

Hydrogen Outgassing, Electrical Consumption and the Myriad Code Requirements Much Venting Over The Need For Ventilation

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Abstract / Digest

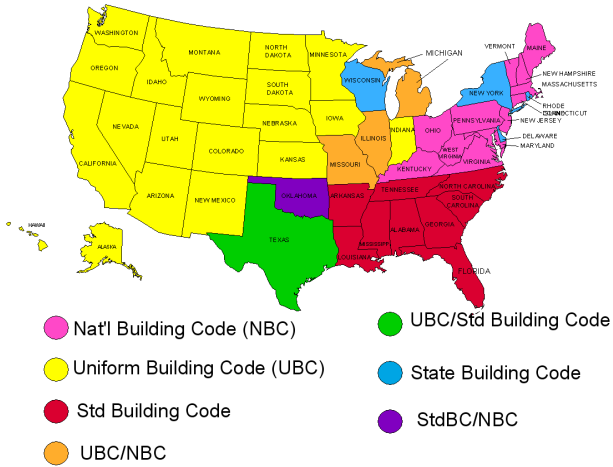
There appears a level of consternation swirling about of late that is rooted in varying interpretations by Authorities Having Jurisdiction (AHJ) such as building inspectors, electrical inspectors and so on regarding international building codes now that they have been adopted over national codes in many US jurisdictions. The intention of this paper is to identify the international codes covering hydrogen evolution in stationary battery strings and compare them with national codes, IEEE practices, Telephone company best practices and practical experience. Conclusions to be drawn will identify perhaps a need for soundly reasoned input to the next international code cycle and a reiteration of best practices for stationary battery installations.

First and foremost, the telecommunications and data center industries have an excellent reputation for safety and that includes its handling of hydrogen evolved from battery cells. In more than a century of operation of greater than a hundred thousand battery installations nationally, one could count on his or her fingers the number of hydrogen related explosions that caused damage to a facility and none of those resulted in injury. Even battery jar explosions are quite rare.

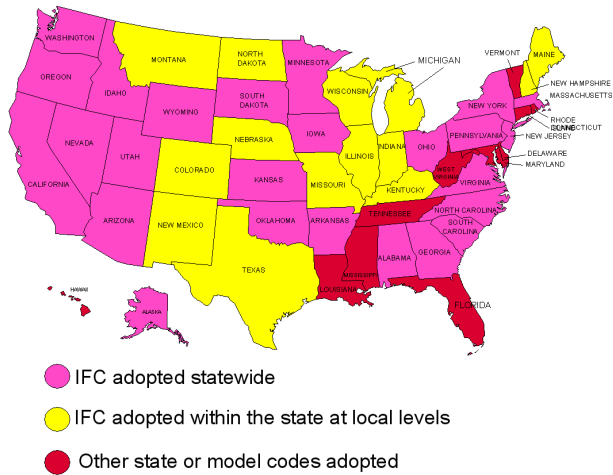
In part, many of the issues at hand are related to the wide deployment of Valve Regulated lead Acid batteries (VRLA) because these cells typically outgas only about 5% of hydrogen volumes as their vented (AKA flooded) counterparts. As written, however, the codes specify that ventilation must limit hydrogen accumulations that might result during worst case conditions, typically an overcharge condition or thermal runaway state when little or no gas recombination is occurring. This requirement causes grief in some instances because in the case of continuous ventilation it flies in the face of energy conservation. To provide ventilation for the worst case battery condition is effective only in unconditioned spaces. However, if the area being ventilated is conditioned space, potentially large volumes of expensively cooled air are being pushed outdoors, thus raising the cooling cost and the carbon footprint for the facility.

An exaggerated model of the problem is seen in the shops and stores in Disney World where customer sales floors are heavily air conditioned but the doors are either wide open or there are no doors at all. The scheme works well for tourist impulse buying but from an energy viewpoint it's wasteful. Another approach is the use of an exhaust fan or purge ventilation, under the control of hydrogen sensors; but experience has shown that most such installations are problematic due to wide variance in sensor product quality, miscalibration or delayed calibration and prolific installation errors. Nothing in the fire codes, nor IEEE 450 and IEEE 1187, the industry standard for Vented (also called 'flooded') cells and Valve Regulated Lead Acid, (VRLA) cells require hydrogen detectors, however many AHJs insist upon them. As a practical matter, natural 'pockets' often form in crowded ceiling spaces and hydrogen will rise towards and accumulate in those pockets. The stratification principle is the same whether the space is in a telecommunications facility accumulating hydrogen or a coal mine accumulating pockets of methane. About the only difference is that in a coal mine, a serious explosion generally is a result of two or more sequential explosions. Usually the first explosion is a pocket of methane and a collateral effect of that event is to push a blast wave through the mine shafts blowing up billowing clouds of coal dust which in turn becomes a secondary, usually more powerful explosion or series of them. In either case, whether the side is coming off a cabinet, the roof is coming off a battery room or a mine shaft is blowing apart, the triggering event was an ignition source finding a pocket of gas that had reached its lower explosive limit. Accordingly, the overall site design must address sufficient airflow to prevent the formation of stratification pockets of hydrogen.

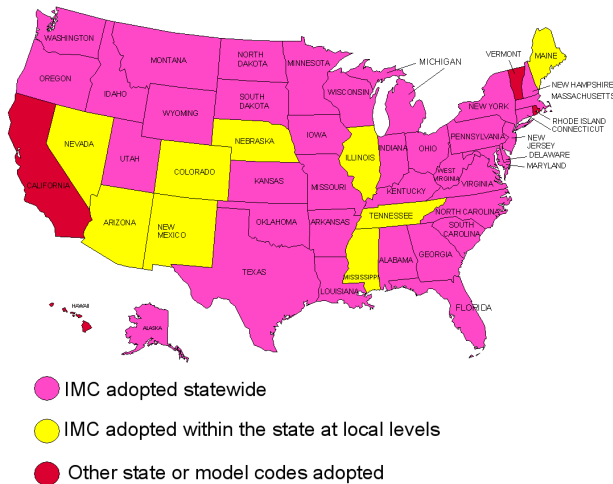
Until recently, three model building codes were adopted across the US as is shown on Map 1. The Uniform Building Code (UBC) was adopted over most of the western US, the National Building Code (NBC) covered the northeast and the Standard Building Code (SBC) covered the southeast. In some jurisdictions, a mix and match of codes were adopted by local AHJs within the state.



MAP 1 depicts legacy code adoption in the US.



Map 2 depicts International Fire Code (IFC) adoption across the US as of November 2009



Map 3 depicts the International Mechanical Code (IMC) adoption across the US as of Sept 2008.

I. INTERNATIONAL MECHANICAL CODE (IMC)

Section 502.4 of the International Mechanical Code speaks to stationary battery systems regulated by Section 608 of the International Fire Code and specifies compliance with Sections 502.4.1 or 502.4.2 of the IMC.

Section 502.4.1 specifies that the ventilation system design must limit the maximum amount of hydrogen accumulation to something less than 1% of total room volume. Section 502.4.2 specifies continuous ventilation at a rate of at least 1 cubic foot per minute per square foot (cfm/ft²) [0.00508 m³/(s • m²)] of floor area within the room.

These requirements apply to vented cells, VRLA cells and nickel cadmium cells. Because non-aqueous battery technologies do not produce hydrogen, Lithium-based cell technologies are exempt from ventilation requirements. These codes also specify requirements for cabinetized systems, however, these are not addressed herein because battery cabinets generally do not employ refrigeration HVAC systems and the burning issue addressed herein is wasted energy.

From the perspective of energy conservation the continuous ventilation requirement of Section 502.4.2 is the least favorable option for most battery rooms, precast shelters and other spaces because conditioned air is lost in the process. In a typical shelter type cell site, the interior dimensions of the room used for batteries and equipment is approximately 12 by 20 feet (3.66m X 6.1m) and so using the proscribed rate of continuous ventilation would result in 240 cfm or more of exhaust airflow. Using the ASHRAE standard requirement for 0.5 air change per hour, a room with those same dimensions needs 18 cfm for human occupation, and usually is more than enough airflow for battery ventilation under most conditions. Accordingly, following the IMC proscribed continuous ventilation formula for cell sites and similar small rooms, results in more than thirteen times the rate of ventilation that would be needed otherwise. Over time this level of ventilation adds a significant operating cost. Among the various cellular carriers there are more than a hundred thousand shelter type cell and microwave sites in the US.

From an environmental perspective, if refrigeration-based HVAC is necessary, it follows that continuous ventilation to the levels specified in the International Mechanical Code is deleterious to the carbon footprint. Obviously, the industry needs more and better vetted solutions. In North America there is enough diversity in regional climates that no one solution is going to suit all areas and so a more pragmatic approach would be to establish a handful of 'niche' applications.

For example, in areas with cool or moderate year round temperatures perhaps copious ventilation without refrigeration is an appropriate remedy. Many newer radio systems are thermally hardened and therefore able to bear the heat of local climates but carriers get concerned that the battery will be overheating for a decreased service life and so the battery guy casts the tie-breaking vote on whether or not to refrigerate.

For applications that fall into this realm, perhaps nickel cadmium cells should be considered as that technology is more tolerant of warm environments. Typically, for each 8 decreed centigrade rise above 25 degrees (15F above 77F) a VRLA battery suffers a half-life. Therefore, a VRLA with an anticipated 10 year service life will require replacement at:

Replace VRLA battery at:		
Temp C	Temp F	
33	92	5 Years (half life)
41	106	2.5 Years (1/4 life)
49	120	1.25 Years (1/8 life)
57	134	1.25 Years (1/16 life)
		8 Months (1/32 life)
Higher		Why bother?

Conversely, a 10 year design life NiCad battery operated in the same temperature conditions

Replace NiCad battery at:		
Temp C	Temp F	
33	92	8 Years
41	106	6 Years
49	120	4 Years
57	134	2 Years

While the material cost of NiCad batteries is higher than Lead Acid, offsets in cooling costs and lifecycle costs could make NiCad the winner in these applications.

Not all sites or systems are thermally hardened however and so another possibility is placing a battery cabinet outside the equipment shelter so that it could be ventilated to whatever degree necessary without impinging on the cost of cooling systems housed within the shelter. There are a variety of cabinets made by a number of industry established vendors. Since many shelters have HVAC units cantilevered on the side of the shelter, one approach might be to 'hang' a battery cabinet on another side or perhaps place it below the waveguide entry hatch.



Figure 1 a NiCad battery used in a shelter application permits operation without refrigeration based HVAC, therefore cooling cost is reduced and ventilation is increased

Below the waveguide hatch with the battery cabinet close to the shelter wall it becomes more difficult for copper thieves to steal the wiring between the hatch and the buried ground (Earthing) ring. Further, from a leasing perspective, the real estate below the ice bridge typically is leased by the shelter owner and so that patch of soil already is bought and paid for. Exterior cabinetry used for batteries or other subsystems should meet all requirements of Telcordia GR-487 and if attached to the shelter wall, be in harmony with the shelter manufacturer's design and Telcordia GR-43.

Besides having battery ventilation that doesn't affect radio equipment cooling costs, there is added reliability because if a battery system experienced a full-on thermal event and even burned, the base station equipment inside the shelter would be relatively unscathed.

Such an external cabinet would need appropriate security and ruggedness as would any outdoor unit.

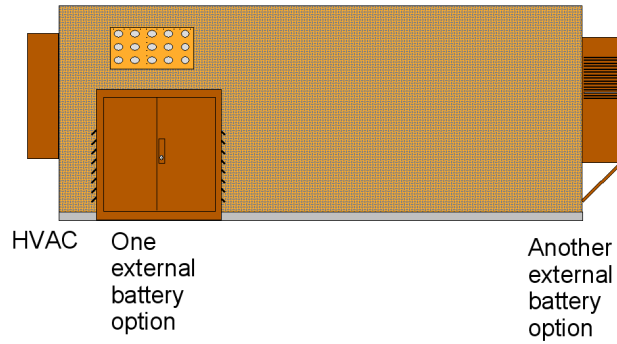


Figure 2 Battery cabinets external to the shelter permit the high ventilation required by Code without impacting on base station cooling costs.

One innovation that's been around for more than a decade now is the Thermal Management feature where a thermocouple senses battery temperature. If the cell approaches a thermal overheat condition, the dc plant controller senses the hot cell and reduces rectifier output to compensate. A thermocouple is a simple temperature sensing device that typically has two dissimilar metals joined together at one end. When that junction is heated, a voltage is produced that is proportional to the amount of heat. Accordingly, some level of voltage from the thermocouple is sensed by the dc plant controller and acted upon accordingly. The down side to this approach is that only one cell is sensed and therefore a thermal event beginning in another cell might be missed. Or, the thermocouple might be defective or even not installed at all. It's not uncommon for the dc power plant equipment and the battery to be installed by two different contractors and this author has seen installations where the thermocouple simply hung in the air somewhere in the vicinity of the battery because the dc plant installer didn't want to assume responsibility for a connection made by the battery installer. Such an installation can't really protect anything. What might solve some of those issues? For effectiveness, the thermocouple should be part of the battery installation kit and therefore the dc plant installer simply makes connections to the thermocouple. One approach might be to use Intercell straps to which a thermocouple has been permanently attached, perhaps by epoxy. Figure 3. In this manner, a thermocouple could "see" a temperature rise in either of the two cells connected to it and therefore a 24 Volt battery would have six thermocouples connected and sensing all the cells.

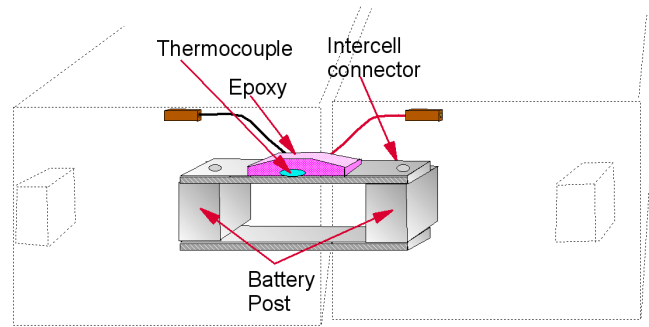


Figure 3 a thermocouple device permanently bonded to an Intercell strap would sense overheat conditions in either of the two cells to which it is referenced.

Temperature is a big word when talking about battery problems. Apart from the obvious accelerated aging that accompanies the high float current brought on by high temperatures, the specter of excessive hydrogen outgassing looms progressively larger as the temperature climbs.

Firstly though, let's 'get real' about thermal runaway. Widespread in our industry, there is the mistaken impression that thermal runaway events are a sudden-onset condition. Such simply is not the case. Thermal runaway events are the result of continual overcharging over the course of weeks and months, typically in cells that have experienced about 10% water loss through cell dry-out. As such, conditions such as room temperature and float current are the genuine indicators heralding the need for automatic or human intervention. These indicators could drive the dc plant controller to follow a programmed algorithm to reduce rectifier output or send a start signal to an exhaust fan circuit as is shown in Figure 4. Such an approach would result in a more effective means of preventing potentially untoward battery aging and fault conditions as well as excessive hydrogen evolution.

Another widespread mistaken impression is that battery cells outgas hydrogen whenever they're on charge. Such is not the case. Hydrogen production in a battery cell is a chemical reaction caused when water in the electrolyte is electrolyzed by current and chemically splits the hydrogen atoms from the oxygen atoms that comprise H₂O – water. Outgassing conditions occur as the battery cell or cells approach a fully charged state and also during a state of overcharge.

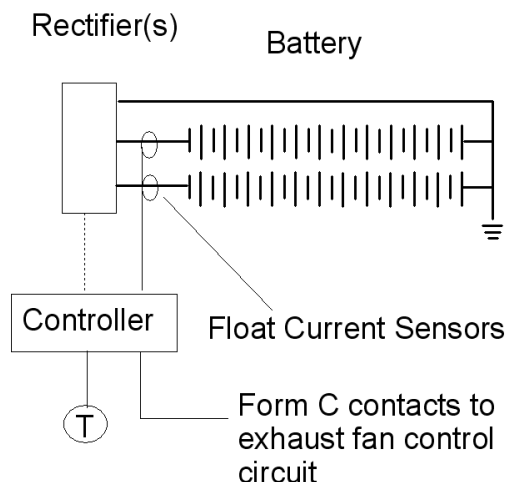


Figure 4 the most reliable controls on rectifiers and exhaust fans are a combination of high float current, high battery temperature and high room temperature.

Overcharge might occur because the plant is set wrong for that particular battery type or room overtemperature is causing high float current. Another overcharge condition may occur if one or more cells in the battery become shorted internally due to a mechanical fault or accumulations of sloughed off cell material piling up at the bottom of the container, shorting the plates, or dendrite growth between positive and negative plates. In any case, when a cell is shorted, the float voltage is now divided by that many fewer cells. In other words, if a 48 volt (24 cell) battery experiences one shorted cell, the float voltage is then 'seen' across 23 cells and not the shorted one. If – say – the cells were VRLA and the float voltage was 54, the 54 Volts would divide by 23 resulting in 2.348 Volts per cell. Under normal conditions the cells would "see" only 2.25 Volts per cell. If more than one cell shorts, the overcharge condition worsens and over time the overcharged cells outgas mightily and possibly result in a thermal runaway.

II. TO EXHAUST OR NOT EXHAUST

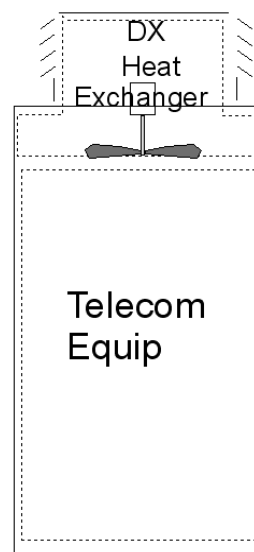
HVAC systems with fresh air economizers generally provide enough fresh air ventilation that exhaust is not needed. Neither the International Fire Code (IFC) nor NFPA 1 require that battery spaces have exhaust fans or ducts, however many AHJs insist upon them. If exhaust fans are provided in conditioned spaces expensive cooled air is lost whenever the fan is operating. Therefore, How to control the exhaust fan directly impacts the energy cost and carbon footprint for a site. Probably the best approach is to control the exhaust fan with a Float Current monitor as was discussed previously. A timer with a high temperature override would be the next best choice because there is no thermal runaway without excessive heat.

Another approach might be a look way back at the earliest of electric refrigerators with top coils such as that shown in a museum photo in Figure 5.

If equipment cabinets had built in HVAC systems with heat exchangers on the top or the rear of the cabinets, airflow through the shelter would prevent hydrogen accumulation under virtually all circumstance, and only enough cooling to maintain the electronics would be operational.



Figure 5 This museum piece early vintage refrigerator might offer a future for telecom equipment cabinets with internal HVAC and external heat exchangers (below). High airflow through the space would carry away the heat while keeping the facility including its battery well ventilated.



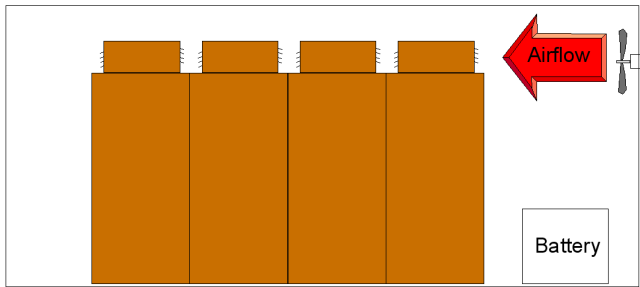


Figure 6 Using the concept of the previous figure the cabinet heat exchangers would discharge their heat into the shelter space where copious ventilation would convey that heat outside.

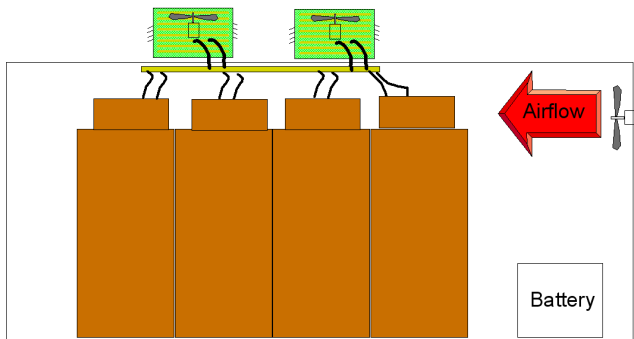
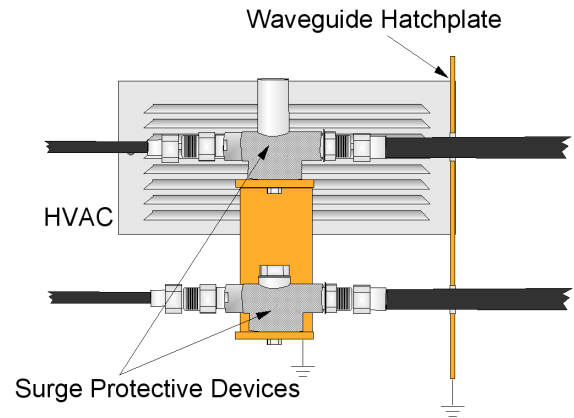
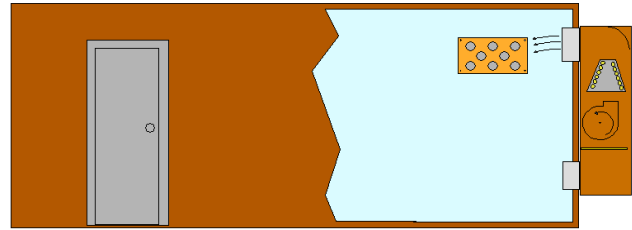


Figure 7 A similar approach might be to connect rooftop mounted HVAC compressor units to a manifold within the shelter and then heat exchangers within the equipment cabinets would connect to the manifolds with Schrader couplings. This approach might reduce ceiling height and noise levels within the shelter. Again, a level of airflow within the shelter would maintain adequate ventilation without sacrificing HVAC cooled air.

III. WHAT NOT TO DO IN USING HVAC VENTILATION

One problem that conventional shelter type cell site HVAC can experience is the juxtaposition of the cold air HVAC discharge and the lightning arrestors for the incoming coax cables. When the path for cold air blows directly across coax connectors and surge protective devices, there is significant thermal cycling of what could be dissimilar metals between the coax connectors, the SPDs, the coaxial wire itself and any solders used to bind the connections. The frequent expansion and contraction of these metals, due to HVAC cycling on and off, can cause poor connections or cracked solder joints to develop which are primary root causes for passive intermodulation (PIM) interference on the RF conveyed in the transmission path. Cold air should not be blowing directly on such equipment.



Figures 8 above and below depict cutaway side and frontal views of poor placement of an HVAC cold air discharge that blows directly on incoming RF coax connections and Surge Protective Devices. Thermal expansion and contraction of the connections and metal bodies of the SPDs will degrade RF performance by introducing passive intermodulation (see text). The two most commonly deployed types of coaxial SPD are shown, the Quarter Wave Stub (upper SPD) and the Gas Tube type (lower SPD)

IV. WHAT IF THERE IS A THERMAL RUNAWAY?

Almost universally, technicians and contractors responding to overheating battery situations tend to mishandle the event. The primary reason is a lack of training but also the fact that in reality, so few events occur. One approach to safely handling a battery thermal event is to place a placard of instructions on the door to the facility so that someone can read the instructions from the relatively safety (fresh air) environment outside the facility.

Such a placard might include the following information:

Caution

If you encounter batteries too hot to touch or that make hissing or whistling noises from their vents and/or there is a strong rotten egg odor in the facility: **Evacuate the space, ventilate if possible and call for help from a safe place.**

If:

- There is fire or smoke
- If the fire alarms are sounding
- If there is a strong rotten egg (Hydrogen sulfide) odor

Important: **Take no action that could produce a spark and ignite airborne hydrogen**

If you encounter batteries too hot to touch but there is no smoke or rotten egg odor and it is deemed safe to remain in the facility:

- Call for technical help.
- Increase ventilation in battery area.
- Reduce charge current either by turning off enough rectifiers so that the load barely is covered or by lowering the float voltage.
- Increase cooling in the battery area if possible.

If there is a spill or other Hazmat situation alert your company's environmental organization and/or contractor

Do not over-react to battery emergencies. Burning batteries may release potentially lethal concentrations of toxic gasses or other chemicals and should be handled by trained First Responders (Fire Departments) with appropriate protective clothing and Self Contained Breathing Apparatus (SCBA).

If battery cells remain hot after rectifiers are turned off, the prudent approach is to remove all battery Intercell straps and cables and not just the battery lead(s). Sometimes battery cells experience container failures and electrolyte leakage causes short circuits between two or more battery cells through the framework. The only way to arrest such an event is to remove all connections and interconnections in the battery.

It would be prudent also, to include a copy of the Material Safety Data Sheet (MSDS) for the battery cells at the facility.

V. CONCLUSIONS

No matter who publishes what, the difficult reality is that in the real-world maintenance often gets postponed, lost in a budget or manpower cut, or quietly signed off on (pencil-whipped) by understaffed technicians and therefore, equipment that needs periodic calibration such as hydrogen sensors will continue to be unreliable. With any luck, by the next code cycle, either hydrogen sensors will have improved markedly or the code making panels will realize that hydrogen sensors are almost useless. Temperature and float current are much more reliable indicators of potential problems and most such designs do not require calibration or other periodic maintenance.

VI. REFERENCES / BIBLIOGRAPHY

1. International Mechanical Code (2009 Ed) International Codes Council
2. International Energy Conservation Code (2009 Ed) International Codes Council
3. International Code Panel Adoptions <http://www.iccsafe.org/gr/Pages/adoptions.aspx>
4. IEEE 450 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications (2002)
5. IEEE 1187 IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications (2002)
6. Temperature up, costs down: the influence of battery technology and thermal management in base stations – Jim McDowall Saft America Inc. William G. Gates Filescan Ltd. INTELEC 2007
7. GR-487 Generic Requirements for Electronic Equipment Cabinets - March 2000 - Telcordia Technologies
8. GR-43-CORE *Generic Requirements for Telecommunications Huts*. - October, 1996 - Telcordia Technologies
9. Using Float Current Measurements to Prevent Thermal Runaway on VRLA Batteries Eric Bois INTELEC 2001
10. Experiments on Thermal Runaway and its Management for Electrolyte Immobilized Lead-Acid Batteries – F.J. Vaccaro and R.E. Landwehrle – INTELEC 1991
11. Battery Codes and Standards: Changes in 2002 and 2003 Steve McCluer (APC) & Curtis Ashton (Qwest) Battcon 2003