Considerations for Using Mobile Computers in Environments Beyond Office Space

Overview

Mobile computers are quite often exposed to and operated within less than ideal conditions. They can be exposed to dust, moisture, extreme temperatures, or UV radiation outside of standard office space, which is temperature controlled, and relatively clean and dry. How the device is designed to withstand these conditions is very important to how it will perform, as well as survive in extreme conditions.

The mobile computer industry uses a standardized rating system for determining how resistant a device is to damage from “ingress” of water and dust. Understanding condensation and what drives it is key to understanding the limitations of devices to withstand condensation and perform the tasks needed in different use cases.

Extreme temperatures and, in particular, the transition between extreme temperatures can provide a different path for moisture to create potential damage without it “leaking” into the product.

Another factor concerning a mobile computer outside the office space is the effect of extremely high or low temperatures on battery performance and life.

This document examines considerations that must be addressed in order for mobile computers to withstand extreme conditions. It also lists various options when choosing devices for their particular applications. The following topics are covered:

- Understanding the standardized rating system of a device’s resistance to damage from water and dust
- Understanding the limitations of devices to withstand condensation
- Understanding the effects on a device of large amounts of UV light
- Effects of extreme temperatures on battery performance and life

Product Sealing Effectiveness and IP Ratings

A standardized Ingress Protection (IP) rating classifies and rates the level of sealing effectiveness provided by mechanical casings and electrical enclosures for a specified application. The IP rating indicates ingress protection for a new product.

A product’s IP rating can, and often does, degrade after the product is dropped and/or exposed to environmental hazards that compromise the material strength, such as a chemical attack, extreme temperatures, impact forces, or other factors due to distortion, cracking, and structural degradation that may occur.

It should also be noted that IP sealing provides little protection against internal condensation formation as the device transitions between warm, humid areas, and refrigerated/air conditioned or freezer environments.

OVERVIEW OF IP RATING SYSTEM

The international IP rating system, IEC 60529, utilizes the two letters “IP”, followed by two numbers, as follows:

IP*XY*

- The first number (*X*) represents a product's resistance to the intrusion of particles or dust
- The second number (*Y*) represents a product's resistance to the intrusion of liquid (standardized testing uses distilled water)

The highest rating level for dust protection is 6, and for water protection it is 8. An IP rating of “IP67” represents a level 6 for dust protection and level 7 for water protection.

Note: The British standard for IP is EN 60529. While slightly different in the details, it is largely the same as the more universal IEC 60529.

IEC 60520 IP RATINGS (DUST AND WATER)

First Digit	Level of Dust Protection	Second Digit	Level of Water Protection
0	No protection	0	No protection
1	Protection against objects over 50mm; accidental touch by hands	1	Protection against vertically dripping water
2	Protection against objects over 12mm; protection against touch by fingers	2	Protection against liquid drops at 15° from vertical
3	Protection against objects over 2.5mm; tools, wires, etc.	3	Protection against rain at angle of up to 60° from vertical
4	Protection against objects over 1mm; small tools, wires, etc.	4	Protection against splash from any direction
5	Complete protection against contact; protection against harmful ingress and deposit of dust	5	Protection against water jets from any direction
6	Complete protection against contact; protection against ingress of dust	6	Protection against powerful jetting
-	N/A	7	Protection against immersion in one meter of water for 30 minutes
-	N/A	8	Protection under continuous immersion in water depths beyond 1 meter

EN 60529 IP RATINGS (SOLID OBJECTS)

First Digit	Access to Hazardous Parts	Solid Foreign Objects
0	No test required	No test required
1	The Rigid Sphere without handle or guard of 50mm +.05 / -0mm diameter shall not fully penetrate and adequate clearance shall be kept. Insertion force 50 N ± 10%.	
2	The jointed test finger may penetrate up to its 80mm length, but adequate clearance shall be kept	The Rigid Sphere without handle or guard of 12.5mm +.2 / -0mm diameter shall not fully penetrate. Insertion force 30 N ± 10%.
3	The rigid steel test rod of 2.5mm +.05 / -0mm diameter with edges free of burrs shall not penetrate and adequate clearance shall be kept. Insertion force 3 N ± 10%.	
4	The rigid steel test wire of 1mm +.05 / -0mm diameter with edges free of burrs shall not penetrate and adequate clearance shall be kept. Insertion force 1 N ± 10%.	
5	The rigid steel test wire of 1mm +.05 / -0mm diameter with edges free of burrs shall not penetrate and adequate clearance shall be kept. Insertion force 1 N ± 10%.	Dust-Protected Dust chamber with or without being under pressure Enclosure: Category 1 (Vacuum Drawn) Category 2
6	The rigid steel test wire of 1mm +.05 / -0mm diameter with edges free of burrs shall not penetrate and adequate clearance shall be kept. Insertion force 1 N ± 10%	Dust-Tight Dust chamber with or without being under pressure Enclosure: Category 1 (Vacuum Drawn)

EN 60529 RATINGS (LIQUIDS)

Second Char. Numeral	Test Means	Duration of Test
0	No test required	N/A
1	Drip Box	10 minutes
2	Drip Box 15° Tilt, 4 positions	2.5 minutes each position
3	• Oscillating Tube ±60° from Vertical or • Spray Nozzle	• 10 minutes • 1 min/m^2 at least 5 minutes
4	Oscillating Tube ±180° from Vertical	• 10 minutes • 1 min/m^2 at least 5 minutes
5	Water Jet Nozzle	1 min/m^2 at least 3 minutes
6	Water Jet Nozzle	1 min/m^2 at least 3 minutes
7	Immersion Tank	30 minutes
8	Immersion Tank	By Agreement between manufacturer and user

What IP Ratings Mean to the Mobile Computer User

A mobile computer user should understand the IP rating necessary for their device, based on the type of environment and conditions in which it will be used. Some examples of use cases and the likely required IP ratings are as follows:

- Clean Indoor Office
  - Will not be going in and out of a cooler or freezer
  - Unlikely to be exposed to water
  - An IP rating on the device may not be needed at all
- Dusty Indoor Office
  - Dust may be in the air from the handling paper and cardboard
  - Will not be going in and out of a cooler or freezer
  - Unlikely to be exposed to water
  - An IP rating of IP53 is probably what is needed, with the “5” protecting against airborne dust and the “3” protecting against a random splash from someone watering a plant or spilling their beverage
- Brief Exposure to Non-Continuous, Soft Rain
  - May be exposed to rain spray (not continuous rain) while running between a vehicle and a building
  - Could be exposed briefly at any angle to the water
  - The desired water ingress rating would likely be a “4”. IP54 ratings are generally good for these applications.

Note: As the water intrusion protection numbers move to “5” or higher, the dust protection number almost automatically needs to move to the highest value of “6”.

- Brief Exposure to Non-Continuous, Driving Rain
  - May be exposed to driving rain (not continuous rain) while running between a vehicle and a building
  - Could be exposed briefly at any angle to the water
  - The desired water ingress rating would likely be a “5”. IP*X***5** ratings are generally good for these applications.
- Continuous Exposure to Driving Rain
  - May be exposed to driving rain continuously
  - Could be exposed at any angle to the water
  - The desired water ingress rating would likely be a “6”. IP*X***6** ratings are generally good for these applications.
- Briefly Submerged in Water
  - May be dropped into a puddle and fully submerged, but NOT exposed to driving rain continuously
  - The desired water ingress rating would likely be a “7”. IPX**7** ratings are generally good for these applications.

  Note: The “7” rating does indicate resistance to submersion for short periods of time, but does not protect against the impact of driven rain.
- Moved In and Out of Cooler or Freezer
  - Will be going in and out of a cooler or freezer
  - An IP rating of any number will **not** protect it from moisture accumulating inside. Only hermetically sealed devices prevent the leaching of moisture over time when cycled through temperatures. Devices made of plastic **cannot** be hermetically sealed due to the nature of plastics.
  - To avoid internal condensation when going in and out of a refrigerated area, the device needs to either have a mechanism for drying the air inside the device (a desiccator) or have a heater that maintains the internal air above the dew point.

Cold and Freezer Applications

INTRODUCTION

Some of the most demanding mobile computer use case scenarios are those that expose the mobile computers to cold or freezer applications; particularly those that involve going from warm to cold environments and vice versa.

A prime example of such a use case would be a warehouse setting where a user needs to go in and out of a freezer and deliver items to warm and humid loading docks. Such environments cause internal and external moisture formation from condensation, which can also freeze upon entering the cold environment again, forming a layer of frost.

In order to circumvent the potential issues that can come about with cold applications, a mobile computer must have special features to allow it to perform normally and protect against damage. Manufacturers offer different product options that have variants designed for cold and freezer applications.

Condensation and Dew Point

Condensation is the formation of liquid water drops when there is direct cooling of warm air at or below the saturation point, also called the *dew point*.

When warm air comes in contact with cold objects, moisture will condense if its surface temperature is at or below the dew point, as shown in Figure 1.

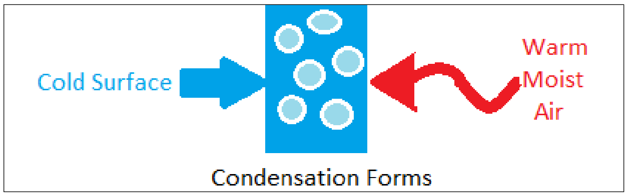

Figure 1: Condensation Formation Due to the Direct Cooling of Warm Moist Air

A common scenario illustrating this phenomenon is the moisture or dew that forms on the grass in the morning. This is a result of the grass being cooled to or below the dew point of the air.

With regard to mobile computers, this situation commonly occurs when warm air around the mobile computer comes in contact with the much colder surface of the device. If the temperature difference is large and the warm air holds a lot of moisture, the dew point will be met more easily.

The diagram below depicts how warm air holds more water since the air particles are more spread out, compared to cold air, in which the particles are pulled together, forcing water to be released.

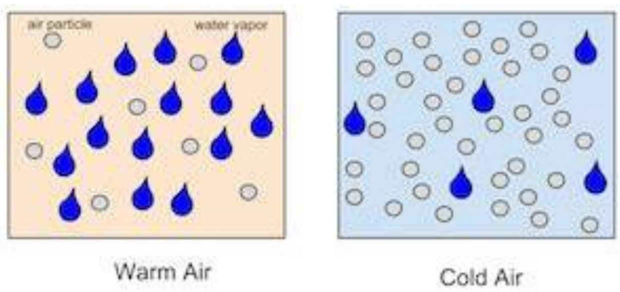

Figure 2: Water Particles in Warm vs. Cold Air

It is important to make sure the device is resilient to such an environment; otherwise, issues can arise from condensation forming within or on the device.

POTENTIAL RISKS FROM CONDENSATION

- Condensation can form on the scan exit window, causing the scanner to function poorly. Scan exit windows cool more quickly than other components since the “thermal mass” is less; this leads to condensation forming on either side of the window more easily than other areas.
- Moisture forming on the touch panel will turn to frost upon entering the freezer environment again; this will make the visibility of the display poor, without defrosting.
- Frozen or stuck keys, if water builds around the keys, and then freezes.
- Moisture forming on sensitive components may lead to internal shorts.

Reasons such as these are why it is critical to understand the particular use case and determine if a product specifically engineered for cold environment applications is required.

Product Sealing

There is a major difference between something being hermetically sealed versus being environmentally (particle and water) sealed, as follows:

- Hermetic Seal—an airtight seal
- Environmental Seal—a seal resistant to water and debris particles according to the associated IP rating (discussed earlier in this document)

Hermetic seals are not possible for mobile computers; with openings such as microphone holes and speaker grates, the device can never be airtight. Moist or humid air naturally moves to an area with lower humidity content. Moving from a hot environment, where air expands, to a cold environment, where air contracts, will enable the air (with water vapor) to migrate into the housing.

Not all products are rated to hold up well in cold applications. Without the right equipment, you face the risk of poor productivity due to the negative effects that can come with out-of-specification usage.

Design Options for Moisture Management

Several design options can be used with a mobile computer to reduce the risks of condensation, and other issues associated with cold usage. The main features to consider when thinking about cold application-ready devices are heaters, housing design, batteries, and components.

HEATERS

The use of a heater within a device helps to mitigate the risk of condensation by maintaining a relative constant temperature within the internal region of the device.

A heater in the device offers the following advantages:

- Reduces Air Cooling—helps to avoid the direct cooling of the air, which causes condensation to form
- Prevents Panel Fogging—limits the risk of touch panels frosting over and restricting the visibility of the display. (A familiar example would be using a defroster in your car to prevent the windshield from fogging with condensation.)

HOUSING DESIGN

Housing design is critical in cold applications, as extremely cold temperatures make the plastics more brittle. Desirable design factors include:

- Resistance to Cracking and Deformation—a poor design or insufficient material selection could cause failures due to cracking or other permanent deformation. Any sort of cracking or deformation can completely void the device's seal (IP) rating, and provide easy paths for moisture to move into the device. (See the Product Sealing Effectiveness and IP Ratings section for more details.)
- Internal Air Volume—another design factor that can help the mobile computer resist condensation is the volume of air that can fill the device. The amount of water vapor that can enter a device is directly related to the volume of air, meaning the condensation resistance is greater if the available volume of air is small.

BATTERIES

Standard Lithium Ion (LI-ion) batteries do not handle cold environments well and will lose their charge more quickly than at room temperature.

Specific cold application batteries are designed for high performance in low temperatures. This is discussed in detail later in this document.

COMPONENTS

Anti-Moisture Coatings

Components and parts designed for cold applications, where moisture due to condensation may form, can benefit from an anti-moisture coating. This avoids the risks of internal shorts or fogged scan exit windows, where non-coated components could have issues.

There are two main types of coatings:

- Conformal Coating—covers the electrical components within the device
- Glass Coating—resists moisture buildup on the scan exit window

For example, a glass anti-moisture coating enables ski goggles to work effectively by keeping moisture from building up, which would limit a skier's vision.

Desiccants

Another primary option to avoid the risk of condensation, causing moisture buildup on critical components, is the use of a desiccant. Different types of desiccants include, but are not limited to:

- Silica gel
- Calcium chloride
- Molecular sieves
- Calcium sulfate

A popular example of a desiccant is the small, porous packet filled with silica gel that is commonly pre-packaged with electronics or a new pair of shoes. Unlike a heater, a desiccant does absorb any moisture that seeps into the device.

Moisture Management System Limitations

Some degree of limitation exists for each method of moisture management for the mobile computer, and is important for the user to consider.

HEATERS

The use of a heater helps keep the internals of the device warm, but does not do anything to absorb moisture. It is natural for moisture to be pulled into the device when it goes into a cold space from a hot space (if the change in temperature is large between the hot and cold environments).

- Heaters do not eliminate the moisture that forms inside, and this moisture may still negatively affect performance if any moisture does find its way to a sensitive component.
- The benefit seen by using a heater only lasts as long as the heater is running. Once turned off, the moisture that has accumulated will condense out onto internal components if the device is left in a cold environment.
- Battery performance of handheld devices will suffer immensely if the heater does runs constantly. (This is *not* an issue for fixed mounted devices with access to power for charging.)

HOUSING DESIGN

No handheld devices can have hermetic seals. Without a hermetic seal, there is risk of moisture entering the device in the form of water vapor within the air, which can condense out; depending on the conditions, this risk will vary.

COMPONENTS

Conformal anti-moisture coatings make servicing printed circuit boards (PCBs) very difficult since the coating needs to be removed and reapplied. Ultimately, repairing the PCB is not worth the labor, and consequently, the boards end up being scrapped if any issues arise.

DESICCANTS

Although using a desiccant is a great way to help with condensation since it absorbs the moisture, the following limitations exist.

- Over time, the desiccant becomes fully saturated and needs to be replaced. Depending on the environment, volume of desiccant, and type of desiccant, the amount of time for the desiccant to become fully saturated (cannot absorb any more water) can vary greatly.
- Usually, space constraints within the handheld devices limit the volume of desiccant that can be used.
- With a rapid change in temperature, some condensation can still form due to this temperature shock, drawing excessive water out of the air.

Best Practices

To limit any reduction in productivity to which condensation will contribute, some basic guidelines should be followed:

- Try to limit the amount of the transitions between cold and hot environments.
- Employ strategic planning on a daily basis to avoid many scenarios where there is high risk of condensation or frost forming.
- Keep the device in the environment in which it is being used (if being used in the “cold”, it would be beneficial to take the battery out to avoid the negative effects on battery capacity).
- If condensation does form on the outside of a mobile computer screen/touch panel, for example, it is critical that the user does not wipe it with anything abrasive, such as a work glove. This will cause permanent scratching, which over time will impact performance to the point that it may not function.
- Good practice for any user of a device where condensation may form includes using a lint-free cloth to non-abrasively clean any moisture.

Battery Performance and Longevity at Extreme Temperatures

This section provides high-level information regarding the effects of temperature on Lithium-Ion batteries during normal use, including tips for increasing battery performance and life.

HOW LITHIUM-ION BATTERIES WORK

The Lithium-Ion (Li-Ion) battery chemistry works by employing a positive electrode (cathode), negative electrode (anode), and an electrolyte in between. Lithium ions flow from the positive to negative electrodes through the electrolyte during charging and in the opposite direction when in use to power a device (see Figure 3).

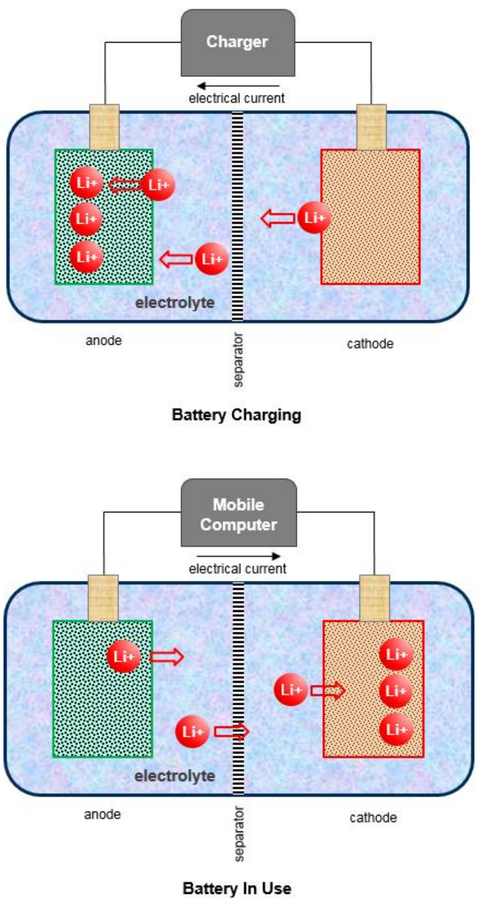

Figure 3: Battery Charging vs. Battery In Use

This process works best at or around room temperature and encounters problems at higher and lower temperatures, which are explained in subsequent sections. For devices that are intended for use in adverse conditions, it is unavoidable that batteries are exposed to environments outside normal operating range. An understanding of the effects temperature has on the battery cells will help users know what to expect, avoid frustration, and increase useful battery life.

CHARGING AT TEMPERATURE EXTREMES

The normal temperature range for charging Li-Ion batteries is 0°C to 45°C (32°F to 113°F). The temperature is measured at the battery cells inside the battery pack by an internal thermistor. It is important to note that the charging or discharging of a battery generates a small amount of internal heat.

The following effects occur near or beyond these extremes.

Charging at Low Temperatures

- Below 5°C (41°F)—charging is slowed to avoid damage to the cells, resulting in an increased charge time.
- At 0°C (32°F) and below—charging is prevented. A layer of metallic Lithium can start to form on the anode, even though the battery appears to be charging normally.
  - This effect is permanent and irreversible, and can lead to cell failure when exposed to shock or vibration (drop, tumble, or use in a vehicle)
  - Internal protection circuitry prevents charging at temperatures below the freezing point; however, because batteries generate their own heat during use, they may still charge just below 0°C ambient conditions

Charging at High Temperatures

Batteries subjected to elevated charging temperatures above 45°C (113°F) experience a decrease in service life (amount of times the battery can be charged and discharged). For this reason, the protection circuitry is used to halt charging above this threshold.

Because batteries generate their own heat during use, an internal battery temperature of 45°C can be reached in an environment where the external temperature is lower than 45°C, and users may see charging stop before the air temperature reaches 45°C.

DISCHARGING AT TEMPERATURE EXTREMES

All batteries are discharged most effectively at temperatures of 20°C (68°F) or slightly lower. Many devices are designed to be used in environments well above and below this range; however, extreme temperatures affect the battery cell's ability to utilize the stored energy. This phenomenon is common with every portable computing device using Li-Ion technology.

This section describes the battery characteristics when discharged close to or beyond the product's ratings.

Discharging at Low Temperatures

Li-Ion batteries work well until the temperature gets close to -20°C (-4°F). Near this temperature, performance drops drastically. Some internal heat is generated by the battery while in use that helps keep the cells warm, but once the cell temperature reaches -20°C, all function ceases with standard Li-Ion chemistry. Functionality resumes when the battery temperature is increased into the working range.

Discharging at High Temperatures

When consistently powering devices at temperatures higher than 20°C, battery cycle life suffers. Batteries used regularly at 30°C will experience a cycle life reduction of about 20%.

For example, if a new battery is designed to last 500 charge/discharge cycles, when used at 30°C regularly, it can be expected that its life will be reduced to approximately 400 charge/discharge cycles. At 40°C, the reduction can be closer to a 40% (approximately 300 total cycles) and at 50°C, it will only retain about half its intended life.

DOS AND DON'TS OF CHARGING LI-ION BATTERIES

Lithium-Ion battery chemistry is currently the best option for general use portable computing device batteries. Charging and using them within the recommended temperature range and the following dos and don'ts (and in the product guides) will increase their performance during use and extend service life, keeping battery replacement costs down, and ensure safe operation.

Dos

- ✓ Keep battery and charger contacts clean and dry to optimize charging and reduce charge times. Dirty contacts increase contact resistance, which generates heat and increases charge time.
- ✓ Charge batteries within the recommended temperatures listed in operation manuals and the above guidelines. Room temperature (around 23°C or 73°F) is best.
- ✓ In cold environments, keep spare batteries (if carried during a shift) warmed in a pocket, if possible, to increase performance. Be sure that there are no other metallic items in the same pocket. When swapping batteries, place the used (depleted) batteries in the pocket so that they stay above freezing and can be readily charged when returned to a docking station.

Note: Batteries used in devices that experience extreme temperatures (below 0°C and above 45°C) need to be brought to a temperature within the charging range above before charging can take place.

- ✓ Batteries that are not being used or charged should be stored as close to room temperature as possible (23°C or 73°F) in a dry location. Li-Ion batteries not in use for a longer period of time (that is, more than a month) should be charged about halfway (about 50% full) before storing, rather than fully charged, to prolong service life.
- ✓ Li-Ion batteries normally become warm (about a 5°C increase) when just finishing a full charge. If the battery feels excessively hot (>10°C difference from room temperature), discontinue use and dispose (recycle) of battery properly.

  Note: Always recycle Li-Ion batteries according to established policies after their useful service life.

Don'ts

- ✗ Avoid discharging batteries completely before charging, as repeated full discharges reduce a battery's cycle life. Instead, carry a spare and replace the battery when the state of charge falls below 20%.
- ✗ Do not place a battery that is at below freezing temperatures into a charger. Allow it to warm up to room temperature before charging.
- ✗ Do not submerge batteries in water.
- ✗ Do not short the contacts on a battery with anything metallic or conductive.
- ✗ Do not clean the battery contacts with any abrasive material or sharp object. Follow the product operation guides for cleaning instructions.
- ✗ Do not use batteries in any device or for any other purpose than the device for which it was intended.
- ✗ Do not attempt to disassemble any type of battery.
- ✗ Never discard Li-Ion batteries in the trash or incinerator.

Effects of UV Radiation

Exposure to large amounts of UV light can have detrimental effects on mobile computers. The sun produces far more UV light and radiated heat than the lights in an office environment. UV radiation is as harmful to almost every material as it is to the human skin and eyes. Understanding this and knowing the limitations of the device can extend its life significantly. Currently, no industry standard exists for UV resistance.

UV radiation breaks down the chemical structure in plastics and causes them to fade, as well as release the plasticizers that make them soft, resilient, and/or impact resistant.

The following list includes design and use guidelines regarding UV radiation:

- Some products use UV-resistant plastics that limit fading and chemical breakdown. Prolonged exposure to the sun, however, can still damage housings over time, as it would do to any product made of almost any material.
- Touch panels used in front of many displays contain a transparent and electrically conductive layer. This material is sensitive to UV radiation. Where possible, Zebra touch panels incorporate polarizers to limit the damage caused by prolonged exposure to UV radiation.
- Avoiding extended exposure to UV radiation is the most effective method to prevent UV damage to a touch panel.