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Corrosion Resistant Servers for Free-Air Cooling Data Centers

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Abstract

The demand for compute capability is growing rapidly fueling the ever rising consumption of power by data centers the worldwide. This growth in power consumption presents a challenge to data center total cost of ownership. Free-air cooling is one of the industrial trends in reducing power consumption, the power usage effectiveness (PUE) ratio, and the total cost of ownership (TCO). Free-air cooling is a viable approach in many parts of the world where the air is reasonably clean. In Eastern China, the poor quality of air, high in particle and gaseous contamination, is a major obstacle to free-air cooling. Servers exposed to outside air blowing in to data centers will corrode and fail at high rate. The poor reliability of hardware increase TCO dramatically.

This paper describes a corrosion resistant server design suitable for reliable operation in a free-air cooling data center located in Eastern China where the indoor air quality can be as poor as ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) severity level G3. An accelerated corrosion test method of verifying hardware reliability in the ASHRAE severity level G3 environment is also described.

Key words: Free-air cooling, total cost of ownership, data center, corrosion resistant servers.

Introduction

The demand for computing capability is growing rapidly fueling the ever rising consumption of power by data centers worldwide. In 2012, the increase in data center energy consumption in the United States and China was 800MWh and 500MWh, respectively, based on Frost & Sullivan market survey [1]. Data centers globally consume about 100 GWh each year. This consumption will increase about 30% in the next two years. The growth in power consumption presents challenge to data centers' total cost of ownership.

Lowering of power usage effectiveness (PUE) and total cost of ownership (TCO) by using free-air cooling have been demonstrated in North America and in many areas of Europe where the air is generally clean. Requirement of high air flow rates for free air cooling data centers limit its application to certain geographies, which has low air pollution and relatively low air temperatures most of year. In Eastern China, the annual average temperature is high and summer is hot and humid. Free-air cooling is more challenge under corrosive particle and sulfur-bearing gaseous contamination. So far, no successfully free-air cooling data center has ever built in Eastern China.

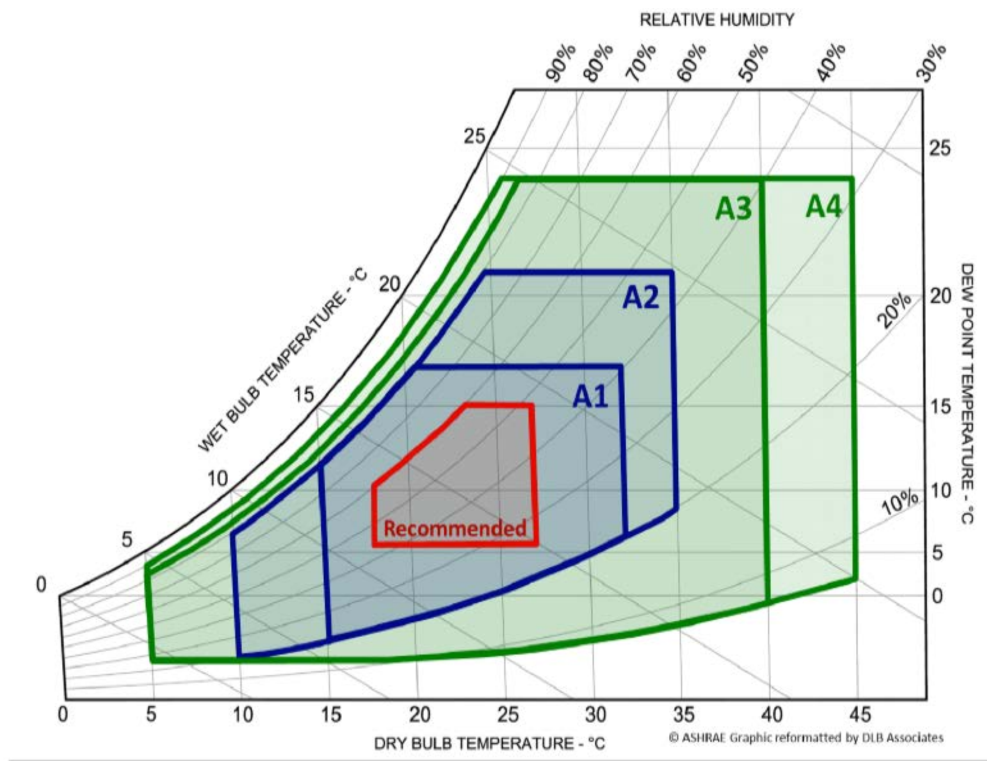

Figure 1: ASHRAE psychometric chart showing recommended and allowable temperature and humidity environmental classes.

However, the overwhelming worldwide trend of data center migrating to free-air cooling behooves us to study the risks of such a move under the Eastern China climatic conditions and to explore ways to mitigate the risks in as cost-effective a manner as is possible. The reductions in data center energy consumption and carbon emissions are too great not to pursue this exploratory endeavor.

Traditionally, data center and IT equipment designs are done in relative isolation. Data center designers are generally mechanical engineers. They focus on the maintenance of temperature and humidity, and less so on the gaseous and particulate contamination issues. IT equipment designers are mostly electrical engineers who focus on improving equipment performance and reliability and reducing cost with the understanding that the equipment will experience service conditions with ISA severity level G1 **[2]** in ASHRAE recommended class with short excursions in to allowable classes A1 to A3 **[3]**. The ISA severity level G1 refers to silver corrosion rate less than 200 angstroms/month and copper corrosion rate less than 300 angstroms/month. The ASHRAE recommended and allowable temperature and humidity ranges are defined in **Figure 1**.

Free-air cooling data center designs could include particulate and gas-phase filtration to ensure reliable operation of IT equipment in ASHRAE allowable classes A1-A3 in polluted locations such as Eastern China, but the construction and maintenance costs will be high. Or, IT equipment designs could be made corrosion resistant to operate in harsh environments, but that would drive the IT equipment cost too high. A third approach is to couple the data center design and the IT equipment design efforts. With coordinated efforts, that make the data center environments somewhat benign and the IT equipment somewhat more robust, to reach an optimized design point at which the total cost of ownership (TCO) of a free-air cooling data center is minimum.

Influence of corrosion resistant server development factors

In the feasibility study of free-air cooling, we need to address the following:

1）Benefits

2）Outdoor air quality and climate

3）Indoor and outdoor air corrosion comparison

Benefits: The benefit of free-air cooling is the lowering of the PUE, though it is not always certain that the TCO will also be lowered. We need to assess the TCO which is a sum of the initial data center infrastructure investment, initial cost of IT equipment and the cost of operating and maintaining the data center and the IT equipment including the replacement of failed parts. When a traditional data center is changed into a free-air cooled data center, the data center infrastructure investment and operating cost will be reduced, but the IT equipment initial and maintenance costs will rise. According to company experience gathered in a real-life data center situation in China, if the data center is built to allow ISA severity level G3 environment, the PUE will be lowered to 1.1. Even with the increased initial cost of making the IT equipment robust to withstand ISA severity level G3 environment, the overall TCO will be lower as shown hypothetically in Figure 2.

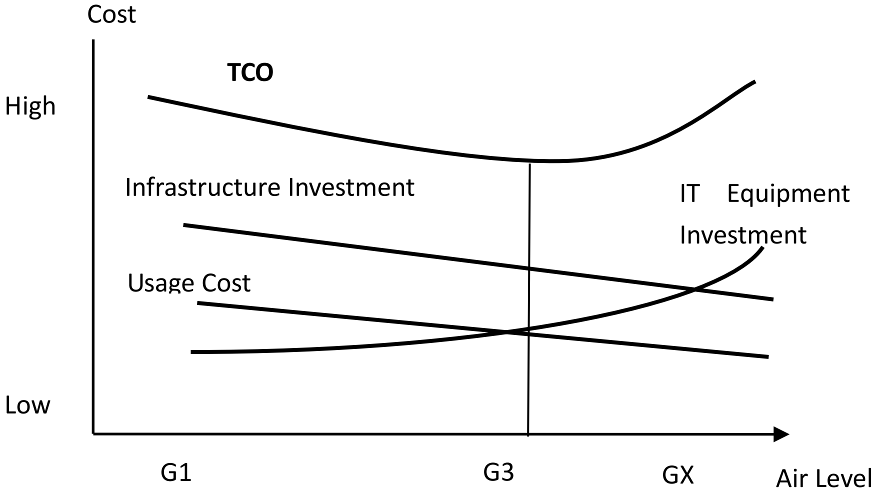

Figure2: Free-air cooled data center TCO optimization

Outdoor air quality and climate: When selecting the location for free-air cooled data centers, the climatic conditions must be considered. In accordance with the company site climate condition requirements for data centers, we selected two very different locations on the basis of temperature, humidity and gaseous and particulate contamination: (1) Guiyang in Guizhou Province in South-East China and (2) Yangquan in Shanxi Province in North-East China, shown in the map of Figure 3.

Figure 3: Guiyang in Guizhou and Yangquan in Shanxi

The typical temperature and humidity conditions at the two locations are shown in Figures 4 and 5.

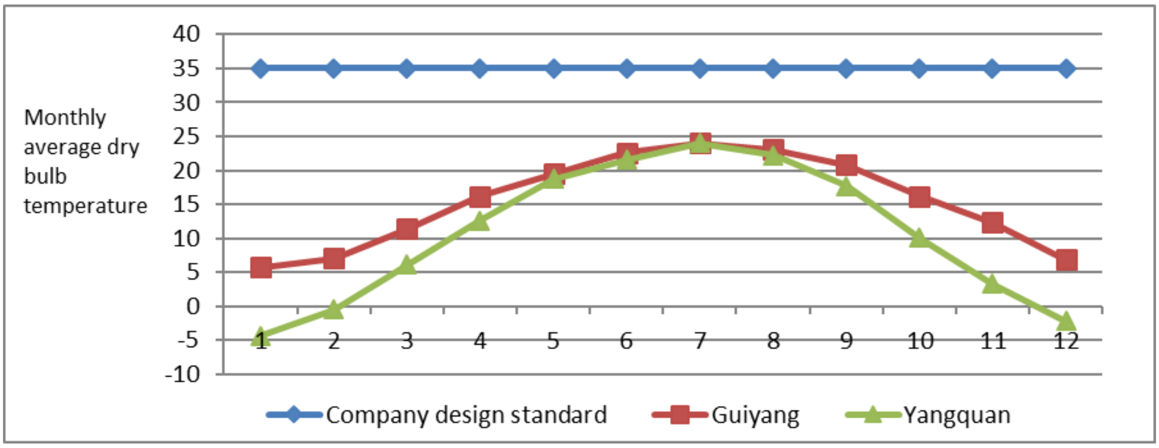

Figure 4: Locations monthly average dry bulb temperature

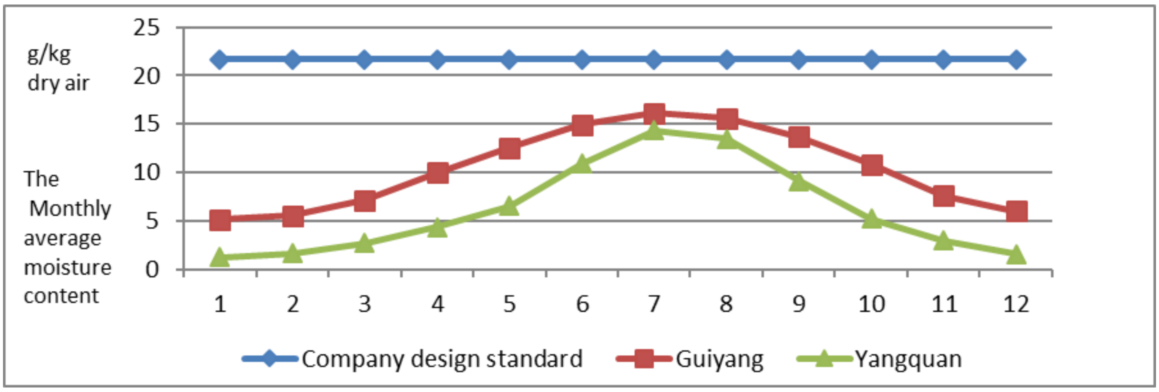

Figure 5: Locations average moisture content of the Month

Typical Locations temperature and humidity is the following in the hottest month(July):

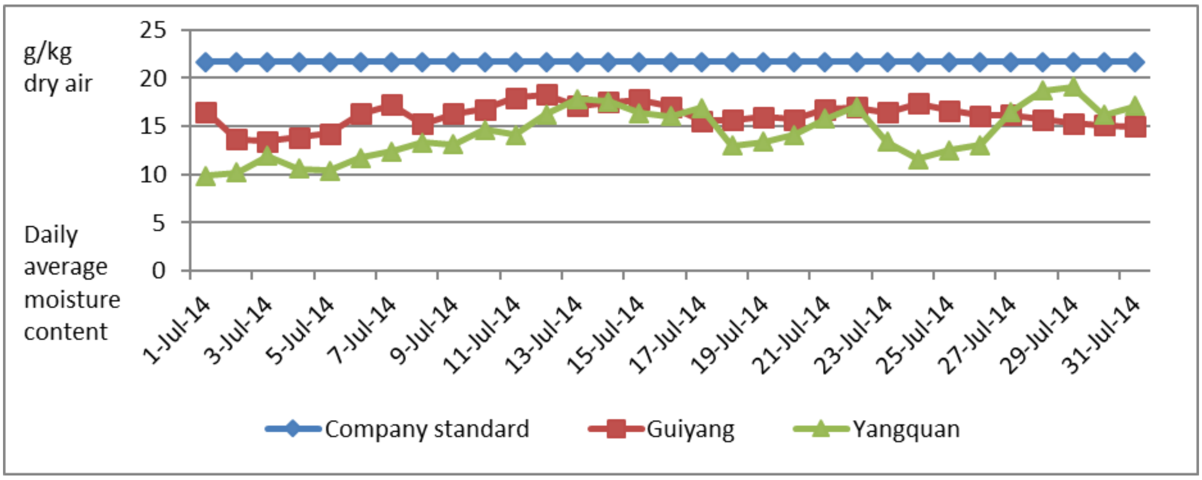

Figure 6: Locations day average moisture content in July

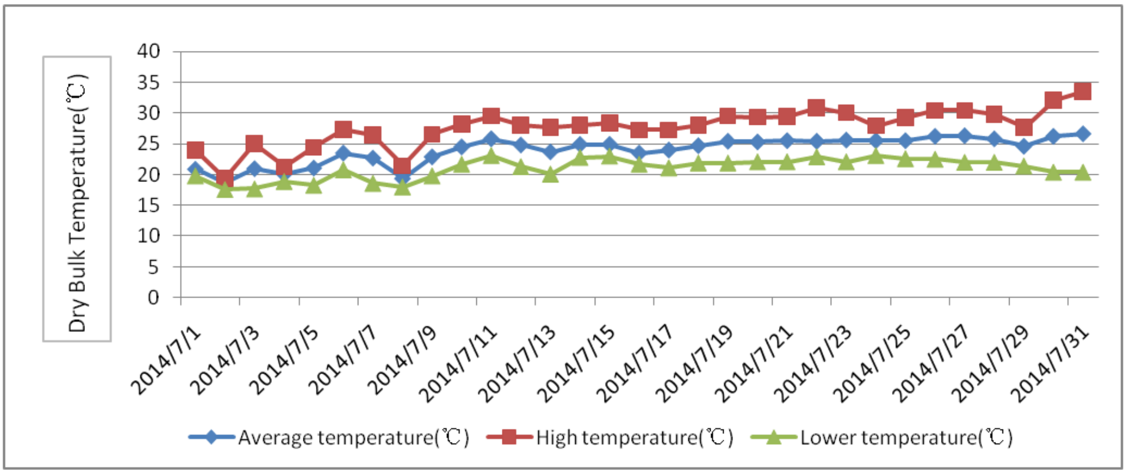

Figure 7: Guiyang Dry Bulb Temperature in July

Yangquan City, Shanxi Province, the hottest month climatic conditions are shown in Figure 8.

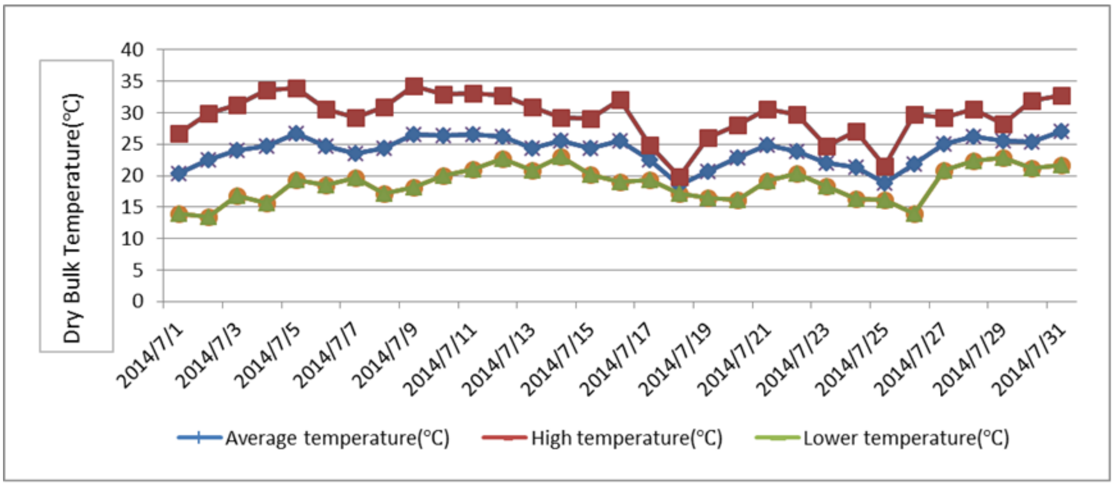

Figure 8: Yangquan dry bulb temperature in July

The Guiyan and the Yangquan temperature extremes are lower than 35℃ and the maximum moisture content of 18.3g/kg dry air are lower than 21.7g /kg.dry air, making both the locations fall within the company temperature and humidity requirements. Data centers at these two locations can be operated under free-air cooling condition year round.

Table 1 shows the officially published particulate matter and gaseous contamination at the two locations.

Table.1: The airborne particles and SO2 concentration of typical locations

Locations	PM2.5		PM10		SO_2(mm3/m3)	
	Max	Average	Max	Average	Max	Average
Guiyang	149	56.74	177	79.78	39.86	11.4
Yangquan	356	77.44	541	160.06	109.79	30.78

The pollution level in terms of both the gaseous and the particulate contamination is higher in Yangquan compared to Guiyang. Yangquan is probably amongst the most polluted cities in China. From company data center requirements, if a data center can operate reliably with low TCO in the free-air cooling mode in Yangquan, then such a data center is feasible in most of China.

Table 2 shows the effect of G4 + F7 filtration on the improvement in indoor particle continuation in a company data center in Beijing, in line with the standard room GR63 **[4].**

Table.2: Inside and outside airborne particles in Beijing

Test Sites	Max（Particle diameter＞2.5um）		Max（Particle diameter＞0.5um）	
	Outdoor	Indoor	Outdoor	Indoor
Fresh air SYSLAB	6929	109	31159	2711

Indoor and outdoor air corrosion comparison: If the specified maximum air temperature and humidity allowed into IT equipment is higher than that outdoors, the outdoor air can be directly used for cooling the IT equipment. If the IT equipment can be designed to operate reliably at higher air intake temperature, free-air cooling can be done for increased number of days in a year.

Indoor and Outdoor Air Corrosion Comparison: In heavily polluted locations, free-air cooling is possible with chemical filtration of the incoming air. Chemical filtration does have a cost penalty that needs to be considered. Particle filtration, with G4+F7 filters, must precede chemical filtration, otherwise the chemical filters will be contaminated and prematurely stop working. In addition, humidity must be controlled in the 30% to 60% RH range and temperature in the20-35 ℃ range. For cost-effective corrosion resistant IT equipment design, the relationship between indoor and outdoor air corrosivity must be known. Fortunately, the indoor air corrosivity is always much lower than for the outdoor air. Table 3 shows how much more the outdoor air corrosivity is comparted to the indoor air.

Table.3: Indoor and outdoor comparison test results of Beijing data center

Test months	**A Site outdoor**			**A Site indoor**		
	Copper coupon corrosion layer, Å	**Silver coupon corrosion layer,** Å	**Corrosion severity level**	**Copper coupon corrosion layer** Å	**Silver coupon corrosion layer** Å	**Corrosion severity level**
July 2012	GX	G3	GX	G1	G2	G2
August 2012	GX	G3	GX	G1	G2	G2
September 2012	GX	G3	GX	G1	G2	G2
October 2012	G2	G2	G2	G1	G2	G2
November 2012	G1	G3	G3	G1	G2	G2
December 2012	G1	G3	G3	G1	G2	G2
January 2013	G1	G2	G2	G1	G2	G2
March 2013	G2	G3	G3	G1	G2	G2
April 2013	G2	G2	G2	G1	G2	G2

Corrosion-resistant IT equipment design

Because of poor air quality in Eastern China in the winter and spring months and hot and humid summer, the indoor air corrosivity levels often exceed ISA severity level G1. The company has conducted many corrosion failure case studies whose results can be applied towards innovative corrosion-resistant IT equipment design.

The server corrosion-resistant design concepts have to be applied on a module by module basis：

- Hard-disc drive: HDD manufacturers should abandon immersion silver finishes and organic acid fluxes on PCBs to eliminate creep corrosion. The vias can be given the plug-tin treatment. The preferred finish and flux are organic surface preservative and rosin flux.

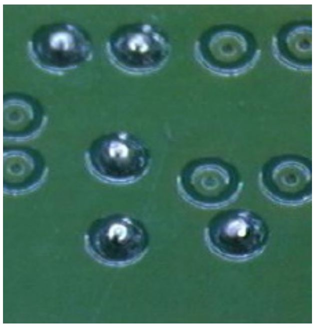

Figure 8:DIMM PCB through-hole with plug-tin treatment

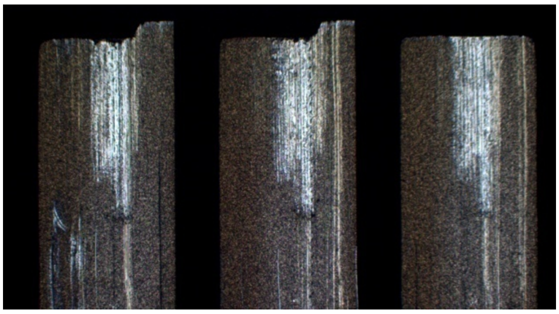	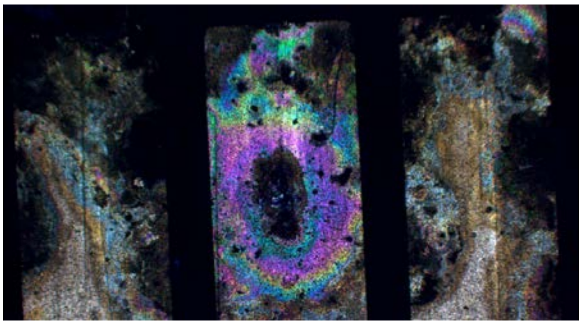
DIMM is plugged in socket	**Naked DIMM**

Figure 9: DIMM corrosion comparison

- Motherboard and PCB assemblies must not use immersion silver finishes. PCBs must be conformally coated with corrosion-resistant polyurethane. Corrosion-resistant polyurethane conformal coatings are available that have a wet film thickness of 180 and dry film thickness of 60 The spraying process operation is the following:

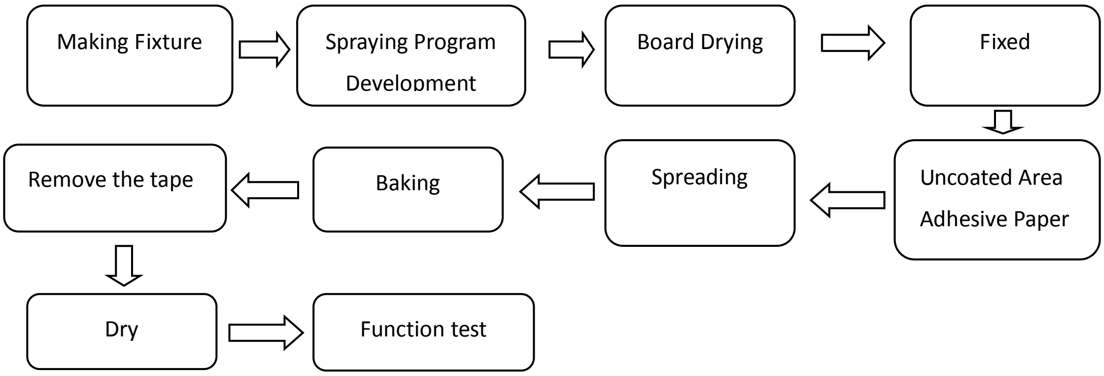

Figure10: Conformal coating process

Figure11: Corrosion-resistant conformal coating equipment

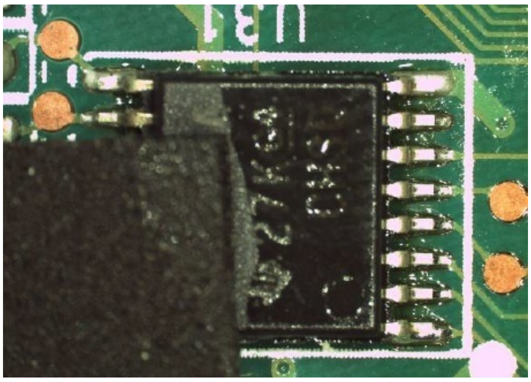

Figure 12: Accelerated corrosion test result.

- Central processor unit (CPU) contacts corroded in the accelerated corrosion life test. The CPU contact corrosion can be prevented by following the industry accepted scheme of sealing the contacts area using a rubber gasket.

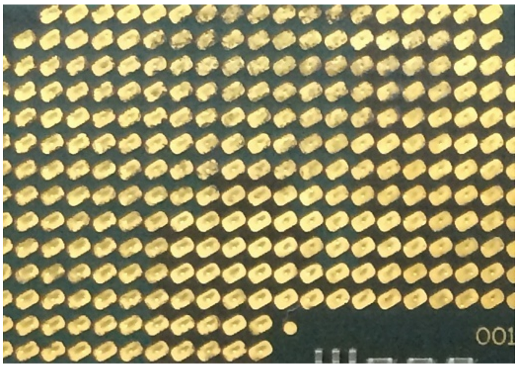

Figure 13: CPU contact corrosion.

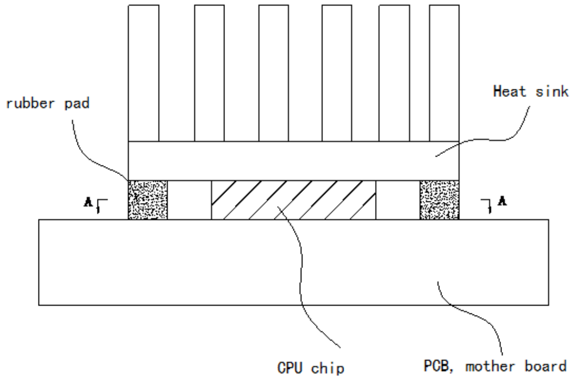

Figure 14: CPU corrosion resistant scheme.

- Power supply PCBs also need corrosion-resistant conformal coatings, while the leaving traces of sensitive devices at least 80 mm from the fan outlets.
- Exposed Ports and Jumpers: The exposed unused DIMM sockets and jumpers will be sealed using plastic caps to reduce corrosion and particulate matter buildup.
- Other external boards

According to the company corrosion accelerated life test model, the boards are tested to identify weak points, targeted improvements. PCB surface prohibits the use of Im.Ag, and the anti corrosion coating treatment is recommended.

3.3Influence of Corrosion-resistant treatment on server performance

The corrosion-resistant servers, made robust using design schemes described above, were tested to ensure proper thermal and electrical performance.

1) **Influence of Corrosion-resistant treatment on thermal performance**

The corrosion-resistant server thermal performance was tested in 35 ℃, 40 ℃, 45 ℃ environment. All the device temperatures were found to be within specifications.

Table.4 Corrosion-resistant server thermal performance test

	Test Items	Corrosion-resistant server thermal comparison test					
	Ambient	**35℃**		**40℃**		**45℃**	
		Normal Server	Corrosion-resistant server	**Normal Server**	Corrosion-resistant server	**Normal Server**	Corrosion-resistant server
BMC Readings	CPU 1 DTS Temp	58.0	59.0	61.0	63.0	66.0	67.0
	CPU 2 DTS Temp	59.0	60.0	62.0	64.0	67.0	68.0
Thermal Couple Date	BMC	61.6	64.5	65.8	65.8	69.8	70.5
	NET	58.1	62.5	62.1	66.4	66.0	70.7
	PCH	69.2	70.1	73.9	74.1	76.5	77.0
	DIMM D	51.0	50.8	54.2	54.1	58.8	58.3
	DIMM E	51.3	50.7	54.4	54.1	59.2	58.4
	CPU1VR	52.2	53.8	56.6	55.7	60.5	60.1
	CPU2VR	53.7	54.4	57.5	58.5	61.7	62.7
	HDD1 Smart	49.0	51.0	52.0	54.0	56.0	57.0
	HDD2 Smart	51.0	52.0	55.0	54.0	58.0	58.0

	HDD3 Smart	51.0	53.0	55.0	55.0	58.0	58.0
	HDD4 Smart	50.0	52.0	54.0	54.0	57.0	58.0
	HDD5 Smart	51.0	53.0	54.0	55.0	58.0	58.0
	HDD6 Smart	53.0	55.0	56.0	57.0	59.0	60.0
	HDD7 Smart	50.0	56.0	54.0	57.0	58.0	60.0
	HDD8 Smart	52.0	54.0	56.0	56.0	59.0	60.0

2) **Influence of Corrosion-resistant treatment CPU and DIMM performance**

The test results of CPU and DIMM with corrosion treatment are as follows:

Table.5 CPU Performance Comparison Test Results

Conditions	35℃			45℃		
	Before treatment	After treatment	Change values	Before treatment	After treatment	Change values
SPEC CPU2006 test						
Integer Base Rate	257	257	0	244	256	+12
Integer Peak Rate	272	272	0	266	271	+5
Floating point Base Rate	190	185	-5	169	183	+14
Floating point Peak Rate	202	197	-5	173	197	+22
Linpack test						
Matrix ScaleN, Test Result(Gflops)	82.89	82.78	-0.11	82.87	82.89	+0.07

Table.6 DIMM Performance Comparison Test Results

Conditions	35℃			45℃		
	Before treatment	After treatment	Change values	Before treatment	After treatment	Change values
Stream Test						
Single(GB/s)						
Copy	7.511	7.505	-0.006	7.607	7.502	-0.105
Scale	4.626	4.626	0.000	4.632	4.626	-0.006
Add	8.324	8.321	-0.003	8.372	8.319	-0.053
Triad	4.716	4.717	0.001	4.720	4.716	-0.004
Multi(GB/s)						
Copy	24.514	24.505	-0.009	24.551	24.519	-0.032
Scale	24.365	24.367	0.002	24.446	24.365	-0.081
Add	28.062	28.031	-0.031	28.123	28.040	-0.083
Triad	29.740	29.664	-0.076	29.785	29.689	-0.096

Corrosion treatment of the CPUs and DIMMs had no apparent effect on their performance.

3.3 Accelerated corrosion life testing

No accelerated corrosion life test standard exists that is applicable to the high pollution levels found in data centers in Eastern China. GR-63 and other standard test conditions do not cover ISA severity level G3 environment.

The approach the company took was to develop its own accelerated corrosion life test. It was found that in the polluted areas of Eastern China, copper corrodes mainly to Cu_2O and Cu0, andCu_2S, with Cu_2S being the dominant component in the corrosion product. Therefore, we considered only Cu_2S in developing the relationship between the environment severity level and the copper foil rate of weight gain. In other words, from the weight gain of copper foils we could determine the air corrosivity level. ISA G3 severity level has an upper limit of the corrosion product thickness of 2000Å/month, which, given a 3-year product life, translates to a corrosion product thickness of 72000 Å over the life of the product. The following calculations show that the upper limit of a copper foil weight gain in ISA severity level G3 environment will be 800μg/cm2. So, we need to design an accelerated corrosion test that will corrode copper such that its weight gain is 800μg/cm2 during the duration of the test.

The Cu_2S density is 5.6 g / cm3.

Copper Coupon Gain: 1μ g= $\frac{2\times63.55+32}{32}$ μ g Cu_2S

$=5\times10^{-6}$ g Cu_2S

$=\frac{5\times10-6}{5.6}$ cm^3 Cu_2S

$=0.9\times10^{-6}$ cm^3 Cu_2S

$1μg/cm^2=0.9\times10^{-6}cm=0.9\times10^{-6}\times10^8$ Å=90 Å

During the accelerated corrosion life test, assuming copper corrosion ingredient is Cu_2S, the gain weight of copper will be:

$\Delta=\frac{72000}{90}μg/cm^2=800μg/cm^2$

In order to simulate the corrosion over a three-year period in the field in ISA severity level G3 environment, company developed the accelerated life test conditions described in Table 7.

Table.7Accelerated corrosion life test conditions

Test conditions	**H_2S** (mm3/m3)	**SO_2** (mm3/m3)	**CL_2** (mm3/m3)	**NO_X** (mm3/m3)	**RH%**	**Temp** (℃)	**Days**
Value	200	750	20	1250	75	45 (p on)	12

If the equipment functions properly after being subjected to the above test environment for 12 days, and there is no significant changes in appearance of the hardware, the equipment is considered reliable for 3 years in G3 environment.

3.4 Server Accelerated Life Test

Two sets of corrosion resistant servers were tested in the accelerated corrosion life test environment for 12 days.

Table.8 Copper coupon weight gains

Sample	**Pre-test** g	**After-test** g	**Gain** mg	**Coupon Area** cm^2	**Weight gain per unit area $μg/cm^2$**
1#	4.01181	4.02793	16.12	18	895
2#	4.03162	4.04847	17.12	18	951

The copper weight gain was more than the 800μg/cm2 lower limit for the test. The corrosion resistant servers passed the test and are expected to perform reliably in the field for 3 years.

4 Summary

Reduction of TCO and PUE using free-air cooling is becoming an increasingly common practice in the USA and Europe and some other parts of the world where the outdoor air is relatively clean. Since the environment in Eastern China is much polluted to allow the straight forward use of free-air cooling, a more innovative approach involving the optimization of the IT equipment and the data center equipment design is needed. The IT equipment can be made robust against corrosive environments by conformally coating the corrosion-sensitive parts of the hardware. The improved IT equipment can be tested in an accelerated corrosion test, that has a copper corrosion rate of>800 $\mu g/cm^2$, to verify that the design improvements will result in 3-year plus reliable operation of the IT equipment in ISA 71.04-2013 severity level G3 environment.

Through additional research on the better understanding of the corrosion mechanisms in IT equipment, improved chemistries and means of applying conformal coating, accelerated corrosion testing of the improved designs and running the corrosion-resistant IT equipment in real-world polluted environments, it is hoped that we will be able to expand the use of free-air cooling in the polluted environments, even those with pollution levels as high as ISA 71.04-2013 severity level G3.

Acknowledgements

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