Providing Environmental Conditions for Electrical Rooms to Improve Component and System Reliability

Robert A. Darling
President, MI Air Systems, LLC
Atlanta, Georgia, USA

Abstract
Electrical equipment is more reliable in controlled environments. We draw from several Standards and discuss particulate and gaseous contaminants, plus address pressurization, filtration and air conditioning in one document as they all impact on the quality of the working environment. As many spaces will also be occupied by personnel either on a full or part time basis, there are also occupational health implications.

Introduction

Electrical rooms at mining and industrial installations are full of equipment that will operate far more reliably and for longer periods if the environmental conditions are good. Failure of a component or system is often not total, but intermittent. Random failures are difficult to detect and reproduce, and typically they result in more than a single part being replaced, often in error, as the failure is chased. Equipment will be more reliable if:

- The system is operating in the correct temperature and humidity range;
- The air is clean without dirt build up on components;
- The air is free of corrosive gases that cause microscopic connection failures.

Temperature impacts a chemical reaction rate and a device's ability to reject heat. The higher the temperature, the higher will be the corrosion rate and stress on a device.

Water in the form of humidity is an essential component with corrosion.

Particulates need to be removed from the air. They are a foreign body whose behavior is often unknown in the presence of electrical equipment. We will be confining this discussion to non-flammable particles and gases.

For occupational health purposes, the listed threshold limit value for total airborne dust is 10 mg/m³. [Chapter 1 of Title 30, Code of Federal Register (CFR)]. If silica is suspected, a respirable dust sample (less than 10 µm) needs to be obtained and analyzed to quantify crystalline silica content.

If crystalline silica is found above 1%, NIOSH (National Institute for Occupational Safety and Health) has a recommended exposure limit (REL) for respirable silica of 50 µg/m³ as a time weighted average for up to 10-hour day during a 40-hour week.

If corrosive gases are present, such as sulfur dioxide (SO_2) and hydrogen sulfide (H_2S), they need to be removed because they can corrode metals, especially copper and silver in an electrical room situation. This is more of a problem with RoHS lead free compliance because lead in solder is far more resistant to corrosion attack than silver.

Controlling particulates and gaseous contaminants requires filtration of both re-circulation and outside pressurization air.

ANSI and ISA Standard S71.04-1985 entitled Measurement and Control Systems: Airborne Contaminants provides Tables as guides for classifying a space with respect to particulates and corrosive gases.

TABLE 1- PARTICULATES

CLASSIFICATION OF AIRBORNE CONTAMINANTS

		SEVERITY LEVEL.CONCENTRATION MEASURED IN µG/M³			
PARTICLE SIZE	CLASS	1	2	3	X
>1mm	SA	< 1000	< 5000	< 10000	≥10000
100 µm to 1000 µm	SB	< 500	< 3000	< 5000	≥ 5000
1 µm to 100 µm	SC	< 70	< 200	< 350	≥350
< 1µm	SD	< 70	< 200	< 350	≥ 350

[Table 2, ANSI/ISA S71.04-1985, Section 5]

TABLE 2- CORROSIVE GASES

CLASSIFICATION OF REACTIVE ENVIRONMENTS

SEVERITY LEVEL		G1- MILD	G2- MODERATE	G3- HARSH	GX- SEVERE
COPPER REACTIVITY LEVEL IN ANGSTROMS		< 300	< 1000	< 2000	≥ 2000
The gas concentrations shown below are provided for reference purposes. They are believed to approximate the Copper Reactivity Levels stated above, providing the relative humidity is less than 50%. For a given gas concentration, the Severity Level (and Copper Reactivity Level) can be expected to be increased by one level for each 10% increase in relative humidity above 50% or for a relative humidity rate of change of greater than 6% per hour.					
	GAS CONCENTRATION				
CONTAMINANT	GAS	CONCENTRATION, PARTS PER BILLION			
GROUP A	H2S	< 3	< 10	< 50	≥50
	SO2, SO3	< 10	< 100	< 300	≥300
	Cl2	< 1	< 2	< 10	≥10
	NOx	< 50	< 125	< 1250	≥1250
GROUP B	HF	< 1	< 2	< 10	≥10
	NH3	< 500	< 10000	< 25000	≥ 25000
	O3	< 2	< 25	< 100	≥100

[Table 3, ANSI/ISA S71.04-1985, Section 6]

The significance of the Classifications by the Standard are:

G1- Mild, Corrosion is not a factor in determining equipment reliability.

G2- Moderate- The effects of corrosion will be measurable and could be a factor in determining equipment reliability.

G3- Harsh- An environment where there is a high probability that corrosion attack will occur.

GX- Severe- An environment that only specially designed and packaged equipment could survive.

Air Conditioning

The American National Standards Association (ANSI) and Instrument Society of America (ISA) share a Standard ISA S71.01-1985 entitled Process Measurement and Control Systems: Temperature and Humidity. It establishes "Uniform classifications of temperature and humidity conditions for industrial process management and control systems".

These are listed in the extract from this Standard in Table 3.

TABLE 3- AIRCONDITIONING

LOCATION, CLASS AND SEVERITY LEVELS (EXTRACT)

LOCATION	CLASS	SEVERITY LEVEL	TEMP. LIMITS (°C)	CONTROL POINT TOLERANCE (°C)	MAX. RATE OF CHANGE (°C/HR)	HUMIDITY LIMITS (%RH)	CONTROL POINT TOLERANCE (%RH)	MAX. MOISTURE CONTENT (KG/KG DRY AIR)
AIR CONDITIONED	A	1	18-27	+/- 2	+/- 5	35-75	+/- 5	N.A.
		2	18-27	+/- 2	+/- 5	20-80	+/- 10	N.A.
		X	T.B.S.	T.B.S.	T.B.S.	T.B.S.	T.B.S.	T.B.S.
ENCLOSURE TEMPERATURE CONTROLLED	B	1	15-30	+/- 2	+/- 5	10-75	N.A.	N.A.
		2	5-40	+/- 3	+/- 10	10-75	N.A.	0.020
		3	5-40	+/- 10	+/- 20	5-90	N.A.	0.028
		4	5-50	+/- 10	+/- 20	5-90	N.A.	0.028
		X	T.B.S.	T.B.S.	T.B.S.	T.B.S.	N.A.	T.B.S.

N.A. – Not applicable
T.B.S.- To be specified

[Extract Table 1, ANSI/ISA S71.01-1985, Section 5]

There are user defined Severity Levels "X" that may be selected within the Classes that allow other tolerances and ranges to be selected, as long as they are within the ranges. For example AX would be a space with temperature and humidity controls with tighter limits.

Typically if an air conditioner is sized properly, and not located in a desert situation, the room will be a B1 by definition but an A1 by functionality. Humidity will be controlled well within the humidity limits as set out in Table 1 of the Standard.

Our recommendations for air conditioning include:

i. Size for the load, and not oversize so humidity control will be better;
ii. Mount the air handler inside the space to eliminate external ducting that can draw in contaminants;
iii. Integrate upgraded return air filtration into the air handler;
iv. Have staged cooling and heating to reduce cycling and maintain less fluctuations in temperature and humidity;
v. Either use water cooled condensers if treated water is available, or external fan forced devices. These should be configured to suit the situation. For example, head pressure control, pulse cleaning of coil in severe dust situations;
vi. Eliminate economizer function unless air comes through a filtration system to suit the site goals.
vii. Establish a Class BX with Temperature Limits 18-27°C, Control Point Tolerance +/- 2°C, Max rate of change +/- 5°C/hr, Maximum moisture content 0.012 kg/kg dry air, 2 stage cooling as a minimum.

Pressurization

A space will require some form of positive pressurization. This assists in reducing the ingress of outside contaminants because most leakage is "out".

It is a common approach to try and control indoor air quality by pressurization. The theory is that all air entering the space comes through a treatment device and achieves a certain standard. By dilution, the room will eventually be cleaned. In a real world situation, we are typically dealing with a room where people are coming and going with doors opening and closing.

What is an acceptable level of pressurization?

There are several Standards including ANSI/IEST/ISO Standard 14644-4 that recommend positive pressurization levels in the 10-20 Pa area between spaces.

NIOSH have done tests to determine what positive pressure is required inside an enclosure to prevent wind driven particulates from entering the space. The results are very significant and they question the validity of a 10-20 Pa figure. Essentially the amount of positive pressure required inside a space is 10 Pa at 12 km/hr; 50 Pa at 32 km/hr and 100 Pa at 48 km/hr. [CDC-NIOSH Dust Control Handbook for Industrial Minerals Mining and Processing- RI 9689, 2012, Chapter 9, Fig. 9.3 page 231 and Equation 9.3, page 230].

The conclusion is that pressurization to 20 Pa probably will not be adequate to prevent contaminants from being driven into the space by wind.

We will be making two recommendations as far as sizing pressurization systems- one for particulates if they are the prime concern, and the other for corrosive gases. The logic is very simple. With particulates, the system removal efficiency typically increases over time as filters become loaded. With corrosive gases, the removal efficiency decreases over time as media becomes spent and sporadic breakthrough can occur with challenge spikes.

Breakthrough of corrosive gases can be very harmful for an electrical room, especially if the quality is only being managed with a pressurization system.

If **particulates** are the problem, our recommendations are to satisfy Severity Level 1 by Table 1. This would involve:

i. A design figure of at least 5% of the room volume per minute be used for flow sizing. If the room does not achieve at least 10-15 Pa, it should be sealed;
ii. Add heating if ambient air is likely to fall below 2-4°C if the air is introduced directly to a space and people are likely to be present;
iii. Evaluate whether the dust loading is severe and reverse air pulse cleaning is justified;
iv. Use variable speed fan controls to maintain a set pressure, rather than a set volume of outside air.
v. Ideally install monitoring equipment in critical situations that can alert to a breach of filter integrity with supply air particulate monitors.

If **corrosive gases** are the problem, our recommendations are to satisfy Severity Level G1 by Table 2- Corrosive Gases. This would involve:

i. 1 to 2% of the room volume per minute for closed or light traffic rooms;
ii. 2 to 3% of the room volume per minute for traffic areas;
vi. Add heating upstream of intake filters if ambient air is likely to fall below 5°C to improve chemical reaction efficiency;

iii. Design media bed life to exceed 12 months service life with full removal capacity, and if contaminant levels are know a figure of 15 months should be the design target;
iv. Use variable speed fan controls to maintain a set pressure, rather than a set volume of outside air.
v. Monitor the space for compliance to a Standard such as ISA S71.04-1985 either with periodic coupon testing or real time monitoring.

Note: we are assuming that the spaces are typically fairly large and the ventilation rate exceeds that listed in ANSI/ASHRAE Standard 62.1-2010: Ventilation for Acceptable Indoor Air Quality. The actual figures can be found in Table 6-1 of this Standard. Figures of around 12 l/s or 25 cfm per person will satisfy this Standard.

Re-circulation Filtration

Cleaning a space is like removing the dark color from a glass of liquid. Removing the color with pressurization alone requires adding a clear liquid until the color clears. This will eventually happen, but in practice, every time a door is opened, more contaminants are introduced. The contaminants are typically coming from outside.

It is logical that cleaning a space with pressurization alone requires a lot of air to be filtered, cleaned, conditioned- and then thrown away! It is an expensive process.

We are recommending more emphasis be placed on re-circulation filtration because it is more effective than pressurization and the lowest cost in energy and materials.

NIOSH have developed a Model for determining an "Enclosure Protection Factor" [CDC-NIOSH Dust Control Handbook for Industrial Minerals Mining and Processing- RI 9689, 2012, Chapter 9, page 229, Equation 9.2].

To emphasize this concept, we will quantify how much material is contained in a contaminated space, and how much material has to be removed if we were to use pressurization alone.

For example, take a space that is 30 m long x 10 m wide x 7 m high = 2,100 m^3. Assume it is at ambient saturation of firstly 2 ppm H2S for a chemical situation, and 10 mg/m^3 of particulates for a mine.

Assume pressurization in both cases of 10% of the space volume per minute, which is often promoted as a standard flow in this application.

If we firstly investigate the gas phase situation, the conversion of ppm of H_2S to mg/m^3 is a factor of 1.4. [NIOSH Pocket Guide to Hazardous Chemicals, Chemical 337- H2S, MW 34.1]. So 2 ppm is 2.8 mg/m^3, and with 2,100 m^3 there would be 5.89 g (grams) of H_2S dispersed in the space.

If the room is pressurized with 10% of the space volume per minute, the amount of H_2S removed in a day would be:

60 minutes x 24 hours x 210 m^3/min x 2.8 mg/m^3 x 1/1000 = 846 g/day (1)

If we investigate the particulate side, the space will have 21 g of particulate suspended in the air. (2100 m^3 x 10 mg/m^3).

Pressurization at the rate of 10% of the room volume will result in:

60 minutes x 24 hours x 210 m^3/min x 10 mg/m^3 x 1/1000 = 3024 g/day (2)

Add the cost of conditioning air to gas phase media and filter consumption, this is clearly an expensive way to clean the space. The ratio requires removing 144 times the amount of contaminant per day than what is in there initially, assuming that the contaminant is actually being managed.

Our recommendations for re-circulation filtration are:

i. 3-5% of the room volume per minute for closed or light traffic rooms;
ii. 5-10% of the room volume per minute for traffic areas;
iii. Design gas phase media life to exceed 12 months based on the lowest range of G3 contaminant levels of Table 2- Corrosive Gases. This "should" provide adequate media and cover synergistic surprises with other gases and temperature and humidity fluctuations;
iv. Particulate filtration efficiency to be at least MERV 11, ideally MERV 14;
v. Ideally integrated into an internally mounted climate control unit;

Modeling Examples

We have taken the room used in the above example and applied various criteria to demonstrate the model.

The model is dimensionless and we are taking an outside concentration of 100 "units". We are demonstrating the "Protection Factor", which is the ratio of outside concentration to inside.

TABLE 4 PRESSURIZATION ONLY

VARIABLE	DESCRIPTION	VALUE
Co	outside air contaminant concentration, units	100
QI	intake air quantity into room, l/s	3500
ηI	intake filter efficiency %	95
QL	air leakage around intake filter, l/s	35.00
QR	recirculation filter airflow, l/s	0
ηR	recirculation filter efficiency, %	95
QW	wind quantity infiltration into room, l/s	0.00
RESULT		
Pen	ratio of outside contamination to inside	0.06
Ci	inside air contaminant concentration, units	6
PF	Protection factor, Co/Ci	17
	INPUT TABLE	
	Space volume, m3	2100
	Pressurization air, % volume per minute	10
	Re-circulation air, % volume per minute	0
	Wind entrance, % volume per minute	0
	Filter bypass, % outside air per minute	1

This demonstrates that with an outside air concentration of "100", 10% pressurization through a filtration system that removes 95% of contaminants, and a filter bypass of 1% (doors opening etc.) the inside level should achieve a level of 6 units, and be 17 times cleaner than the outside.

TABLE 5- PRESSURIZATION AND RE-CIRCULATION

VARIABLE	DESCRIPTION	VALUE
Co	outside air contaminant concentration, units	100
QI	intake air quantity into room, l/s	700
ηI	intake filter efficiency %	95
QL	air leakage around intake filter, l/s	7.00
QR	recirculation filter airflow, l/s	1750
ηR	recirculation filter efficiency, %	70
QW	wind quantity infiltration into room, l/s	3.50
RESULT		
Pen	ratio of outside contamination to inside	0.02
Ci	inside air contaminant concentration, units	2.3
PF	Protection factor, Co/Ci	43
	INPUT DATA	
	Space volume, m3	2100
	Pressurization air, % volume per minute	2
	Re-circulation air, % volume per minute	5
	Wind entrance, % volume per minute	0.5
	Filter bypass, % outside air per minute	1

This is for a light traffic area with 2% and 5% of the room volume per minute for pressurization and re-circulation respectively. Intake filter efficiency remains at 95%, the recirculation efficiency is only 70% and we have added 0.5% of the room volume for wind leakage (unfiltered) and we have used the same amount for filter bypass/doors etc.

The inside concentration reduces to 2 units, and the protection factor rises from 17 to 43. By doubling the re-circulation rate from 5 to 10% of the room volume per minute and keeping all other factors the same the protection factor increases to 70.

If this example is fitted with higher efficiency MERV 14 filters, the protection factors increase from 43 to 50 and from 70 to 85 for the 5 and 10% recirculation factors respectively.

Conclusions

There are many factors that determine the suitability of an environment for electrical equipment. It is necessary to treat the total air "condition" in order to improve the operating conditions for electrical systems. This includes temperature, humidity and airborne contaminants.

Clean air will also have occupational health and safety benefits as most dust, particularly at mine sites, could be toxic. Dust buildup must be reduced for safety reasons as this dust could be toxic.

The math indicates greater emphasis on the re-circulation system, and it also has financial benefits because it can reduce costs with smaller size of climate control equipment and lower filtration costs in fan power and consumption of materials.

References

ANSI and ISA Standard S71.04-1985, "Measurement and Control Systems: Airborne Contaminants".

- Table 3, Section 6
- Table 2, Section 5

ANSI and ISA Standard S71.01-1985, "Measurement and Control Systems: Temperature and Humidity".

- Extract Table 1, Section 5

ANSI/ASHRAE Standard 62.1-2010, "Ventilation for Acceptable Indoor Air Quality". Table 6.1

ANSI/IEST/ISO Standard 14644-4, "Cleanrooms and associated controlled environments- Part 4: Design, construction and start-up". A.5.3 Pressure differential concept.

ASHRAE Handbook- HVAC Applications, 2011, Chapter 18, "Clean Spaces", Section Environmental Systems, sub section Pressurization, page 18.16.

Cecala, A.B., O'Brien, O.D., Schall, J., Colinet, J.F., Fox, W.R., Franta, R.J., Reed, R., Reeser, P.W., Rounds, J.R., Schultz, M.J., 2012 "Dust Control Handbook for Industrial Minerals Mining and Processing". Report of Investigations 9689, 2012.

- Introduction, Page 2;
- Chapter 9, Fig. 9.3 page 231 and Equation 9.3, page 230;

National Institute for Occupational Safety and Health (NIOSH), "Pocket Guide to Hazardous Chemicals"

- Chemical 337- Hydrogen sulfide (H2S)
- Chemical 553- Crystalline silica (as respirable dust)

Mine safety and Health Administration (MSHA), "30 CFR", www.MSHA.gov/30cfr/CFRINTRO.HTM