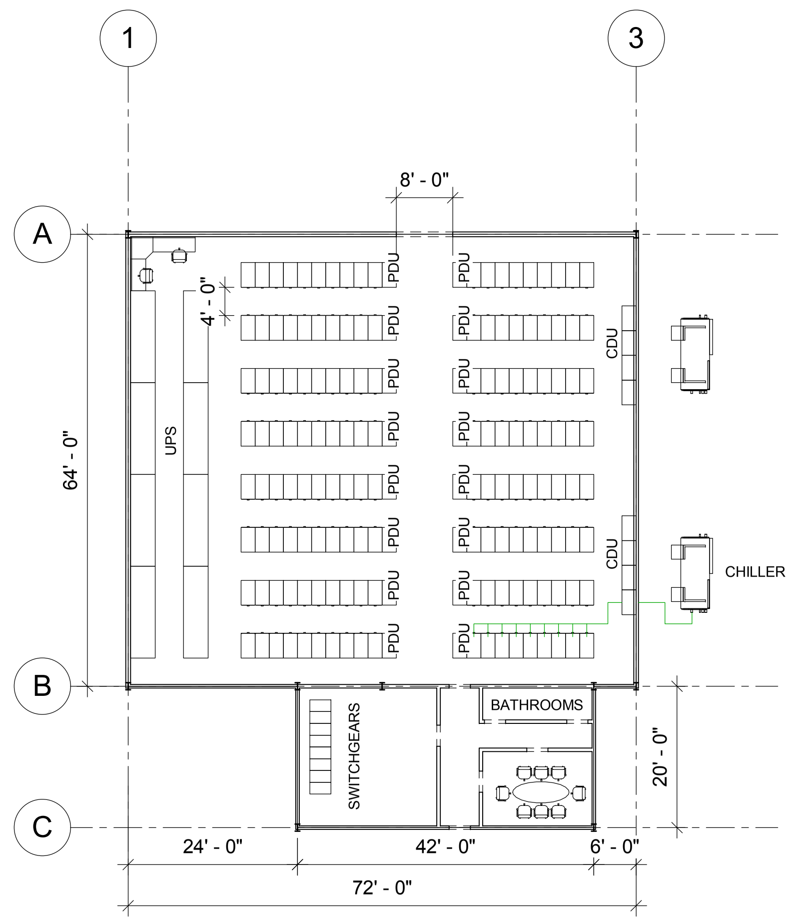

1 RACK LAYOUT
1/16" = 1'-0"

balanced design

BROCADE

DATA CENTER

No.	Description	Date

RACK LAYOUT

Project number	031301
Date	03.05.13
Drawn by	C. Morehardt
Checked by	Team 6

S.2

Scale 1/16" = 1'-0"

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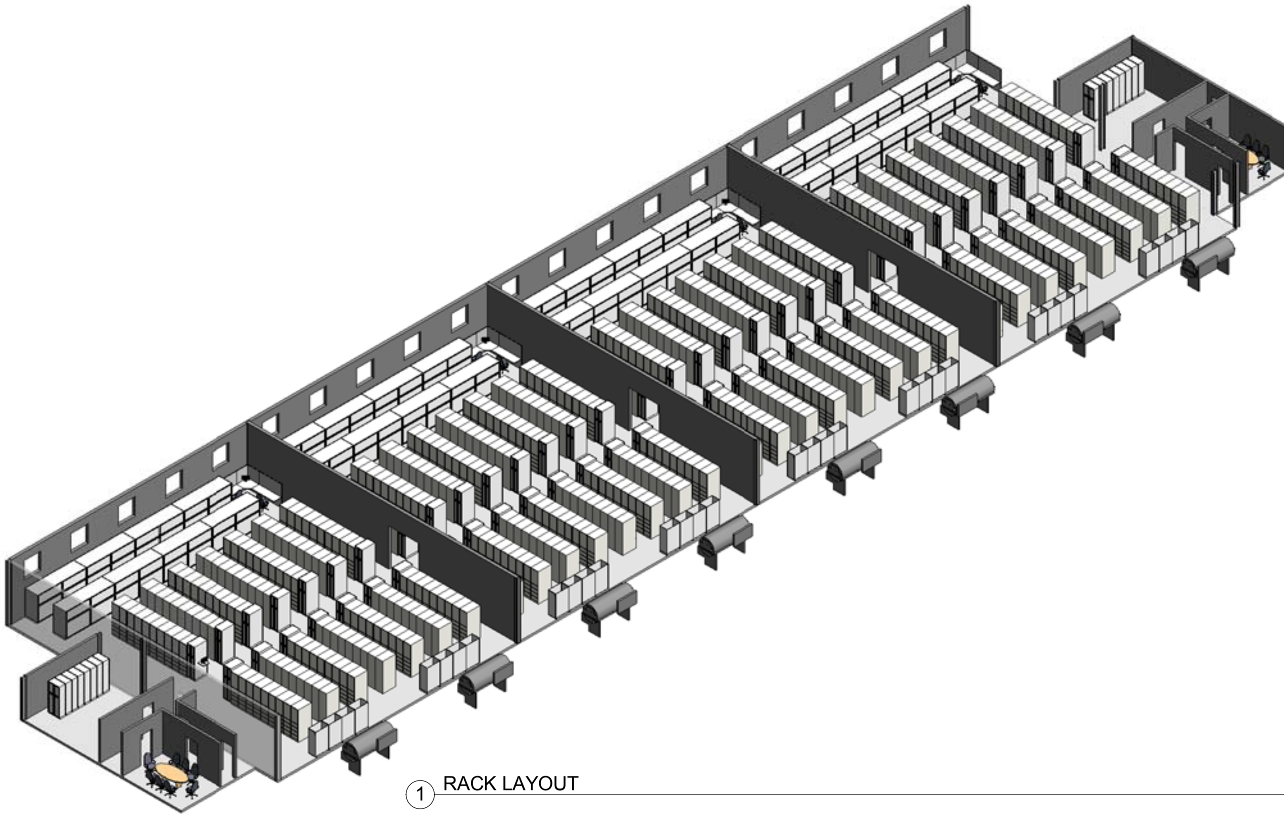

1 RACK LAYOUT

balanced design

BROCADE

DATA CENTER

No.	Description	Date

RACK LAYOUT 3D

Project number	031301	S.3
Date	03.05.13	
Drawn by	C. Morehardt	
Checked by	Team 6	Scale

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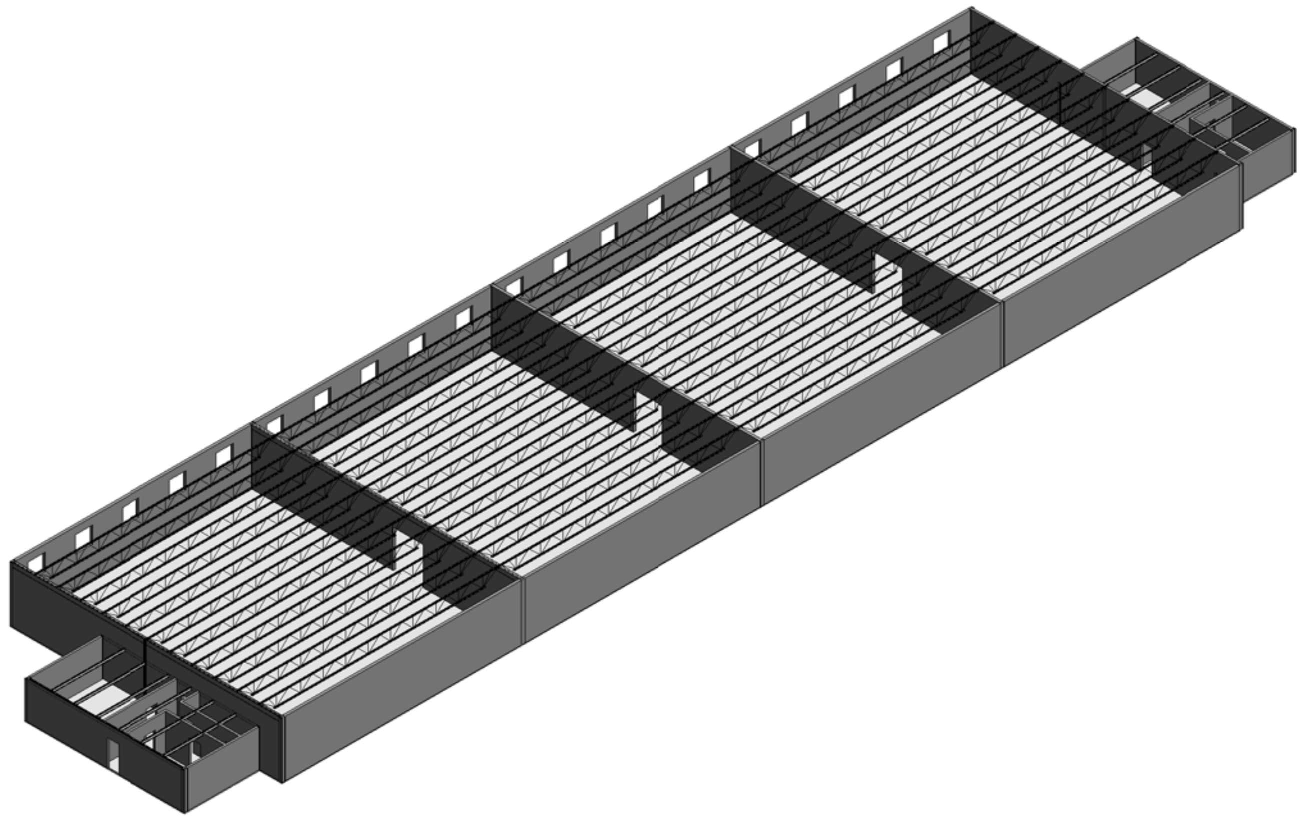

1 STRUCTURAL 3D VIEW

balanced design

BROCADE

DATA CENTER

No.	Description	Date

STRUCTURAL 3D VIEW

Project number	031301	S.4
Date	03.05.13	
Drawn by	C. Morehardt	
Checked by	Team 6	Scale

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APPENDIX: Mechanical

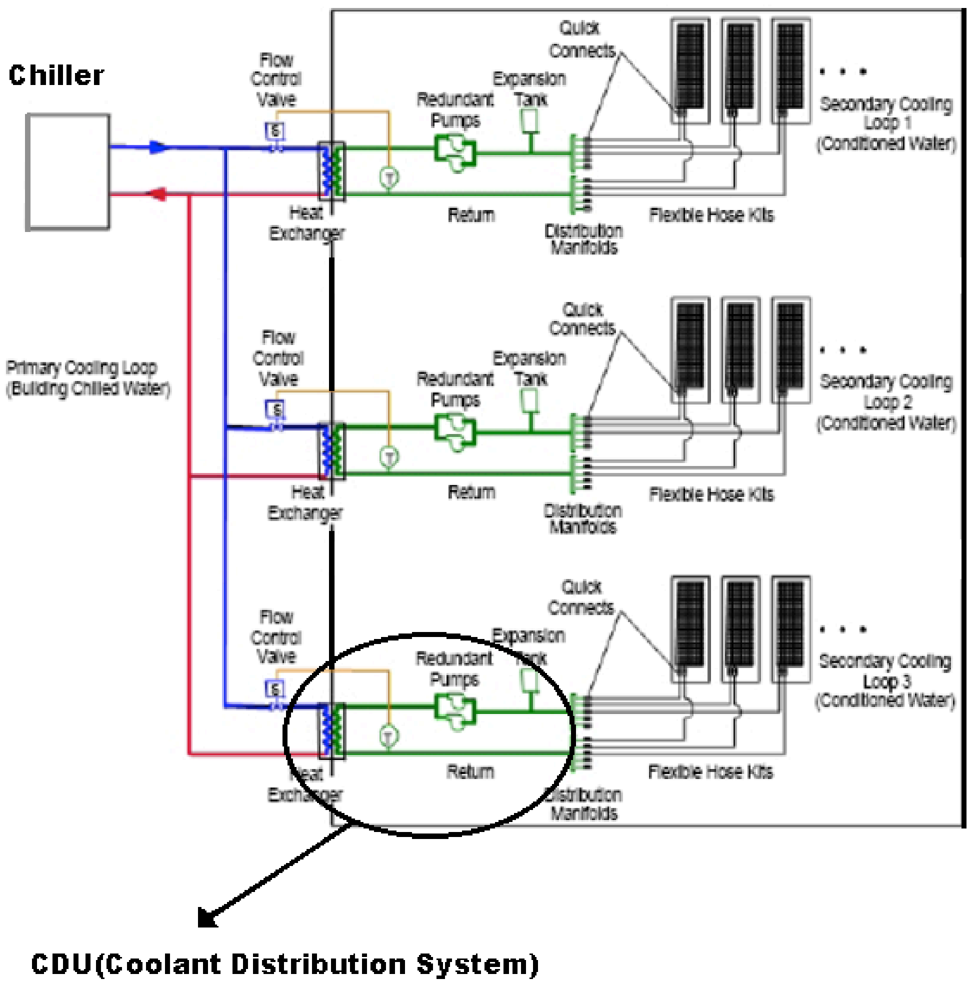


Figure 1. Single Line of Mechanical System

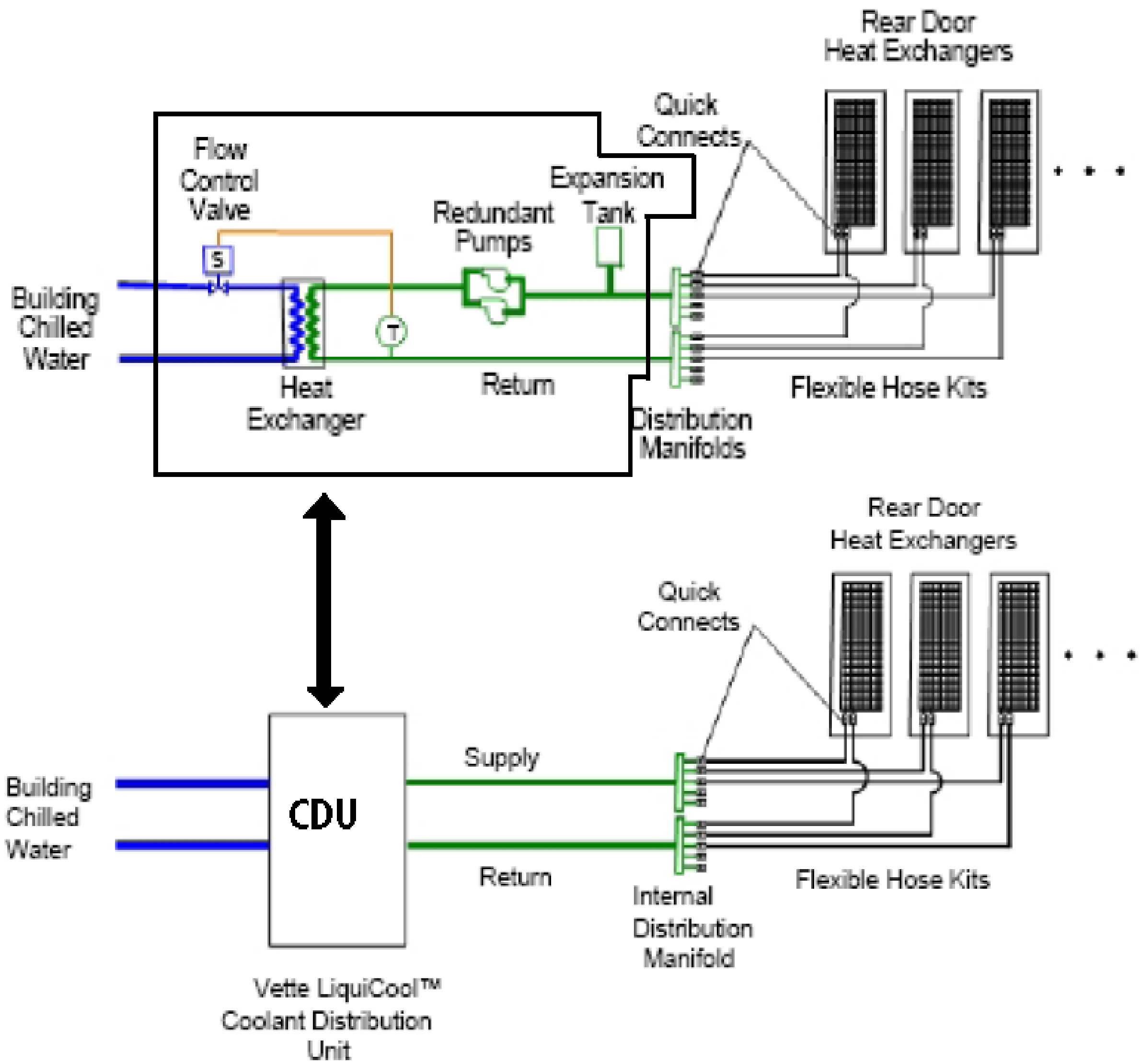


Figure 2. CDU Schematic

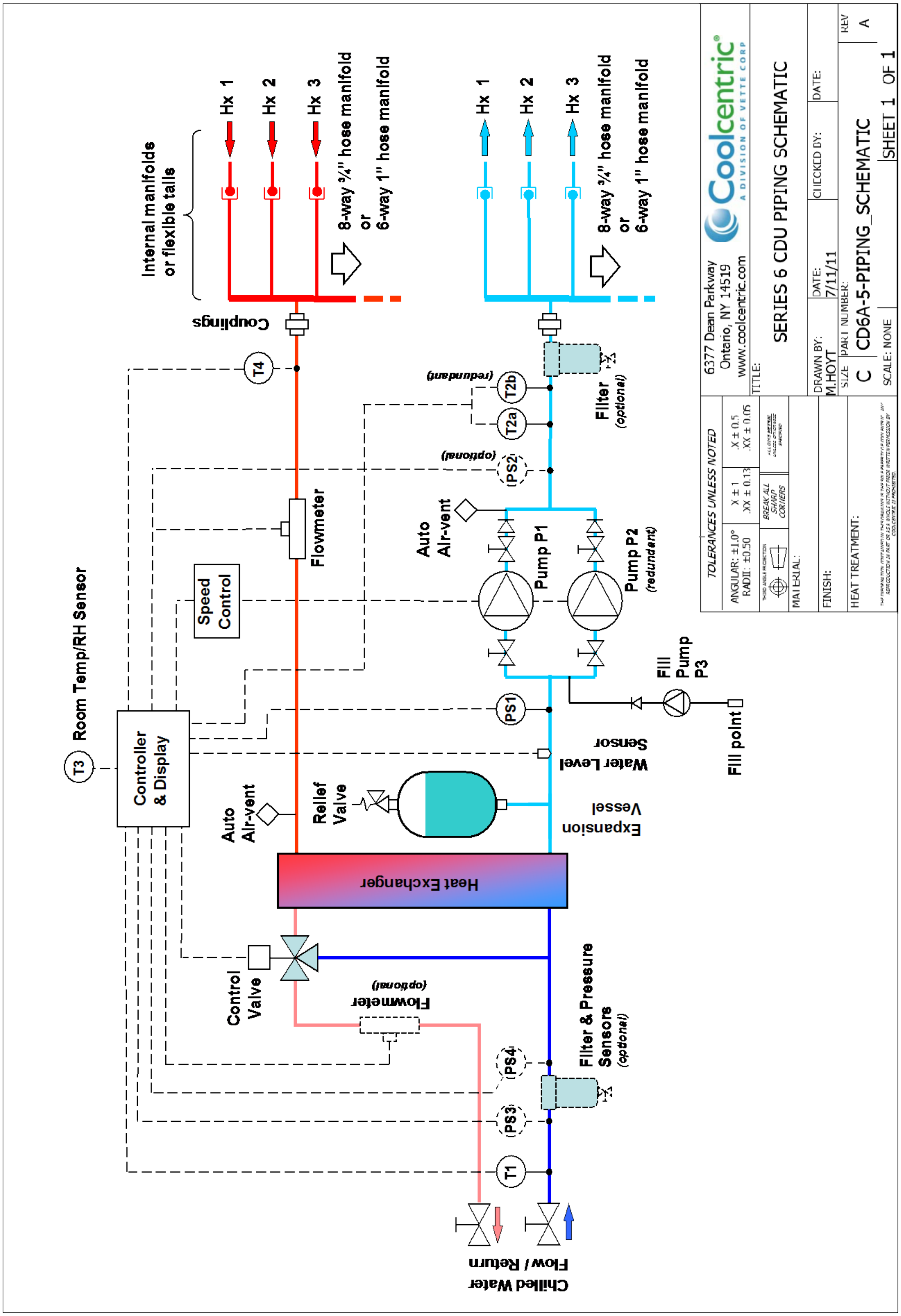


Figure 3. CDU Single Line

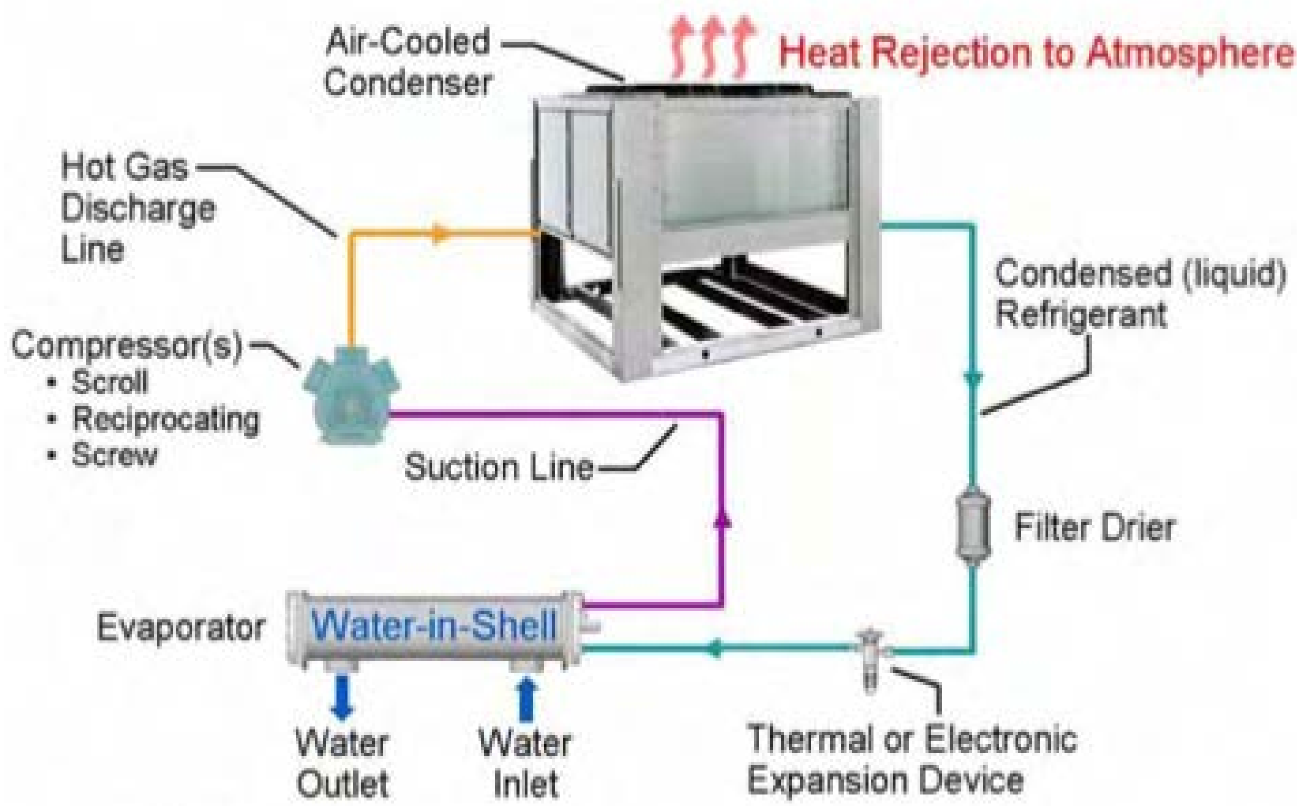


Figure 4. Air-cooled Chiller Single Line

Cooling Load and Power Consumption Calculations:

*Accounts for Initial Size of 150 racks and also scalable to 600 racks

$W_{min} = 4kw/rack$

$W_{max} = 12kw/rack$

$W_{\max cooling} = 260kW/CDU$ (max cooling capacity per CDU)

$W_{\max power} = 3.7kW/CDU$ (max power capacity per CDU)

For our CDU, the maximum cooling capacity is 260kW. Each CDU is design to cover about 19 racks at maximum capacity. Assuming each rack initially performs at 4kW, so the maximum and minimum-cooling power of each row is calculated as following:

RDHx's:

$W_{min,row} = \frac{4kw}{rack} \times 19 = 76kW/row$

$W_{max,row} = \frac{12kw}{rack} \times 19 = 228kW/row$

CDU's:

The range of percentage of the CDU usage calculated as following:

$$\% \min cooling\ power\ of\ CDU = \frac{76}{260} \times 100\% = 30\%$$

$$\% \max \text{cooling power}\ of\ CDU = \frac{228}{260} \times 100\% = 88\%$$

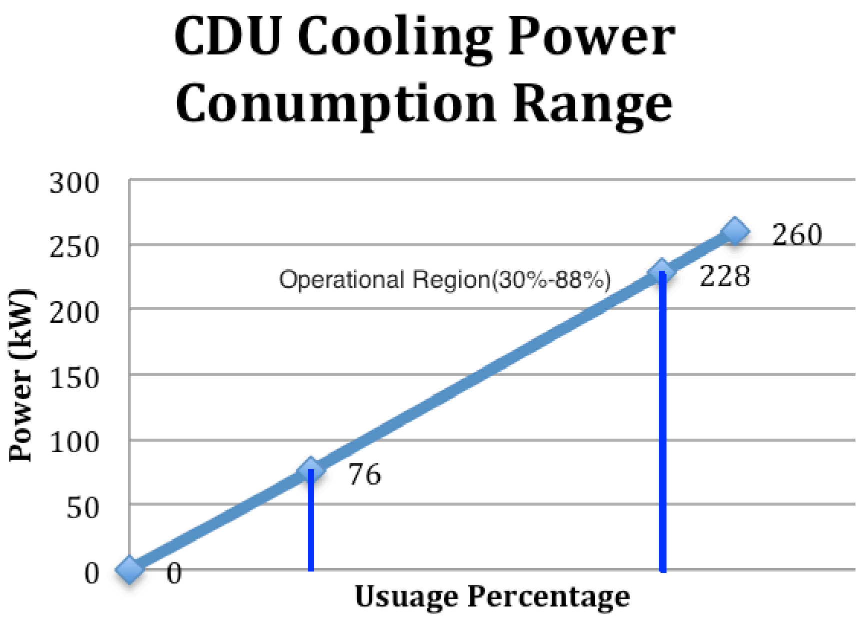


Figure 5. Power Consumption Range

For each CDU itself, it runs at 3.7 kW. Using the same percentage calculated above, the maximum and minimum of electrical power of each CDU is:

$$\% \min electrical\ power\ of\ CDU = 3.7 \times\ 30\% = 1.11\ kW$$

$$\% \max \text{electrical power}\ of\ CDU = 3.7 \times\ 88\% = 3.26\ kW$$

<u>For 8 CDU's:</u>

$$W_{8\ CDUs\ max} = 3.7kw \times 8 = 29.6\ kW$$

$$W_{8\ CDUs,30\%} = 29.6\ kW \times 30\% = 8.88\ \text{kW}$$

$$W_{8\ CDUs\ 88\%} = 29.6\ kW \times 30\% = 26.05\ kW$$

We have 8 rows of racks, each row has 19 racks, so total is 152 racks. Therefore, 8 CDU is needed for the 152 racks. So for maximum, minimum cooling power of 152 racks is calculated as following:

$$W_{min,150} \approx W_{min,152} = \frac{76kw}{row} \times 8 = 608kW$$

$$W_{max,150} \approx W_{max,152} = \frac{228kw}{row} \times 8 = 1824\ kW$$

The max CDU cooling power is calculated:

$$W_{max,8\ CDU} = 260kW \times 8 = 2080\ kW = 592\ tons(refrigeration)$$

CHILLER:

Using the number 592 tons, we decided to pick our chiller from Johnson Control. The maximum cooling power of the chiller (Model: YCIV0307P75) is 307 tons (1080 kW). We need 2 chillers to cover all the CDUs. So, total Maximum cooling power of 2 chillers is 614tons (2160 kW). Again, our operation range is from 30% to 88%. Therefore,

Cooling Capacity of the Chiller:

$$W_{max,2\ chillers} = 2362kW$$

$$W_{30\%,2\ chillers} = 2362kW \times 30\% = 708.6kW$$

$$W_{88\%,2\ chillers} = 2362kW \times 88\% = 2079kW$$

MODEL: YCIV0307S/P																								S_IPLV = 12.6		P_IPLV = 14.6	
	AIR TEMPERATURE ON - CONDENSER (°F)																										
LCWT	75			80			85			90			95			100			105			110			115		
(°F)	TONS	KW	EER	TONS	KW	EER	TONS	KW	EER	TONS	KW	EER	TONS	KW	EER	TONS	KW	EER	TONS	KW	EER	TONS	KW	EER	TONS	KW	EER
40.0	298.0	251.5	13.0	295.2	272.2	12.0	292.2	294.8	11.0	289.0	318.9	10.1	285.6	344.0	9.3	279.8	366.7	8.6	271.4	384.3	8.0	260.3	394.8	7.5	229.5	358.3	7.2
42.0	307.4	253.3	13.3	304.5	273.7	12.3	301.3	296.0	11.3	297.9	320.0	10.4	294.3	345.1	9.6	287.9	367.5	8.8	278.6	384.1	8.2	267.2	395.1	7.7	232.1	349.9	7.5
44.0	317.0	255.6	13.6	314.0	275.5	12.6	310.6	297.5	11.6	307.1	321.3	10.7	302.9	345.6	9.8	296.2	368.1	9.1	286.0	383.8	8.4	274.2	395.1	7.9	235.1	342.1	7.7
45.0	321.9	256.9	13.8	318.8	276.5	12.8	315.4	298.3	11.8	311.7	322.0	10.8	307.3	345.8	10.0	300.4	368.5	9.2	289.7	383.6	8.5	277.7	395.0	8.0	236.5	338.1	7.8
46.0	326.9	258.2	13.9	323.7	277.6	12.9	320.2	299.2	11.9	316.4	322.7	11.0	311.7	346.1	10.1	304.7	368.8	9.3	293.5	383.3	8.7	280.1	392.1	8.1	237.9	334.0	8.0
48.0	336.9	261.3	14.2	333.6	280.0	13.2	329.9	301.2	12.2	326.0	324.5	11.2	320.6	346.9	10.4	313.4	369.4	9.6	301.2	382.7	8.9	283.2	382.4	8.4	240.7	326.4	8.3
50.0	347.2	264.7	14.5	343.7	282.9	13.5	339.9	303.5	12.5	335.8	326.6	11.5	329.8	347.7	10.7	322.0	369.6	9.8	309.0	382.1	9.1	286.4	372.5	8.7	243.0	318.5	8.5
52.0	357.7	268.6	14.7	354.1	286.1	13.7	350.1	306.2	12.7	345.8	328.8	11.8	339.1	348.7	10.9	330.3	369.0	10.1	317.0	381.4	9.4	289.6	362.8	9.0	245.3	311.0	8.8
55.0	373.9	275.3	15.0	370.0	291.6	14.1	365.8	310.9	13.1	360.8	332.0	12.2	353.5	350.8	11.3	343.0	368.4	10.5	329.2	380.5	9.8	294.2	349.6	9.5	248.8	300.0	9.2

Figure 6. Johnson Controls Chiller Data

Operational power load needed for the chiller:

Efficiency rating, e

e=(power load)/(cooling load)

=Wp/Wc

e=13.3 EER

≈0.90226 kW/ton

Wp= $0.90226kW/ton \ \times 307ton$

= 277kW (total electrical power consumption for one chiller)

$W_{power,2\ chillers,max} = 554$ kW

$W_{power,2\ chillers,30\%} = 554$ kW$\times$ $30\% = 166.2kW$

$W_{power,2\ chillers,88\%} = 554$ kW$\times$ $88\% = 487.5kW$

NEGATIVE PRESSURE VENTILATION FANS

Negative pressure fans will help get rid of building heat and each fan runs at 1.1 kW and we are using 10 fans. The negative pressure fans are from Hangzhou Xin Beili Environmental Science&Technology Co. and model: XBL-138-PD

$W_{NPFans} = 1.1$ kW

$W_{Total\ fans} = 1.1$ kW$\times\ 10 = 11kW$

We will have a total of 44 negative pressure fans for the expanded data center.

WALL MOUNT AC UNIT

We will be using a SAMSUNG AQ24VBAN wall mount ac unit for the office room.

With the expanded data center we will have only 2 of these ac units.

WcoolingAC= 6.8 kW (cooling load)

Wpower= 2.6 kW (Power consumption)

YEARLY CONSUMPTION

We calculate a total power usage then multiply by it the number of days of operation, which in our case will be 365 days and 24 hours a day (8760 hours). Cost is $0.07/ kWh.

Energy=188.68 kw X 8760 h

= 1652836.8 kWh

Cost=($0.07/kWh) X 1652836.8 kWh

= $115,698.58

POWER LOAD RESULTS

	CDUs (8)	Chillers (2)	AC units	N.P. Fans	Total	Yearly Consumption ($)
150 racks 30%	8.88 kW	166.2 kW	2.6 kW	11 kW	188.68 kW	115,698.58
150 racks 88%	26.05 kW	487.5 kW	2.6 kW	11 kW	527.15 kW	323,248.38
150 racks, Max	29.6 kW	554 kW	2.6 kW	11 kW	597.20 kW	366,203.04
600 racks 30%	35.52 kW	664.8 kW	5.2 kW	44 kW	749.52 kW	459,605.66
600 racks 88%	104.2 kW	1950 kW	5.2 kW	44 kW	2103.40 kW	1,289,804.88
600 racks Max	118.4 kW	2216 kW	5.2 kW	44 kW	2383.60 kW	1,461,623.52

Table 1. Power Load Results

COOLING LOAD RESULTS

	CDUs (8)	Chillers (2)	AC units	Total
150 racks 30%	624 kW	708.6 kW	6.8 kW	1339.4 kW (381 ton)
150 racks 88%	1830.4 kW	2079 kW	6.8 kW	3916.2 kW (1114 ton)
150 racks, Max	2080 kW	2362 kW	6.8 kW	4448.8 kW (1265 ton)
600 racks 30%	2496 kW	2834.4 kW	13.6 kW	5344.0 kW (1519 ton)
600 racks 88%	7321.6 kW	8316 kW	13.6 kW	15651.0 kW (4450 ton)
600 racks Max	8320 kW	9448 kW	13.6 kW	17782.0 kW (5056 ton)

Table 2. Cooling Load Results

COMPARISON

We will be comparing 3 cooling methods that were mentioned in *Rittal White Paper 507: Understanding Data Center Cooling Energy Usage & Reduction Method* by Daniel Kennedy. The 3 methods (not including ours): Passive liquid cooled doors, CRAC cooled system with containment, and pumped refrigerant system.

Annual Cooling Energy cost Per Year Calculation	
Energy Cost kW/Hr	**$0.10**
kW of IT Load	**2000**
Tons of Cooling Required	**569**
Annual Energy Cost	
CRAC Cooled System	$1,434,101.64
CRAH Cooled System	$1,350,885.88
CRAC Cooled System W/Containment	$1,331,452.26
CRAH Cooled System W/Containment	$1,262,413.07
Liquid Cooled Racks Unoptimized	$1,179,695.60
Liquid Cooled Racks Chilled Water Temperature Optimized	$857,072.56
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	$694,428.09
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$600,548.75
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$583,008.66
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$463,417.14
Pumped Refrigerant Systems	$865,543.63
Air Side Economizing	$705,988.61
Liquid Cooled Servers	$259,114.96

Figure 7. Annual Cooling Energy Comparison

The results from table use an energy cost of $0.10 kW/h and use a total cooling load of 569 tons. We doubled the results from both power and cooling charts for 150 racks at 30% utilizing a cooling load of 381 tons. Doubling the results will get us rather close to comparing our energy cost to other methods. Our scenario will be for 300 racks at 30 % using 762 tons of cooling, and for this we also doubled the annual energy cost. Since they used a $0.10 kW/h and we used $0.07 kW/h, it will be a simple calculation to get the energy cost on the same charge factor.

Sample calculation for cost conversion of passive liquid cooled doors:

$$Cost = \$463{,}417.14 \times \frac{0.07}{0.1}$$

=$324,392

	Annual energy cost	
SYSTEMS	$0.10	$0.07
RDHx		$231,397.16
Passive Liquid Cooled Doors	$463,417.14	$324,392
CRAC Cooled System with Containment	$1,331,452.26	$932,016.58
Pumped Refrigerant System	$865,543.63	$605,880.54

Table 3. Annual Energy Cost

Even though we are utilizing a much higher cooling load, our system still functions with a much cheaper operating cost compared to the rest.

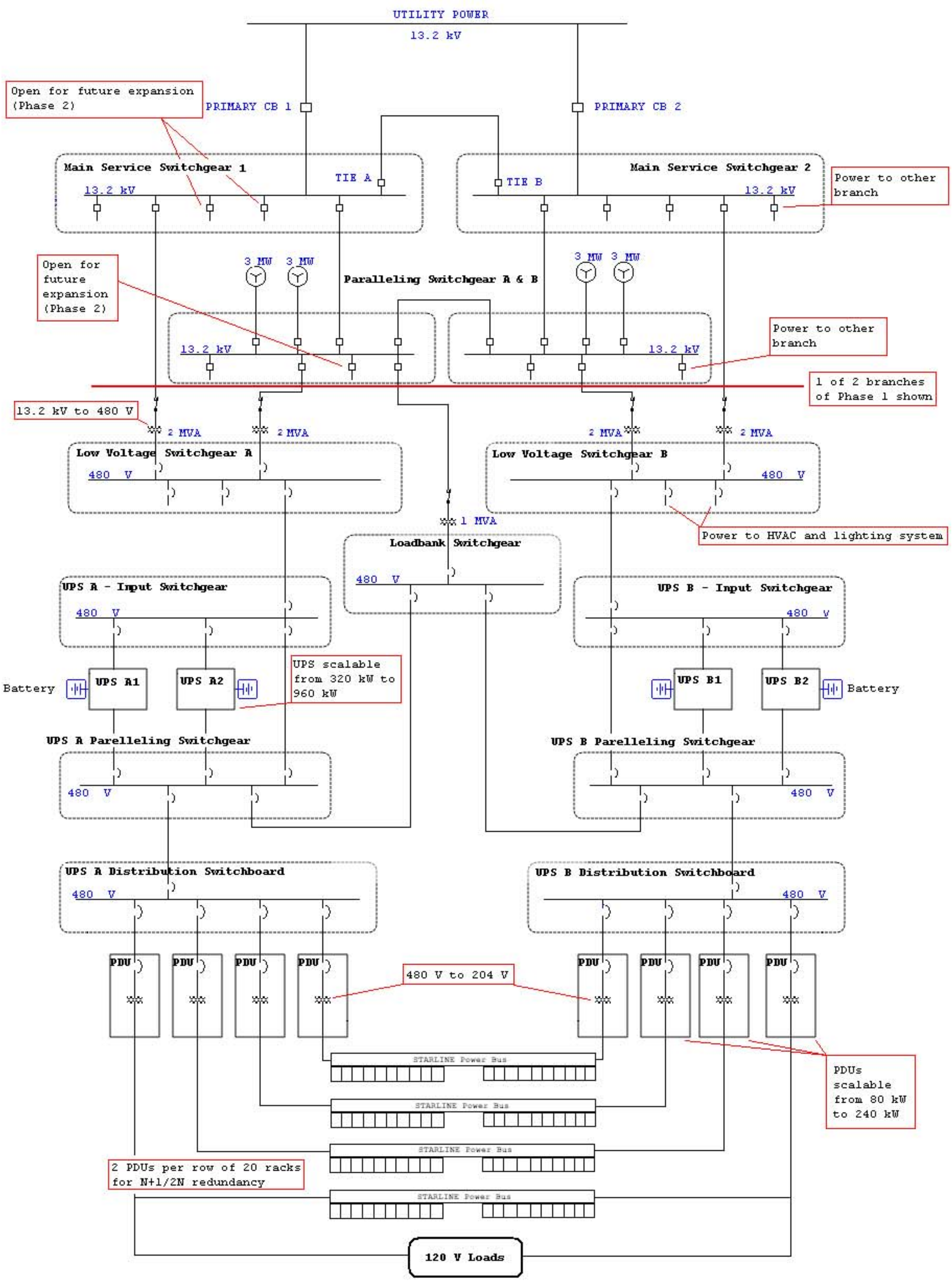
Escalating Electric Cost

Electricity cost will escalate 3% every year and the bottom table shows the results for the different Load percentages for a span of 10 years.

	Annual Energy Escalating cost ($)					
	150 racks			600 racks		
years	30%	88%	100%	30%	88%	100%
1	115,698.58	323,248.38	366,203.04	459,605.66	1,289,804.88	1,461,623.52
2	119,169.54	332,945.83	377,189.13	473,393.83	1,328,499.03	1,505,472.23
3	122,640.49	342,643.28	388,175.22	487,182.00	1,367,193.17	1,549,320.93
4	126,111.45	352,340.73	399,161.31	500,970.17	1,405,887.32	1,593,169.64
5	129,582.41	362,038.19	410,147.40	514,758.34	1,444,581.47	1,637,018.34
6	133,053.37	371,735.64	421,133.50	528,546.51	1,483,275.61	1,680,867.05
7	136,524.32	381,433.09	432,119.59	542,334.68	1,521,969.76	1,724,715.75
8	139,995.28	391,130.54	443,105.68	556,122.85	1,560,663.90	1,768,564.46
9	143,466.24	400,827.99	454,091.77	569,911.02	1,599,358.05	1,812,413.16
10	146,937.20	410,525.44	465,077.86	583,699.19	1,638,052.20	1,856,261.87

Table 4. Annual Escalating Cost

Appendix: Electrical Single Line Drawing



balanced design	BROCADE DATA CENTER	Electrical Single Line Drawing