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Guidelines for UPS & Battery Storage

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1 Battery Overview

There are primarily three kinds of batteries used in UPSs—**vented lead acid (VLA)** (also called flooded-cell),**valve-regulated lead-acid (VRLA)**, and sealed or maintenance-free **lithium-ion** batteries.VRLA batteries usually have lower up-front costs but have a shorter lifetime of around five years.Flooded-cell batteries require more maintenance but have a longer lifetime, up to 20 years.**Lithium-ion batteries** are smaller and lighter than the above types and have changed the traditional status quo for UPS use.Costs are like VRLA, and new energy storage applications with UPS systems, such as gridsharing and peak shaving, are now viable.These new capabilities provide more than just backup time and can now contribute to significant cost savings for the user in their day-to-day operations.

2 Lead-Acid Batteries

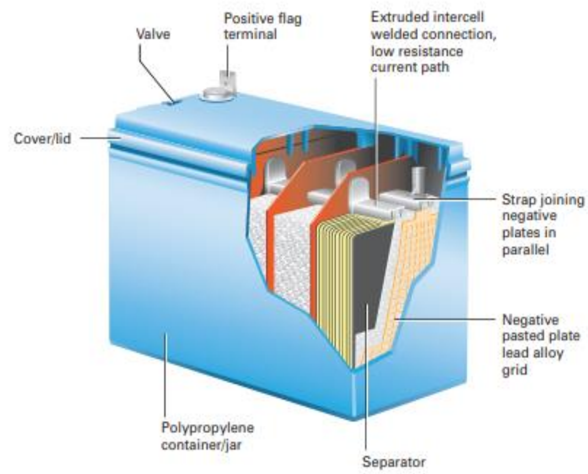
Lead-acid batteries are the most widely used electrical energy storage, primarily for uninterrupted power supply (UPS) equipment and emergency power system (inverters). Lead-acid batteries release hydrogen gas that is potentially explosive.The battery rooms must be adequately ventilated to prohibit the build-up of hydrogen gas.The hydrogen generation is relatively small during normal operation.However, significant hydrogen can be produced during rapid and deep discharge of the battery.

2.1 Types Of Lead-Acid Batteries

2.1.1 Vented Lead-acid (VLA) Batteries

Vented Lead-acid Batteries are commonly called “flooded” or “wet cell” batteries. VLA is an exceptionally reliable design, so failures are uncommon until halfway of their 20-year pro-rated life. The most common failure mode is a short circuit and even that is not an emergency, as long as the fault is localized. However, there are downsides to flooded-cell batteries. VLA batteries require more maintenance,safety and space. VLA batteries have thick lead-based plates that are submersed in an acid electrolyte. The electrolyte depletes over time so distilled water must be added periodically. Also, hydrogen is produced during charging. The hydrogen is

Flooded-cell batteries require more advanced maintenance but have a longer battery service life



Internal and external components of a valve-regulated lead-acid (VRLA) battery

evacuated through vents. Hydrogen is highly flammable and explosive, so these batteries must be installed in a ventilated room. OLSEH mandates 6 air-changes per hour in the battery room.

2.1.2 Recombinant Valve-Regulated Lead-acid (VRLA)Batteries

VRLA batteries are sealed, usually within polypropylene plastic, so there is no sloshing acid that can leak or drip when inverted or handled roughly.The term “valve-regulated” refers to the method of gas release.If the gas pressure becomes too great inside the battery, the valve will vent when it reaches a certain pressure.

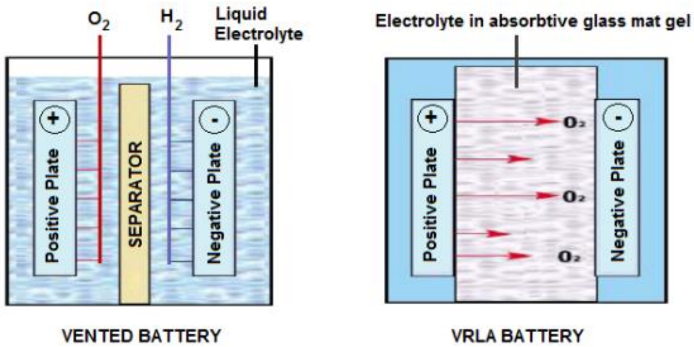
Recombinant cells have a starved or gelled electrolyte.The oxygen generated from the positive electrode during charging diffuses to the negative electrode producing water:

$$\mathbf{Pb + H_2SO_4 + \frac{1}{2}O_2 \rightarrow PbSO_4 + H_2O}$$

The recombinationreaction suppresses hydrogen evolution at the negative electrode, thereby allowing the cell to be sealed.In practice, the recombination efficiency is not 100% and a pressure relief valve regulates the internal pressure at a relatively low value, generally below 10 psig.

2.2 Comparison between flooded and sealed batteries

The diagram below shows a comparison between vented battery gassing and VRLA battery recombination.



Both the vented and the VRLA batteries work on the principle of chemical reactions between positive and negative plates. But there are some key differentiating characteristics:

a. In flooded cell batteries the electrolyte is in liquid form, while in VRLA batteries it is immobilized in a gel or absorbent glass mats.
b. The flooded cell batteries release hydrogen continuously during charging while the VRLA batteries release hydrogen only when overheated and/or overcharged. The flooded cell batteries emit approximately 60 times more hydrogen than comparably rated VRLA batteries.
c. The flooded cell batteries require dedicated ventilation system to maintain hydrogen concentration below the lower explosive limit. VRLA batteries have lesser risk, and these can be housed without mechanical ventilation. Supplier guidance must be applied.
d. The flooded cell batteries should be installed in dedicated rooms physically separated from other areas. Room construction shall be designed to meet the required fire resistance rating for the application. VRLA batteries have less risk and can be used in the same room as the equipment they support.
e. VRLA batteries are prone to failure condition known as “thermal runaway.” It is a condition when the heat generation rate inside the battery is faster than the heat dissipation. To prevent the failure and the battery dry out, the safety valves open and the battery vents hydrogen until temperature and/or voltage are reduced. This condition can be triggered by charger over-voltage. Flooded cell batteries are immune to thermal runaway condition.
f. Flooded lead-acid batteries can be charged at high voltage settings which improve performance. VRLA batteries are usually set to a lower voltage limit, which shelters the battery but produces poor performance. Check with your battery vendor for guidance.
g. VRLA batteries usually have lower up-front costs but have a shorter lifetime than wet cell, usually around five years. Flooded cell batteries require more advanced maintenance but have a longer lifetime, up to 20 years

3 Lithium-Ion Batteries

Lithium batteries have significant benefits over lead-acid batteries for UPS, for example,smallsize, light weight, high cycle-count (charge-discharge cycles), faster recharge times, and built-in battery management (not just monitoring). The technology is underactivedevelopment due to the demand fromheavy-duty sectors like e-mobility.

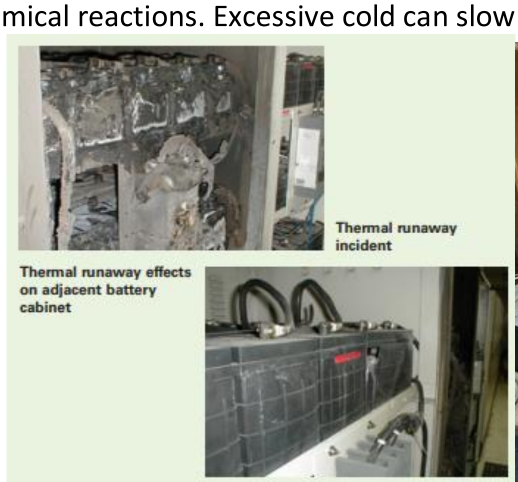
Li batteries have a battery management system in each battery, as well as in a system-level master controller.It manages charge current, voltage, and cell voltage balance, while adjusting as necessary to eliminate any chance of overtemperature.If temperatures rise above safe levels, the management system will independently disconnect the battery or string via multiple different disconnection means, and notify the user via the battery cabinet monitor, and an alarm on the UPS.

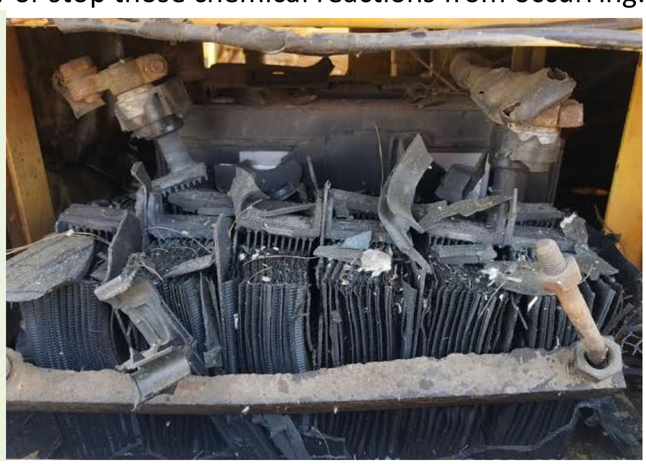
4 Battery Hazards

4.1 Thermal Runaway

Batteries are designed to operate in a relatively narrow temperature range. Thermal runaway occurs when the heat generated in a battery exceeds its ability to dissipate it. Thermal runway can occur without warning, with the battery cell temperature rises incredibly fast (milliseconds). The energy stored in that battery is released suddenly. The chain reaction creates extremely high temperatures (around 752 degrees Fahrenheit / 400 degrees Celsius), causing a fire that is nearly impossible to extinguish. Thermal runaway in lithium-ion batteries has receiveda lot of attention due to fires in cell phone and hoverboard batteries.However, thermal runway can happen in all battery types.In extreme cases, thermal runaway can cause batteries to explode and start fires.In minor cases, it can cause batteries to melt or be damaged beyond repair.

Several conditions can cause thermal runaway in a battery. Thermal runaway can occur due to an **internal short circuit** caused by physical damage to the battery or poor battery maintenance. The same type of scenario could cause an external short circuit which could also kick off the chain reaction. **Overcharging** a battery beyond its safe max voltage (to extend the distance an electric car will run, for example) can permanently damage the battery and lead to thermal runaway. **Rapid charging** can also lead to thermal runaway because rapid charging can lead to excessive currents. Finally, **temperatures outside** of the safe region on either the low or high side degrades a battery’s performance. This leads to irreversible damage to the battery and possible triggering of the reaction. While the danger of excessive heat may be obvious, the danger of excessive cold may be confusing. The functioning of lithium-ion batteries depends on chemical reactions. Excessive cold can slow or stop those chemical reactions from occurring.





4.2 Overcharging and Undercharging

Modern batteries have an efficiency of > 90%. To fully charge a battery one only requires 107% to 115% of the rated energy.For example, 10.7 ampere-hours is sufficient to fully charge a 10-ampere-hour battery.Pushing more than 107% energy or charging at too high a rate, constitutes overcharging. Overcharging is a common cause of premature battery failure.

Undercharging of the battery occurs when a battery is not fully recharged during the recharge cycle. The residual lead sulphate (PbSO4) remains on the positive and negative plates and eventually 'hardens'.With successive cycles of undercharging, the layer of residual lead sulphate becomes thicker, the electrolyte specific gravity decreases, and the battery cycles down in capacity.In the 'hardened' condition, it may not be possible to convert the residual lead sulphate back into the original lead dioxide, sponge lead and sulphur acid active materials, even with higher voltage charging efforts.In this case, the battery will suffer a permanent loss in capacity.

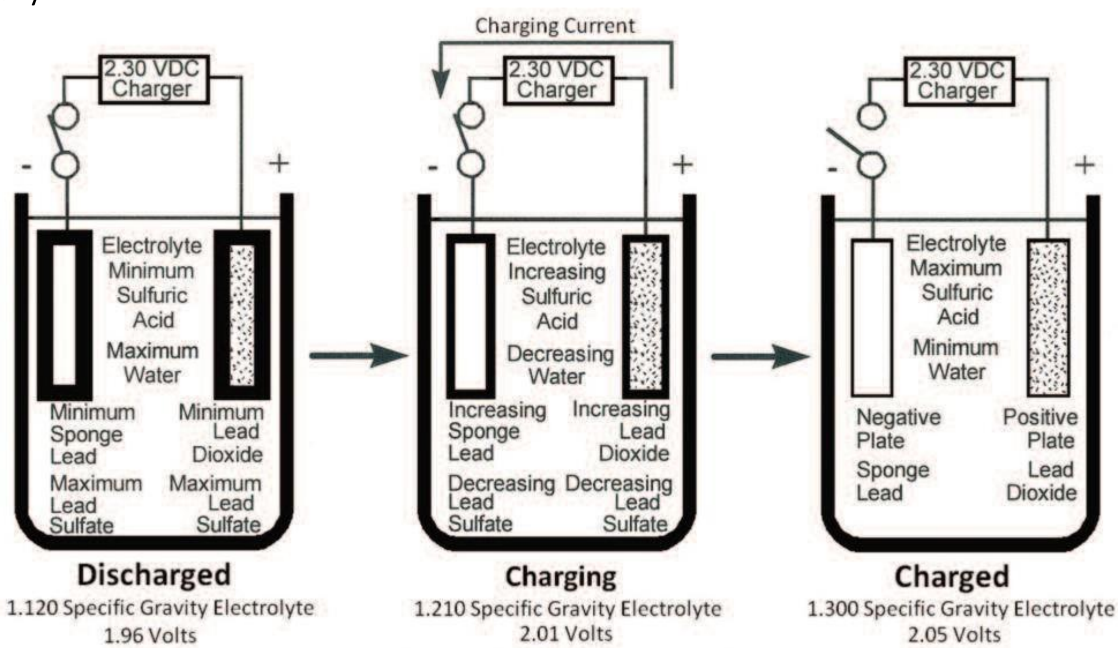


Figure 2 - Lead Acid Battery Recharge

4.3 Electrical hazards

a. Electric shock may occur when one makes direct contact with the exposed battery terminals stayed at different potential or with the exposed conductor ofcables or conductive parts connected with the battery, resulting in the passing of electric current through the body of the victim.
b. Short-circuit of the battery terminals or other electrical conductors stayed at different potential would cause a high current flow.The sudden release of energy stored in the battery in a short time and under an uncontrolled manner may cause a flashover and explosion, thus resulting in the rupture of battery housing, spillage of electrolyte, melting down of battery terminals or other metal parts, and subsequent splashing of molten metal, etc.

4.4 Fire and explosion hazards

a. When the charging operation is close to completion, explosive gas may be generated from the battery due to the action of electrolysis of water contained in the electrolyte solution.
b. The gases produced are hydrogen and oxygen.The former is much lighter than the air and would accumulate in the air space above the electrolyte solution inside the battery.These gases may also leak through the battery vents and disperse to the surrounding of the battery room or workplace.
c. Hydrogen gas when mixed with oxygen or air can be explosive.Any spark or naked flame present may cause a fierce explosion of the explosive mixture.Sparks may be generated by electrostatic discharge, abrasion of some metals, normal switching, or abnormal tripping of electrical equipment, etc.A smoldering burn may turn into a blaze in the presence of enriched oxygen.Any combustibles in the vicinity, which are not ignited in the air normally, may ignite by itself in the presence of enriched oxygen.

4.5 Chemical hazards

a. Electrolyte (Sulfuric acid) is combustible. Contact with organic materials may cause fire and explosion. It also reacts violently with strong reducing agents, metals, sulphur trioxide gas, strong oxidizers, and water. Contact with metals may produce toxic sulphur dioxide fumes and may release flammable hydrogen gas. Workers may suffer from skin burn or eye injury caused by spillage or splashing of electrolyte. It is important to take precautionary measures likePPE, ventilation,housekeeping, and personal hygiene.
b. For lead compounds, avoid contact with strong acids, bases, halides, halogenates, potassium nitrate, permanganate, peroxides, nascent hydrogen and reducing agents.
c. For lithium-ion batteries, consult the vendor's Material Safety Data Sheet (MSDS) for list of hazards.

5 Battery Safety

5.1 Prevent thermal runaway

a. **Proper Storage Temperature**: Always store batteries at safe temperatures.The ideal storage temperature for most lithium-ion batteries is between 40-70 degrees Fahrenheit (5-20 degrees Celsius).However, this can differ based on the battery and manufacturer, so consult the label for your specific battery.
b. **Proper Ventilation:** One of the easiest ways to maintain a safe operating temperature is properly ventilation.All the electronics needed to manage your battery system, plus the batteries themselves, produce heat.The heat generated by the batteries and electronics must be dissipated.
c. **Replace Old Batteries**:Old battery must be replacedbefore end-of-life.If you have an old battery that has been uncharged or undercharged, it may have built up gasses within the casing, which can easily cause an explosion.If you see a deformed or "bubbled" battery, do not attempt to charge it.Properly dispose of and replace any deformed batteries.

d. **Don't Overcharge**:Overcharging a battery can cause an electrochemical reaction that may result in thermal runaway.Monitoring the charge status of your battery is essential for this reason.
e. **Battery Management System(BMS):**Battery management systems (BMS) monitor and manage cell voltage, cell current, cell temperature, cell charge balancing, charge control, and internal short circuit detection.Essentially, the BMS is an electronic system that manages either a single cell or an entire battery pack.It monitors the state of the battery and reports the data.It also protects the battery (or cell) by controlling or balancing the environment of the battery (or cell).

5.2 Manage spills or leaks for lead acid batteries

Stop the flow of materials and contain/absorb small spills with dry sand, earth, or vermiculite. Don't use combustible materials. If possible, carefully neutralize spilled electrolyte with soda ash, sodium bicarbonate or lime. Wear acid-resistant clothing, boots and gloves, and a face shield. Do not allow discharge of un-neutralized acid to get to the sewer.

5.3 Read MSDS

The materials in batteries make them volatile and therefore potentially hazardous. Performing regular periodic maintenance on your batteries can go a long way in preventing unsafe situations before they occur. Aways refer to the material safety data sheet for specific precautionary measures. Sample MSDS of the three types of batteries are available in the links below:

	Type of battery	**MSDS**
1	Lithium Ion Battery	1935761.pdf
2	VLA Battery	VLA Batteries.pdf
3	VRLA Battery	MSDS-VRLA-Non-Hazardous.pdf

5.4 Proper storage

The batteries need to be stored as per the following rules.

a. Always store the battery in cool and covered areas.Do not keep the battery in direct sunlight, dust, or moist place.
b. Keep the battery away from sparks, heat source or fire.Do not store batteries near other hazards like cylinders and chemicals. There must be a separation like a physical barrier or 20 ft of space.
c. Do not let dust accumulate on the battery. Clean the dust with a dry cloth, not wet.
d. Provide proper isolation between battery and battery rack.Do not allow any metal object to rest on the battery - this may cause short circuit.
e. Do not add acid or distilled water in VLRA or lithium ionbattery
f. Do not mix batteries with different capacities, different make, different types (VRLA, Flooded/ Tubular batteries) and different manufactures' batteries in the same circuit.
g. Never install any type of battery in a completely sealed enclosure or room. Sufficient ventilation must be provided.

Table 1: Summary of storage requirement for batteries.

	Vented Lead-acid (VLA)	Valve Regulated Lead-acid (VRLA)	Lithium-Ion Batteries
			
Storage area	Separate storage area (cabin) required	Separate storage area not required	Separate storage area not required
Ventilation	Forced ventilation for the separate cabin is required	Room/lab should be adequately ventilated	Room/lab should be adequately ventilated
Ideal temperature	25 C	25 C	25 C
Flammable Gas cylinders/pipelines	20 Ft clearance distance required	20 Ft clearance distance required	20 Ft clearance distance required
Housekeeping	Dust accumulation should be prevented	Dust accumulation should be prevented	Dust accumulation should be prevented
PPE required for accessing the storage area	Electrical safety shoes & acid resistant gloves are required	Electrical safety shoes are required	Electrical safety shoes are required
Sign boards required	Entry restricted; Electrical hazard 	Electrical hazard 	Electrical hazard 

6 Some Common Issues Related to Storage of Batteries & UPS in IISc

	➢ Storage of batteries in poor ventilated area ➢ Matal toolbox stored near to batteries. ➢ Batteries should not be kept beneath any table, closed cabinets, etc.
➢ Storage of wet lead acid batteries in poor ventilated area ➢ Poor housekeeping near battery storage area. ➢ Wet lead acid batteries should be stored in separate cabin with forced ventilation	
	➢ Storage of VRLA batteries in poor ventilated area ➢ Poor housekeeping near battery storage area. ➢ Wet lead acid batteries should be stored in separate cabin with forced ventilation
➢ Dust accumulation ➢ Poor housekeeping near battery storage area. ➢ Wash basin near the battery storage area	
	➢ Storage of VRLA batteries in poor ventilated area ➢ Storage of compressed gas cylinder near battery
➢ Storage of other equipment ups and battery storage area ➢ Poor housekeeping near battery storage area.	

7 References

[1] Battery Room Ventilation and Safety, Continuing Education and Development, Inc.

[2] Bro, P. and Levy, S., 2006. Battery Hazards and Accident Prevention. New York, NY: Springer.

[3] Exide's Do's and Don'ts for Sealed Maintenance Free Batteries, 2022

[4] The large UPS battery handbook, EATON

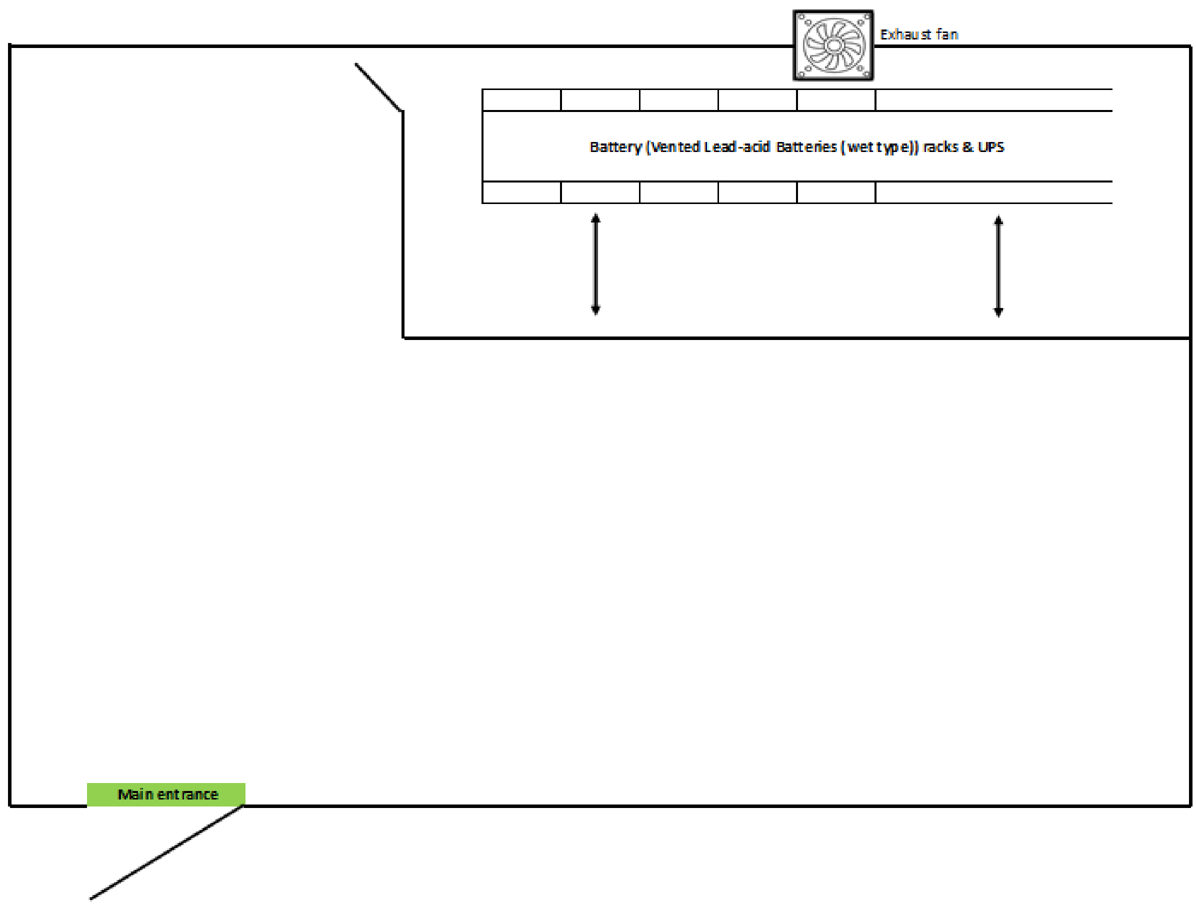
[5] Technical Bulletin, 41-2128, Charging Valve Regulated Lead Acid Batteries, C&D Technologies

8 Appendix

8.1 Typical Layouts of a Battery & UPS Room

Below if sample layout of the battery room in a lab. The layout is exemplary. It does not include dimensions because details will be different for each lab.

8.1.1 For Vented Lead-acid Batteries



8.1.2 For Recombinant Valve Regulated Lead-acid-VRLA (Dry type) or Lithium-ion batteries