

IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications

Co-Developed by

IEEE Power and Energy Society
Stationary Batteries Committee
and

ASHRAE
Guideline Project Committee 21 (GPC 21)



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IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications

Co-Developed by

**Energy Storage and Stationary Battery Committee
of the
IEEE Power and Energy Society**

and

**ASHRAE
Guideline Project Committee 21 (GPC 21)**

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Abstract: Vented lead-acid (VLA, including those fitted with recombination vents), valve-regulated lead-acid (VRLA), nickel-cadmium (Ni-Cd – both fully vented and partially-recombinant types), and Li-ion stationary battery installations are discussed in this guide, written to serve as a bridge between the electrical designer and the heating, ventilation, and air-conditioning (HVAC) designer. Ventilation of stationary battery installations is critical to improving battery life while reducing the hazards associated with hydrogen production [hydrogen production is not a concern with Li-ion under normal operating conditions (it is under thermal runaway conditions)]. This guide describes battery operating modes and the hazards associated with each. It provides the HVAC designer with the information to provide a cost-effective ventilation solution.

Keywords: ASHRAE Guideline 21, battery, battery cabinets, battery gassing, battery room, battery vaults, forced ventilation, hydrogen, IEEE 1635™, natural ventilation, recombination vent, stationary battery, thermal management, ventilation, ventilation system maintenance

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

ASHRAE
1791 Tullie Circle, NE, Atlanta, Georgia 30329-2305, USA

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Participants

At the time this IEEE/ASHRAE guide was completed, the Ventilation Working Group had the following membership:

Curtis Ashton, *IEEE, Co-Chair* **Deep Ghosh**, *ASHRAE, Co-Chair*
John B. Riley, *ASHRAE Vice Chair*
David Rosewater, *IEEE Vice Chair*
Mike Nispel, *IEEE Secretary*

Gary Balash
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Bill Cantor
Siu-yee Ching
Ryan Franks
David Hood
Rich Hutchins

Wayne Johnson
Andy Keels
Rich Kluge
Jeff LaMarca
Dan Lambert
Jim McDowall
Steve McCluer

Jim Midolo
Russ Miller
Art Salander
Andres Tapia Carillo
Rick Tressler
Lesley Varga
Steve Vechy
Rachel Wood

At the time this guide was approved, ASHRAE Guideline Project Committee 21 (GPC 21) had the following membership:

Cognizant TC: TC 9.2, Industrial Air Conditioning

Jay Kohler, *SPLS Liaison*

Deep Ghosh, *Chair**

John B. Riley, *Secretary**

Mark A. Hartfiel*
Dennis G. Hellmer*
N. Eileen Jensen*
Erich Binder*

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The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

Samuel Aguirre
Edward Amato
Curtis Ashton
Gary Balash
Thomas Barnes
Paul Barnhart
Brian Baumgart
Jason Bellamy
Steven Bezner
Erich Binder
Paul Boman
Mark Bowman
Koti Reddy Butukuri
John Byrne
William Cantor
Paul Cardinal
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Diego Chiozzi
Randy Clelland
Michael Connor
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Daniel Lambert
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Michael O'Brien
Erik Ostberg
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Lorraine Padden
Bansi Patel
Branimir Petosic
Edward Rafter
Robert Rallo
John B. Riley
Hugo Ricardo Sanchez Reategui
Bartien Sayogo
Daniel Seidel
Robert Seitz
Nikunj Shah
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Mark Siira
David Smith
Jeremy Smith

Gary Smullin
Joseph Stevens
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Andres Tapia
David Tepen
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Nikolay Tsanov
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Gerald Vaughn
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Jason Wallis
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Introduction

This introduction is not part of IEEE Std 1635-2022/ASHRAE Guideline 21, IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications.

The primary purpose of this guide is to assist users involved in the design and management of new stationary lead-acid, valve-regulated lead-acid, nickel-cadmium, and lithium-ion battery installations. The focus is the environmental design and management of the installation, and to improve workplace safety and improve battery reliability as well as the safety of personnel and equipment. This guide is a joint effort by the IEEE and ASHRAE.

IEEE Std 1635/ASHRAE Guideline 21 was first published in 2012, and a 2nd edition was published in 2018. Per IEEE bylaws, a Sponsor and Working Group can conduct the revision of a standard at any time. A revision prior to year 10 will keep the standard continuously active for another 10-year period after the approval of the revision by the IEEE-SASB. The joint IEEE and ASHRAE working groups identified a need to add information on thermal management and thermal runaway gassing of Li-ion installations due to their rapidly increasing usage.

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IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications

1. Overview

1.1 Scope

This guide discusses the ventilation and thermal management of stationary battery systems as applied to the following:

- Vented (flooded) lead-acid (VLA)
- Valve-regulated lead-acid (VRLA)
- [Vented](#) nickel-cadmium (Ni-Cd)
- Partially recombinant [vented](#) nickel-cadmium
- [Lithium ion \(Li-ion\)](#)

For each category, both the technology and the design of the battery are described in order to facilitate user understanding of the environmental issues associated with each type of technology.

The scope of this document includes only stationary batteries under conditions of expected use. Multiple operating modes are identified, [including failure modes](#).

The ventilation practices described in this guide represent the “best practice” based on the information available at the time this document was developed. The user should evaluate these practices against their operating experience, operating conditions, number and size of battery systems, manufacturer’s recommendations, resources, and needs in developing an environment that is conducive to safety and optimum operation of the equipment. These recommendations were developed without consideration of economics, availability of equipment and personnel, or relative importance of the application. Design of a ventilation system for a specific battery installation requires consideration of all issues, not just the technical issues considered in this document.

1.2 Purpose

The purpose of this document is to provide heating, ventilation, and air conditioning (HVAC) and battery system designers and users with information and recommendations concerning the ventilation and thermal management of stationary battery installations.

1.3 Exclusions

Purposefully ~~Specifically~~ not included (other than possibly brief mentions) in this document are the following:

- Ventilation for spilled electrolyte, as a spill is considered an accident condition. Ventilation for fumes associated with spills due to handling of batteries is addressed in IEEE Std 1578™ [B55 B39].¹
- Recharging stations for motive power or automotive batteries. These stations use different charging regimes from stationary float applications, although the charging gases produced can be managed in accordance with the guidelines in this document.
- Batteries that are embedded in small equipment such as desk-top uninterruptible power supply (UPS) systems and emergency lighting systems.
- Battery installations in classified (hazardous) environments.
- ~~— Ventilation for gases or other byproducts given off by battery installations involved in fires. The latter are not considered conditions of expected use, and in such circumstances ventilation could be disabled. For example, Li-ion batteries do not vent Hydrogen under normal or extreme conditions, and thus are not covered in this document; however, they do give off byproducts of combustion in cases of thermal runaway. For installation requirements (other than ventilation, which is covered in this document) for all stationary battery types in areas where the model Fire Codes are applicable, see NFPA 1 [B44] and the IFC [B28].~~

¹ The numbers in brackets correspond to those of the bibliography in Annex I H.

- Ventilation of the charger, UPS, or other equipment associated with the battery system.
- Design for fire or smoke events [for lead-acid or Ni-Cd batteries](#).
- Ventilation and management of gases [produced by lead-acid batteries under extreme overcharge conditions \(e.g., charger malfunction or multiple shorted cells\)](#).⁷ Such gases include ~~as~~ arsine, stibene, hydrogen sulfide, ozone, sulfur dioxide, sulfur trioxide, or chlorine, ~~produced during extreme over charge conditions (e.g., charger malfunction, multiple shorted cells)~~.
- General design criteria for HVAC systems and/or design alternatives and schemes.
- [Thermal management of Li-ion batteries with direct liquid cooling systems as their primary or only source of cooling rather than traditional HVAC](#).

1.4 Word usage

[The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted \(*shall* equals *is required to*\).](#)^{2, 3}

[The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required \(*should* equals *is recommended that*\).](#)

[The word *may* is used to indicate a course of action permissible within the limits of the standard \(*may* equals *is permitted to*\).](#)

[The word *can* is used for statements of possibility and capability, whether material, physical, or causal \(*can* equals *is able to*\).](#)

²[The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.](#)

³[The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.](#)

1.5 Document organization

This ~~guide recommended-practice~~ is divided into nine clauses. Clause 1 provides the scope of this guide. Clause 2 lists references to other standards that are useful in applying this guide. Clause 3 provides definitions, acronyms, and abbreviations that are either not found in other standards, or have been modified for use with this guide. Clause 4 discusses battery safety hazard considerations. Clause 5 provides information on battery fundamentals. Clause 6 provides information on heating, ventilation, and air conditioning. Clause 7 provides information on environmental design. Clause 8 discusses the economics of battery ventilation system design. Clause 9 provides information on environmental management.

This guide has nine [informative](#) annexes. [Informative annexes do not contain mandatory requirements, but provide background information, details, examples, and other subject matter that will aid users of this guide in understanding the overall subject matter addressed by the guide.](#) Annex A provides the gassing calculations. Annex B provides heat generation calculations. Annex C provides information on codes and standards. Annex D provides information on explosive and toxic gas allowance considerations. Annex E provides information on thermal runaway. Annex F provides sample HVAC calculations. Annex G contains example battery data sheets. Annex H [provides references to document that discuss stationary Li-ion battery fires and mitigating controls.](#) [Annex I](#) provides bibliographic references.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

NFPA^{4 2} 90A, Standard for the Installation of Air-Conditioning and Ventilation Systems.^{4 2}

^{4 2} NFPA publications are published by the National Fire Protection Association (<http://www.nfpa.org/>).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. IEEE Std 1881™ [B57 B41]; ~~should be consulted for the primary definition of battery-related terms not otherwise uniquely defined in this document.~~ the *IEEE Standards Dictionary Online*; and *ASHRAE Terminology of Heating, Ventilation, Air Conditioning, & Refrigeration* [B11 B9] should be consulted for terms not defined in this clause. 5.6 3,4

confined space: A space that (1) is large enough and so configured that an employee can bodily enter and perform assigned work; (2) has limited or restricted means for entry or exit (for example, tanks, vessels, silos, storage bins, hoppers, vaults, and pits); and (3) is not designed for continuous employee occupancy.

NOTE—See Code of Federal Regulations (29CFR1926 [B23 B47]). 7 5

controlled environment vault (CEV): A remote and partially or fully buried structure to house electronic and telecommunications equipment that includes backup power.

flammable: Subject to easy ignition and rapid flaming combustion. A flammable liquid is a liquid with a flashpoint of not more than 93 °C. A flammable solid is one that is readily combustible or may cause or contribute to fire through friction. A flammable gas is a gas having a flammable range with air at 20 °C and a standard pressure of 101.3 kPa.

NOTE—See UNECE GHS [B98 B58].

5 3 *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. [An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.](#)

6 4 *ASHRAE Terminology of Heating, Ventilation, Air Conditioning, & Refrigeration* is available at www.ashrae.org/resources-publications/free-resources/ashrae-terminology

7 5 Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

flammable-air-vapor mixture: Mixture of a flammable vapor in air between the lower [flammable](#) ~~flammability~~ limit

(LFL) and upper [flammable](#) ~~flammability~~ limit (UFL).

hydrogen pocket: A volume of air in which hydrogen accumulates to a concentration approaching or exceeding the lower [flammable](#) ~~flammability~~ limit (LFL).

hydrogen trap: A spatial feature that prevents diffusion of hydrogen, thereby leading to the creation of a hydrogen pocket.

recombination vent: [An assembly on a vented cell in which most of the hydrogen and oxygen gasses escaping from the head space of a cell are catalytically recombined and returned to the cell as water.](#)⁸

NOTE— [Catalytic recombiners are also found in some VRLA cells, but they are mounted internally in the cell headspace.](#)

string: A grouping of interconnected cells that has the same nominal voltage as the dc system.

thermal management: The use of various temperature monitoring devices, heating and cooling methods to control temperature within a defined space.

thermal runaway: A condition that is caused by a battery charging current or other process that produces more internal heat than the battery can dissipate.

3.2 Acronyms and abbreviations

ac alternating current

Ah ampere-hours

AGM absorbed glass mat

⁸ [Recombination vents on vented cells also typically substantially reduce the amount of combustible gasses released to the surrounding area/enclosure.](#)

AICHE American Institute of Chemical Engineers

API American Petroleum Institute

B combustible (gasses)

BESS battery energy storage system

BMS battery management system

BTU British thermal unit

C capacity (rated in Ah)

~~ASHRAE~~ ~~American Society of Heating, Refrigerating and Air Conditioning Engineers~~
~~Inc.~~

~~BTUH~~ ~~BTUs (British Thermal Units) per hour~~

CEV controlled environment vault

cfm cubic feet per minute

CFR Code of Federal Regulations

CO carbon monoxide

CRC Chemical Rubber Company

dc direct current

DEC diethyl carbonate

DMC dimethyl carbonate

E energy, rated in kWh

EEGL emergency exposure guidance level

EEL emergency exposure limit

EMC ethyl methyl carbonate

~~EEC~~ ~~European Economic Community~~

EU European Union

EVPC end voltage per cell

FM Factory Mutual

FPRF Fire Protection Research Foundation (of the NFPA[®])

GCPS Global Congress on Process Safety

~~FV~~ ~~final voltage~~

GHS Globally Harmonized System of classification and labeling of chemicals

HazMat hazardous materials

HF hydrogen fluoride

HSE Health and Safety Executive (UK Health and Safety agency) HVSD high-voltage shutdown

HVAC heating, ventilation, and air conditioning

IBC[®] International Building Code[®] 9 [B40]

~~ICBO~~ ~~International Conference of Building Officials~~

ICC[®] International Code Council[®]

IDLH immediately dangerous to life or health

^{2 6} IBC, ICC, and IFC are ~~is a~~ registered trademarks of the International Code Council.

IFC [®]	International Fire Code [®] [B41 ~~B28~~] ⁷
INL	Idaho National Laboratory
IT	Information Technology
IU	current-limited constant potential charging
kWb	kiloWatts of battery power in a UPS battery system
LC	lethal concentration
LCO	lithium cobalt oxide
LEL	lower explosive limit (see LFL)
LER	light electric rail
LFL	lower flammable ~~flammability~~ limit
LFP	lithium iron phosphate
Li-ion	rechargeable (secondary) lithium-ion batteries/cells of all types
LMO	lithium manganese oxide
LTO	lithium titanate oxide
~~LOI~~	~~limiting oxygen index~~
MERV	minimum efficiency reporting values
mvpc	minimum voltage per cell (EVPC is preferred)
NCA	lithium nickel cobalt aluminum oxide

⁷~~IFC and International Fire Code are registered trademarks of the International Code Council.~~

NCBI	National Center for Biotechnology Information
NEC [®]	National Electrical Code [®] [B68 B45] ¹⁰ ⁸
NESC [®]	National Electrical Safety Code [®] [B45 B30] ¹¹ ⁹
Ni-Cd	nickel-cadmium battery
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NMC	lithium nickel cobalt manganese oxide
NO	nitric oxide
NRC	National Research Council
OCV	open circuit voltage
OSHA	Occupational Safety and Health Administration
P	power rating in kW/cell
Pa	pascals (international unit of pressure)
PBE	plastic-bonded electrode
PC	propylene carbonate
PEL	permissible exposure limit
PLC	private line controller

¹⁰ ⁸ [NEC, the](#) National Electrical Code, and [NFPA](#) [NEC](#) are registered trademarks of the National Fire Protection Association, ~~Inc.~~.

¹¹ ⁹ ~~The~~ National Electrical Safety Code and NESC are registered trademarks of the IEEE.

PoD point of delivery

POD performance-optimized datacenter

ppb parts per billion

ppm parts per million

PSOC partial state of charge

PV photovoltaic

REL recommended exposure limit

RP Recommended Practice

s.g. specific gravity

SCBA self-contained breathing apparatus

SEI solid electrolyte interphase

SOC state of charge

STEL short-term exposure limit

TWA time-weighted average

UEL upper explosive limit (see UFL)

UFL upper flammable ~~flammability~~ limit

UNECE United Nations economic commission for Europe

UPS uninterruptible power supply

VEWFD very early warning fire detection

VLA vented lead-acid battery

[VOC](#) [volatile organic compound](#)

VPC volts per cell

VRLA valve-regulated lead-acid battery

4. Battery safety hazards and considerations

There are two primary safety considerations associated with the ventilation and thermal management of stationary battery installations. The first is personnel safety; the second is the reliability of the battery and the equipment located in the same or adjacent spaces. This document focuses primarily on personnel safety hazards that can be mitigated through ventilation and thermal management, although where equipment reliability is affected, it will be noted. Safety hazards associated with gas evolution from stationary battery installations include the following:

- [Flammable](#) ~~Explosive~~ gases
- Toxic gases
- Corrosive gases
- Acid vapor and or mist

The causes, risks, and mitigation of these safety hazards are discussed in detail in Clause 6 and Clause 7 following a discussion of battery types and typical applications for each type.

[While electric shock is not a part of this standard, batteries can pose an electric shock risk when connected together in series. See NFPA 70E \[B69\] for guidance on electric shock protection when dealing with batteries.](#)

5. Fundamentals

5.1 Battery types

Rechargeable batteries store and release electrical energy through reversible chemical reactions. As the batteries release or discharge their stored electrical energy, the principal inefficiency involves electrical resistance to the current flow, causing thermal energy to be released. The process of storing electrical energy is also accompanied by inefficiencies, resulting in the release of thermal energy and evolution of gases. The release of thermal energy is due to electrical resistance or exothermic chemical reactions. The evolution of gases is due to incidental chemical reactions. Some of these incidental chemical reactions result in the release of oxygen and hydrogen gas.

5.1.1 Lead-acid batteries

5.1.1.1 Cell reactions

Lead-acid is the most common battery type used in stationary applications. In the charged condition, the active material in the positive plate is lead dioxide; in the negative, it is sponge lead. The sulfuric acid electrolyte solution is an active component in the cell charge/discharge reaction. The plate structure is typically grids or spines of pure lead or lead alloys with various hardening and grain refining agents added such as calcium, tin, antimony, selenium, etc. The alloy composition affects the gassing characteristics of the battery (see 7.2).

~~The ideal, reversible discharge/recharge reaction is as follows [see Equation (1)]:~~



~~(Deleted)~~

~~where~~

~~Pb is metallic lead~~

PbO_2 is lead dioxide

H_2SO_4 is sulfuric acid

$PbSO_4$ is lead sulfate

H_2O is water

The ideal recharging reactions are as follows:

Positive plate [see Equation (2)]



where

SO_4^{2-} is the sulfate ion

H^+ is the hydrogen ion

e^- is an electron

Negative plate [see Equation (3)]



When a cell is subjected to an overcharge it will electrolyze water in the electrolyte. The electrolysis will produce oxygen gas at the positive plate ~~as noted in Equation (4)~~. As long as the oxygen gas production does not exceed the achievable oxygen gas diffusion rate of the cell, the principal reaction at the negative plate will be recombination ~~as noted in Equation (5)~~. The recombination reaction is exothermic, producing heat at the negative plate. To the extent the overcharge current leads to oxygen production exceeding the achievable oxygen diffusion rate of the cell, the negative plate reaction will proportionately shift to hydrogen gas production ~~as noted in Equation (6)~~, leading to the release of both hydrogen and oxygen gas from the cell.

~~Overcharge reactions are as follows:~~

~~Positive plate~~



~~(Deleted)~~

~~where~~

~~O_2 is oxygen gas~~

~~Negative plate reactions are as follows:~~

~~Recombination~~



~~(Deleted)~~

~~Gas production:~~



~~(Deleted)~~

where

H_2 is hydrogen gas

~~During normal charging of lead-acid batteries a small portion of the charge current results in corrosion of their lead positive plate grid structure. This process is represented by Equation (7) [with the corresponding reaction at the negative shown in Equation (6)].~~

~~Positive plate grid corrosion reaction:~~



~~(Deleted)~~

5.1.1.2 Vented lead-acid (VLA) batteries

The VLA battery is simply a lead-acid battery with a free-flowing liquid electrolyte that allows any gases generated during charging to be vented directly to the atmosphere. That volume below the cover and above the electrolyte level can be up to 67% hydrogen and 33% oxygen by volume, which is an explosive mixture. Typically, these gases are vented via a flame arresting (safety) vent to prevent ignition from a spark or flame outside the cell from entering the cell container and igniting the contained gases. [In some cases, recombination vents may be used to reduce maintenance. See 7.2.1 for recommendations for ventilation calculations when such vents are used.](#)

For VLA batteries being overcharged, the principal reaction at the negative plate involves gas production. ~~as in Equation (6).~~ Recombination ~~as in Equation (5)~~ does occur, but at such a low rate that it can be disregarded. The reason is that oxygen gas diffuses at a very slow rate through liquid electrolyte. During a ~~charge~~ [recharge](#), the rate of gas production is dependent on a number of factors involving characteristics of both the batteries and the charger. In general, peak gas production occurs at the end of [a](#) ~~the~~ recharge as the batteries near their full state of charge. At this point, most of the charge energy results in electrolysis of water.

VLA batteries use pure lead as well as a variety of lead alloys, which impact the generation rate and types of gases produced during an overcharge condition. The alloys discussed in the tables in Clause 7 are lead- calcium, lead-antimony, and lead-selenium. Lead-calcium batteries have low float currents. Lead-antimony and lead-selenium have higher float currents, which increase over the life of the battery. Pure lead cells have the lowest float current. All lead-acid batteries are capable of producing hydrogen sulfide gas (toxic and corrosive) and acid mist under extreme overcharge conditions, but such failure modes are beyond the scope of this document. See Annex D for additional information.

5.1.1.3 Valve-regulated lead-acid (VRLA) batteries

VRLA batteries are designed to take advantage of the naturally occurring recombination cycle where internally generated oxygen gas molecules are recombined with hydrogen ions to form water molecules. Key construction elements of these batteries are pressure relief valves and immobilized electrolyte construction to permit oxygen gas migration to the negative plate.

To reduce electrolysis of the electrolyte and the resulting water loss, VRLA batteries are designed to have low float current. Today's VRLA battery technologies are based on lead-calcium, lead-tin, or pure-lead grid alloys. The electrolyte is immobilized in either a glass mat [absorbed glass mat (AGM)] or a silica gel (gelled- electrolyte cell).¹² These construction methods achieve rates of oxygen gas migration sufficient to allow recombination at a level to substantially reduce or eliminate the need for watering for the life of the battery.

¹² [Many users improperly refer to all VRLA batteries as "gel cells", but the majority of VRLA batteries produced and installed around the world are actually of the AGM type \(although gel does have a significant market share in certain industries and/or parts of the world\).](#)

~~Recombination occurs when oxygen gas generated at the positive plates migrates to the negative plates for recombination with hydrogen ions to form water molecules.~~ The principal limiting factor to recombination is the sustainable rate of migration of oxygen gas molecules to the negative plate. In order to minimize negative plate depolarization from the recombination reaction, some manufacturers in some of their VRLA products add catalysts in the internal headspace part of the vent. This removes some of the recombination process from the negative plate but accomplishes the same goal of limiting water loss (and thus flammable gas venting) from the cell.

The one-way¹³ pressure relief valve allows excess internal pressure from generated gases to be relieved while preventing atmospheric air from entering the battery. When the valves do function to relieve internal pressure, the gases that escape directly equate to a loss of water from the battery that generally cannot be replaced.¹⁴

The recombination reaction is exothermic, releasing heat at the negative plate. The greater the overcharge current, the greater the oxygen generated at the positive plate. This will result in greater heating at the negative plate and that heat must be dissipated. If thermal equilibrium cannot be reached, thermal runaway may occur (see Annex E). Regardless of whether or not thermal runaway occurs with increasing overcharge current, at some point the oxygen generation rate will exceed the diffusion rate to the negative plate and oxygen and hydrogen gas will be expelled as with a vented cell. The vented gas will remove some of the excess heat, but this is at the expense of water loss from the cell.

¹³ Because this valve only opens one-way, VRLA batteries are often incorrectly called “sealed”, and even so-marketed by some manufacturers. This is not true at all of any lead-acid battery, because if they were sealed the pressure buildup from self-discharge in storage or from charging in use would result in failure of the valve (and thus the capacity of the battery would be fairly quickly compromised by a significant amount), or an explosion (or at least cracking) at the weakest point on the case or cover, or case-to-cover seal.

¹⁴ The exception to not being able to replace this “lost” water is described in IEEE Std 1188a-2014 [B52], informative Annex C.8.3, and is colloquially known as the “special recovery process” or “rehydration”.

During normal charging of VRLA batteries, a small portion of the charge current results in corrosion of their lead positive plate grid structure ~~[Equation (7)]~~. The oxygen consumed by this reaction is not available for recombination at the negative plate, so the only possible reaction at the negative plate is hydrogen gas evolution, ~~in accordance with Equation (6)~~. This low rate but continuous release of hydrogen results in a gradual increase in pressure in the head space of the cell; when the pressure reaches a predefined level the valve opens, some hydrogen is released, and then the valve reseals. The rate of hydrogen release from this process is significantly lower than from vented cells. See 7.2 for gassing rate information.

5.1.2 Nickel-cadmium (Ni-Cd) batteries

Vented Ni-Cd batteries behave in a similar way to VLA batteries on overcharge, releasing hydrogen and oxygen gases in a 2-to-1 ratio: ~~(see 7.2 for gassing rate information)~~. There are also partially recombinant designs, which may or may not be fitted with pressure valves. Consult the manufacturer for specific information regarding gassing rates under ~~the~~ expected operating conditions. In the absence of such information these products may be conservatively treated in the same way as vented designs. In some cases, external recombination vents may be used to reduce maintenance. See 7.2.1 for recommendations for ventilation calculations when such vents are used.

Fully sealed Ni-Cd cells, such as those used in portable appliances, are not suitable for use in stationary float applications.

5.1.3 Lithium-ion (Li-ion) batteries

Unlike their lead-acid and Ni-Cd counterparts, no Li-ion batteries (including the common chemistries of LCO, LFP, LMO, LTO, NCA, and NMC) have a water-based (aqueous) electrolyte (their electrolyte is a flammable organic solvent containing dissolved Lithium salts). From a ventilation perspective, this is important because electrolysis of water (and thus Hydrogen generation and ventilation) does not occur as a normal part of the charging process.

The cells are sealed and do not vent unless they undergo thermal runaway, in which case, measurable amounts of Carbon Dioxide (CO₂), Carbon Monoxide (CO), Hydrogen gas (H₂), other combustible gasses (methane, ethane, propylene, ethylene, etc.), Hydrogen Fluoride (HF), benzene (although not from LFP cells), and volatile organic compounds (VOCs, primarily DEC, DMC, EMC, and PC), and other trace inert and toxic gasses are produced (Baird, et al. [B13] Sturk, et al. [B89]) and vented from the cell. Depending on multiple factors, these gasses may be “contained” inside the battery module or pack unless there is significant cell-to-cell propagation of the thermal runaway and/or fire.

Toxic and combustible gasses that are typically generated, like hydrogen fluoride, carbon monoxide, hydrogen, and methane, from a lithium-ion thermal runaway may reach the immediate danger to life or health (IDLH) or lower flammable limit (LFL) depending on cell size, cell-to-cell propagation, and battery enclosure volume. When they do, the response of the fire suppression system is critical to reduce the chance of combustion and further cell-to-cell propagation through the introduction of clean agents and water; and either the reduction of oxygen (including shutting off sources of outside air), or the venting of the space to reduce buildup of heat and combustible gasses in the space.

Depending on chemistry, cell layout, and other design parameters, early detection [whether built into the battery management system (BMS) or as a separate monitor] of a rise in cell/module temperatures and/or early detection of ejected thermal runaway gasses can be used to possibly limit some of the damage of a thermal runaway event by early control of fire suppression and ventilation systems. Note that these after-the-fact detection systems cannot usually prevent the thermal runaway event from happening, but may limit the number of cells/modules involved. The BMS can prevent thermal runaway from external causes, such as a malfunctioning charging system, but cannot control a thermal runaway resulting from an internal cell short.

Other than LTO (which has a wider operating temperature range), most Li-ion chemistries have a relatively tight temperature window (which varies by chemistry type) in which they can receive full charge current. Outside of this relatively tight window, there is an extended temperature window in which their BMS will allow them to charge at reduced rates. Charging at higher-than-allowed rates results in premature aging and, in extreme cases, can result in short-circuits and possible fire. A well-designed HVAC system can maintain the battery at an appropriate charging temperature, while optimizing its overall performance and life.

More information on Li-ion batteries can be found in IEEE Std 1679.1 [B56].

5.2 Battery application

5.2.1 General

~~Batteries can be categorized either by the type of service or by the type of installation enclosure. Battery applications by service application and by enclosure application are discussed as follows.~~

5.2.2 Service applications

5.2.2.1 Standby or float service

~~In standby or float, a battery is maintained by a charger at or near full charge to maximize the energy available to the application. Common application types are as follows:~~

- ~~—— Telecommunication (low rate, long duration)~~
- ~~—— UPS (high rate, short duration)~~
- ~~—— Switchgear (general purpose, medium duration)~~
- ~~—— Starting batteries (high rate, short duration)~~

~~5.2.2.2 Cycling service~~

~~These applications are characterized by frequent discharge/charge cycles. The increase in discharge/recharge cycles typically increases the amount of gas and heat generated by the installation. However, this is not always true, particularly in photovoltaic (PV) and other applications designed to operate at a partial state of charge (PSOC).~~

5.2 Installation enclosure applications

5.2.1 General

Personnel safety and proximity to critical equipment are important considerations when deciding whether ~~or not~~ a dedicated battery room is ~~needed~~ necessary. For safety reasons, batteries should be enclosed to prevent unauthorized access. An ~~because of safety considerations. The necessary~~ enclosure may consist of a battery cabinet, a cage, enclosing partitions or walls, or a vault. If ~~When~~ enclosure is not feasible, notify personnel ~~should be appropriately notified~~ of any battery-related hazards present. In some cases, local building codes will require batteries to be installed in a dedicated ~~battery~~ room. As the nature of the facility in which the batteries are installed becomes more critical, it is common to see the batteries isolated from other equipment.

5.2.2 Dedicated battery rooms

A dedicated battery room is a specially constructed and equipped area typically used primarily for installation of the battery and other components of the dc system. Batteries are typically installed on open racks. The room is physically separated from other areas, avoiding localized heat sources, with controlled access and doors and partitions determined to meet the required fire resistance rating for the application. For purposes of this guide, a battery room may include the charging or UPS equipment to which the batteries are connected.

Edge¹⁵ IT equipment installations (which are very small) are springing up in telecommunications buildings and other types of commercial/industrial sites. In some cases, usually for fire protection reasons, but also for better thermal management efficiency; the data center/IT equipment may be segregated in an indoor room or pod¹⁶ that has its own fire suppression system, and is generally sealed off from the rest of the building environmental envelope with the exception of interfaces to the building HVAC and power systems. This pod may have its own built-in UPS with batteries (typically VRLA or Li-ion). The pod ranges in size from a single cabinet to an indoor self-contained “room” (see Figure 1¹⁷).



(New)

Figure 1 — Example indoor pod/edge data center

¹⁵ Edge computing typically refers to small conglomerations of 1-12 cabinets/racks of data center equipment (using less than 100 kW) but at a location closer to the end use customer (in order to reduce data transfer latency by milli-, micro-, or nanoseconds) rather than a centralized large data center or “the cloud”.

¹⁶ A pod, PoD (Point of Delivery), or POD (Performance Optimized DataCenter) refers to a small, modular cluster of computing, networking, and storage equipment all contained within a single cabinet, or an indoor or outdoor container with several racks or cabinets contained inside.

¹⁷ Picture reprinted with permission from Delta Group.

5.2.3 Indoor cabinets

Indoor cabinets are enclosures housing batteries and/or monitoring equipment. The purpose of the cabinet is to house the batteries in a compact space while limiting unauthorized access to live electrical components. The batteries in indoor cabinets are almost exclusively of the VRLA type. For small systems, the batteries and charging system or UPS might be located in a common cabinet. While acid mist or vapor is not normally an issue during normal charge modes, if the batteries are vented type, it is preferred that the cabinet ventilation system provide for isolation of the battery exhaust from the electronics.

5.2.4 Outdoor cabinets

The most common (but not the only) applications for outdoor battery cabinets (or equipment cabinets that also contain batteries) are for telecommunications electronic equipment, signal cabinets, and utility substations. Most of these cabinets are equipped with VRLA, VLA, or Ni-Cd batteries for backup. Some outdoor cabinets may have an HVAC system, but many others do not. Those that do not have HVAC may use passive heat exchangers to reduce the interior cabinet temperature rise to no more than 10 °C above outdoor ambient temperatures. Usually, the electronics in the cabinet are in a sealed chamber, so the batteries are typically ~~usually~~ kept in a separate chamber with some sort of ventilation. Outdoor ambient temperature extremes, radiant heating, and cabinet positioning can all affect the performance and health of the batteries.

In addition to the ISO containers described in 5.2.6, some battery energy storage systems (BESS) are deployed in modular cabinets.

Figure 2¹⁸ is an example of one type of outdoor cabinet (they come in many shapes and sizes) that can contain batteries and electronics.

¹⁸ Reprinted with permission from EnerSys, Inc. <https://www.alpha.com/products/item/se48-1616> Alpha Technologies, Inc. SE48-1616 – Datasheet, © 2020.



(New)

Figure 2 — Example of an outdoor cabinet that can contain batteries and electronics

5.2.5 Controlled environment vault (CEV)

The most common application for CEVs is to house telecommunication equipment. CEVs are remote, partially or fully buried structures to house equipment including backup power. CEVs are locked and unoccupied except when maintenance or installation is taking place so they must be remotely monitored. The batteries are normally installed in relay racks and co-located with other electrical and electronic equipment. As the name implies, ventilation and temperature control ~~are~~ are is always present in order to keep the electronic equipment operating within its recommended range. Temperature tolerance of the batteries may be lower than for the electronics (see 7.8.4).

5.2.6 ISO containers

Many energy storage systems with Li-ion batteries are being placed outdoors in modified ISO shipping containers (ISO 668 [B61]) that include HVAC and fire suppression systems. The primary reasons for doing this are to save valuable indoor space for other uses, but also because fire codes (ICC IFC [B41], NFPA 855-2020 [B75]) have more stringent limitations on maximum energy and spacing for indoor applications than they do for outdoor containers.

In addition, data center equipment (along with attendant UPS, batteries, and integral HVAC) is also being placed in modified ISO containers outdoors for space-saving reasons.

ISO shipping containers come in several standard sizes, and the “self-contained” data centers and energy storage systems use a few of these sizes. An example of a modified ISO container used for data center or energy storage equipment is shown in Figure 3.¹⁹



(New)

Figure 3—Example of a modified energy storage or self-contained data center ISO container

¹⁹ Picture reprinted with permission from Saft, a TotalEnergies company. © Saft IHE.

5.2.7 Integrated battery and equipment areas

Sometimes batteries are integrated into equipment areas. For example:

- Telecommunication and UPS system battery plants often share the same space as the equipment they support. Many battery systems in these environments use VRLA batteries. In smaller telecommunications installations, batteries are often mounted on trays in open relay racks below the rectifiers. UPS equipment is more often enclosed in cabinets. The batteries can be integrated into the UPS equipment, or they can be in cabinets.
- Batteries used in larger utility substations are most often VLA. These systems are generally located in the substation control house along with control equipment. In smaller substations where the control house is ~~consists of~~ a single cabinet, the batteries are typically VRLA and enclosed in the substation cabinet.

6. Heating, ventilation, and air conditioning

6.1 General

A well-designed HVAC system for environments in which stationary batteries are installed should simultaneously achieve the following objectives:

- Provide ~~maximum~~ *safety* for personnel and infrastructure
- Optimize *performance* of the battery system within the project's budget ~~budgetary~~ constraints ~~of the project~~ (see Clause 8)

6.2 HVAC design for performance

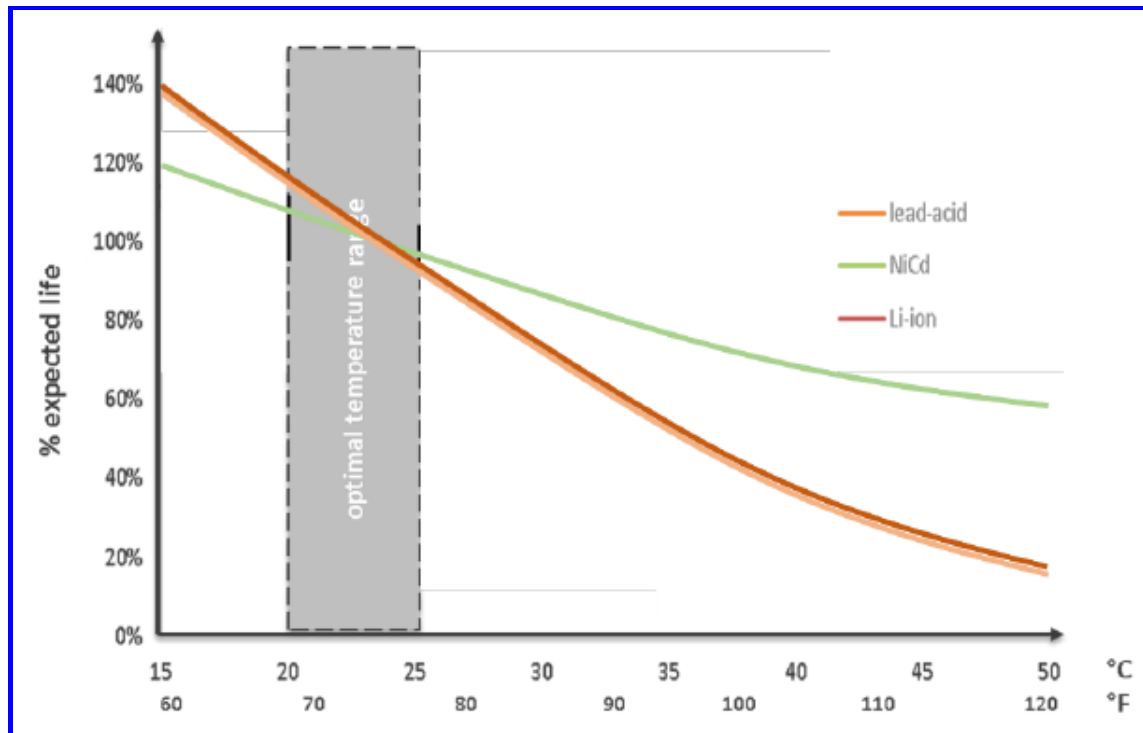
6.2.1 Temperature

6.2.1.1 Battery life

The stated operating life of a stationary battery is typically based on an electrolyte temperature of 25 °C (77 °F) in North America and 20 °C (68 °F) in other parts of the world. Ni-Cd batteries are less affected than lead-acid batteries by temperature extremes. Continuous operation at elevated temperature will reduce the life of a [VRLA ~~lead-acid~~](#) battery by approximately 50%~~%~~ for every increase of 8.3 °C (15 °F) in [continuous ambient temperatures above 25 °C \(77 °F\)](#). For [vented lead-acid \(VLA\) cells, the same holds true for every increase of approximately 10 °C in](#) electrolyte temperature ~~above 25 °C (77 °F)~~. For Ni-Cd batteries life is reduced by 50% for every 30 °C (54 °F) [of continuous operation](#) above 25 °C (77 °F). Operation at reduced temperatures results in some gain in battery life, but the gain is significantly less than the loss of life above the design temperature.

[It is important to note that temporary excursions of temperature do not generally have significant long-term effects on battery life. For example, if an HVAC system fails and is not repaired for three days, during which time a VLA string operates at 35 °C instead of its normal 25 °C, it has not experienced a life reduction of 50%. Instead, it has experienced approximately 6 days of aging in those three days.](#)

[The most accurate information for expected life versus operating temperatures may be obtained from battery manufacturer for specific types and models. However, using the rules of thumb discussed above; the Arrhenius equation; and bibliographic documents Eaton BAT11LTA/GG \[B29\], IEEE Std 1361 \[B53\], and Peng Zhang, et al. \[B79\]; some general differences between VLA, VRLA, Ni-Cd Li-ion chemistries can be derived \(see Figure 4\).](#)

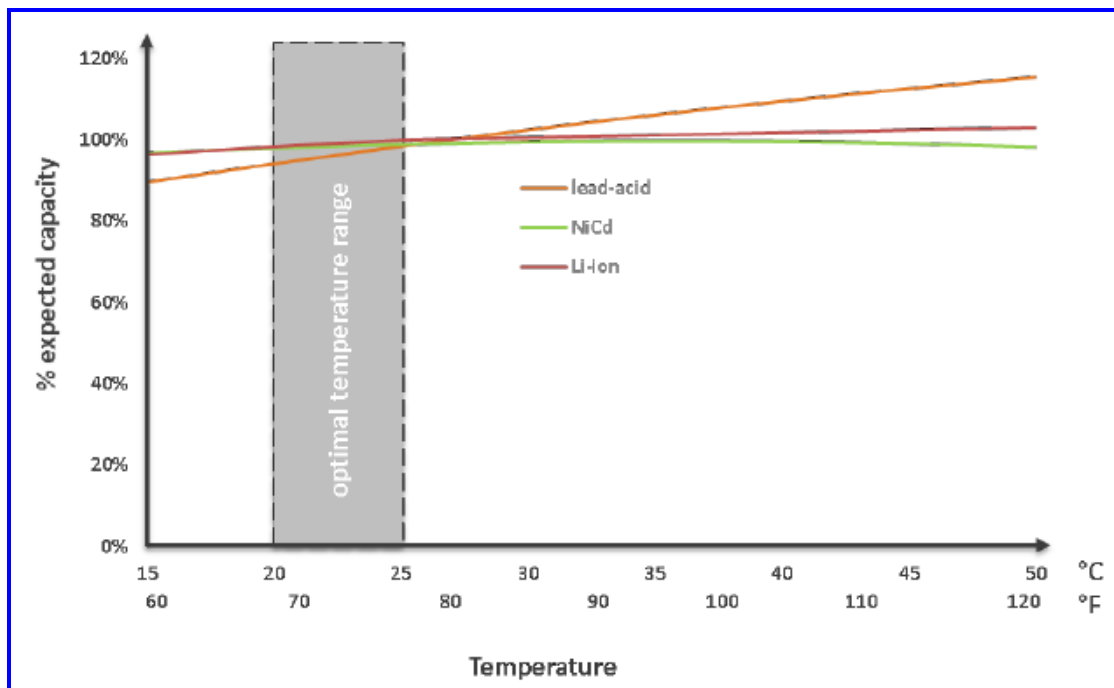


(New)

Figure 4 — Approximate battery life vs continuous ambient operating temperature

6.2.1.2 Battery capacity

The ability to provide power on demand decreases as electrolyte temperature is reduced (and increases as temperature rises). The extent of this decrease or increase depends on battery chemistry, cell design, and discharge rate. The minimum design temperature is established during battery sizing and requires coordination between the battery system and HVAC design engineers. Maximum design temperature affects hydrogen evolution; and thus, both maximum and minimum design temperatures should be known. From the HVAC system design perspective, the ambient temperature is a representative measure of the electrolyte temperature even though the electrolyte temperature will lag behind the ambient temperature. Always consult the battery manufacturer for the specific temperature adjustment factors for capacity for the cell type, but the following example (Figure 5, derived from Groß [B35]) is provided for comparison purposes to show the relative difference in capacity effects of temperature on lead-acid Ni-Cd, and Li-ion batteries.



(New)

Figure 5— Battery capacity vs. temperature approximation

6.2.1.3 Ambient temperature

Changes in electrolyte temperature lag behind changes in ambient air temperature. Parameters that can affect electrolyte temperature as a function of ambient temperature include the following:

- Battery mass
- Spacing/airflow between batteries
- Duration of temperature deviation
- Charging current

[Consult with the battery manufacturer for the optimal temperature ranges for each specific product. However, the following paragraphs give general guidance.](#)

The optimal operating range for [an aqueous](#) a battery (VLA, VRLA, or Ni-Cd) is an electrolyte temperature between 20 °C and 25 °C [\(68–77 °F\)](#). Operation in this temperature range provides the best balance between capacity and battery life. [However, most lead-acid cells can safely operate \(with significant effects on life and/or capacity\) at ambient temperatures between –10 °C to 75 °C \(14–167 °F\). Ni-Cd cells can operate safely at temperatures as low as –40 °C/F with less effect on life/capacity than their lead-acid counterparts.](#)

When a [VRLA](#) battery is float charged, the heating due to the charge current and ~~in the case of VRLA,~~ the recombination reaction results in the internal battery temperature being approximately 1 °C (2 °F) higher than the ambient temperature. Because of this heating effect, the optimal ambient temperature range is 19 °C to 24 °C (66 °F to 75 °F). The optimal temperature range for a specific application depends on the balance between battery life and capacity, the capital and operating costs of the HVAC system, and the requirements of other equipment located in the same area. Achieving this balance requires dialogue between the battery system specifier and HVAC system designer.

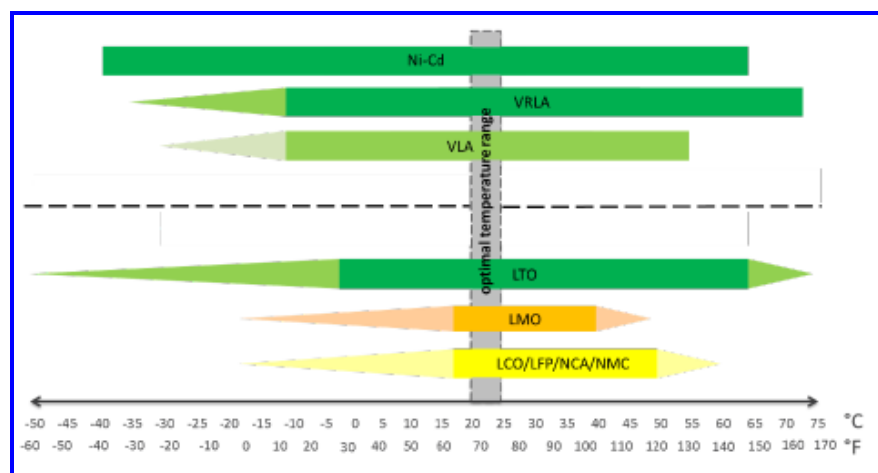
Gassing [of aqueous batteries](#) increases with increasing temperature. In lead-antimony batteries, gassing also increases with age. See Clause 7 for methods to calculate the gassing rates.

As noted in 5.1.3, most Li-ion chemistries have a fairly narrow operating temperature range where they will accept full charge, and a slightly wider range where the BMS will limit the charging current. While the exact values of these ranges depends on the design and exact chemistry mix employed by the manufacturer (thus they should be consulted for the allowable operating ranges), Figure 6 gives an example of the general operating temperature ranges for various chemistries, including comparing them to aqueous chemistries. For the lead-acid chemistries on the low end of the temperature scale, their limitations are on full discharge capability (as opposed to charging capability) at those low temperatures (due to potential electrolyte freezing as they discharge and the electrolyte specific gravity decreases).

Maintaining the battery installation within the optimal temperature range reduces the possibility of thermal runaway [in both lead-acid and Li-ion cells](#).

6.2.1.4 Temperature gradients

Installation design should allow for radiant and convective heat dissipation around the battery. Heat sources and airflow should be managed so as to limit electrolyte differential temperature within a series battery string to a maximum of 3 °C for lead-acid and 5 °C for Ni-Cd batteries.



(New)

Figure 6— Allowable ambient operating temperature ranges for stationary batteries

6.2.2 Air humidity

Batteries can function across a very wide range of humidity. High humidity is generally not a problem [for aqueous batteries without a BMS \(like VLA, VRLA, and Ni-Cd\)](#) unless it condenses and causes oxidation of exposed metal parts, such as intercell connections. [However, it can cause damage to Li-ion battery BMS electronics if condensation occurs.](#) Low humidity conditions are a long-term issue for VRLA batteries due to increased water loss that results in reduced battery life. Low humidity presents no problem for [vented VLA](#) batteries, but it does increase the potential for electrostatic discharge (ESD). Personnel working in close proximity to a battery vent, regardless of humidity level, should take precautions to avoid generating an ESD as it can ignite the hydrogen and oxygen in the head space of a battery, thereby creating the possibility of an explosion even when the battery is fitted with flame arrestors. Relative humidity should be maintained above 20%, ideally between 35% and 65%. No special humidity control features are normally necessary [for aqueous batteries. HVAC systems for outdoor Li-ion enclosures often include a dehumidification capability \(see 7.8.3\).](#)

6.2.3 Air contaminants

6.2.3.1 Dust

Water soluble salts found in dust particulate buildup, especially when it has metallic (conductive) elements and/or is combined with humidity levels above 40%, can lead to accelerated corrosion levels, tracking, and electrical shorting or arcing problems on batteries. It is recommended that medium efficiency filters be used to filter outside air supplied to an indoor battery installation. Filters with ASHRAE 52.2 [\[B9\]](#) minimum efficiency reporting values (MERVs) between 7 and 11 should be used to filter the outside air source ~~(ASHRAE Standard 52.2-2007 [B8])~~.

6.2.3.2 Other contaminants

A comprehensive HVAC design should take into account not only any vapors or gases produced by the battery, but other vapors or gases present in the facility that could potentially damage the batteries or associated equipment. Chemical process industry facilities are an example of facilities likely to contain other vapors or gases of concern. Electrical contacts and connections are particularly susceptible to damage from corrosive chemicals. In more extreme environmental conditions, battery racks may also be vulnerable to corrosive attack.

6.3 HVAC design for safety

6.3.1 Flammable/explosive gases

The potentially explosive gas emitted by all ~~vented~~ lead-acid and Ni-Cd stationary batteries is hydrogen. The hydrogen gas is released in a two-thirds/one-third mixture with oxygen gas. The evolution of this gas mixture depends highly upon the charging current flowing through the battery. The relationship of current to operating mode, temperature, and other factors are covered in more depth in Clause 7.

Flammable and explosive limits apply generally to vapors and are defined as the concentration range in which a flammable substance can produce a fire or explosion when an ignition source (such as a spark or open flame) is present. The concentration is generally expressed as percent fuel by volume (Interactive Learning Paradigms [[B60](#) ~~B42~~]).

Above the [upper flammable limit \(UFL\)](#), the mixture of substance and air is too rich in fuel (deficient in oxygen) to burn (Interactive Learning Paradigms [[B60](#) ~~B42~~]). ~~The upper explosive limit (UEL) is the mixture of substance and air that is too rich in fuel to explode.~~

Below the [LFL](#), the mixture of substance and air lacks sufficient fuel (substance) to burn. ~~The lower explosive limit (LEL) is the mixture of substance and air that is too lean in fuel to explode.~~

WARNING

Any concentration between the LFL and UFL limits can either ignite or explode. While hydrogen and air mixtures above the UFL ~~and UEL~~ cannot burn or explode ~~respectively~~, the introduction of air would cause the mixture to become diluted and the concentration could drop into the hazardous range (Interactive Learning Paradigms [B60 B42]).

The ~~LFL LEL~~ of hydrogen is approximately ~~17% and the LFL is approximately 4% (NFPA 497 [B50]).~~ ~~The UEL is about 56%~~ and the UFL is approximately 75% (NFPA 497 [B74 B50]). While technically incorrect, it is common for the ~~flammable flammability~~ limits to be referred to as the explosive limits.²⁰ In stationary battery installations, the UFL for hydrogen is not exceeded because the gas released from the batteries is not pure. It is a mixture that is one third oxygen gas, two thirds hydrogen gas, and accompanied by small amounts of other elements.

6.3.2 Hydrogen traps

Hydrogen molecules are the smallest and lightest of all naturally occurring molecules. Accordingly, hydrogen is very easily dispersed with a minimum amount of air movement. Hydrogen also mixes with air by diffusion. Usually, unrestricted natural air movement in the vicinity of the battery is sufficient to disperse released hydrogen. If there is insufficient airflow to disperse hydrogen vented from a battery, ~~slightly higher concentrations of concentrated~~ hydrogen ~~pockets~~ may form near the battery vents on the lower tiers of a battery rack. Ensuring good air movement through the battery racks will prevent hydrogen concentration.

²⁰ The flammable range for hydrogen (4-75% concentration in standard atmosphere at standard temperature and pressure) is much more well-accepted by international standards and safety professionals than are the explosive limits. NFPA recognizes that there is a difference between flammable and explosive (NFPA 68 [B66], NFPA 69 [B67]). Depending on conditions (including pressure buildup) the lower explosive limit for hydrogen is slightly higher than the LFL, and the upper explosive limit is slightly lower than the UFL. Because of the dependence on conditions range of the explosive upper and lower bounds, most standards and safety professionals do not differentiate between flammable and explosive limits, i.e., LEL=LFL, and UEL=UFL.

6.3.3 Confined spaces

Ventilation of confined spaces ([HSE L101 \[B39\]](#)) is of particular importance because of the increased possibility of hydrogen traps forming flammable or explosive hydrogen concentrations. One example of such a space, where batteries are installed, is a CEV in a remote telecommunications site (see 7.8.4).

6.3.4 Thermal runaway

Thermal runaway can occur in any aqueous battery type, but is [more prevalent](#) ~~most likely to occur~~ in a VRLA [AGM](#) battery due to its [“starved electrolyte” design](#).²¹ ~~limited water content~~. HVAC designs that fail to provide adequate ventilation and temperature control, or electrical designs with oversized chargers or excessively high charger voltage settings contribute to the phenomenon. Operational issues such as ventilation or temperature control malfunctions, individual cell failure(s), or charger malfunctions may aggravate the situation. During thermal runaway, hydrogen gas evolution greatly increases. The event may continue without abatement, causing other gases and particulates to become airborne. ~~For VRLA batteries,~~ Thermal runaway is a ~~significant~~ safety concern, but it can be detected and controlled with appropriate safeguards in the electrical system design. See Annex E for more information on thermal runaway.

Thermal runaway in vented lead-acid batteries is rare and most commonly occurs [when batteries have been left in past their useful expected lifetime and develop micro-shorts \(typically due to shedding of the active material from the plates, or antimony migration\)](#) ~~in lead-antimony designs towards the end of life when charging current is at its maximum~~.

Thermal runaway in Ni-Cd batteries is normally associated with separator breakdown resulting in recombination heating (see Annex E for additional information).

²¹ [Gel VRLA cells have greater thermal mass than their AGM VRLA counterparts, thus making them less susceptible to thermal runaway.](#)