Cold Weather Shipping Acclimation and Best Practices

White Paper Developed by
ASHRAE Technical Committee 9.9, Mission Critical Facilities,
Data Centers, Technology Spaces, and Electronic Equipment

ASHRAE®

Peachtree Corners

This white paper was developed by
ASHRAE Technical Committee (TC) 9.9, Mission Critical Facilities, Data Centers, Technology Spaces, and Electronic Equipment.

www.ashrae.org/datacenterguidance
http://tc0909.ashraetcs.org

Contents

Acknowledgments

The ASHRAE TC 9.9 committee would like to thank the following list of contributors for their time and expertise in writing this white paper:

- Mark Steinke—Cray
- Paul Artman—Lenovo
- Eric Tunks—Dell
- Scot Heath—Microsoft
- Matt Shumway—Seagate
- Dustin Demetriou—IBM
- Milnes David—IBM
- Sharon Spaulding—IBM
- Bill Green—IBM
- Bob Sanders—IBM (Retired)
- Joe Prisco*—IBM
- Roger Schmidt—Syracuse University

These contributors invested a considerable amount of time in conference calls, doing research, writing drafts, and creating figures and tables, as well as reviewing and editing text.

* Lead of the white paper team

Introduction

New information technology (IT) equipment hardware is scheduled for delivery. It is January in the northern hemisphere and the winter season. The weather is very cold with daily low temperatures far below 0°C (32°F). The delivery arrives at the receiving area, the shipping doors open, and everyone in the immediate area can see their breath as each exhalation meets the frigid air. The IT equipment is unloaded from the truck and brought indoors. The shipper is asked to immediately remove the protective cardboard and plastic polyethylene bag (commonly referred to as a poly bag) in the receiving area before the IT equipment is moved into the data center. As the minutes pass inside the humidified space of the data center, frost or ice crystals start to form on the covers of the new IT equipment. See Figure 1.

What is going on? Is this going to damage the new IT equipment rack, cabinet, or frame and its contents? What can be done to prevent condensate? This white paper will address these questions and provide additional guidance on shipping IT equipment that is not covered in *Thermal Guidelines for Data Processing Environments, Fourth Edition* (ASHRAE 2015).

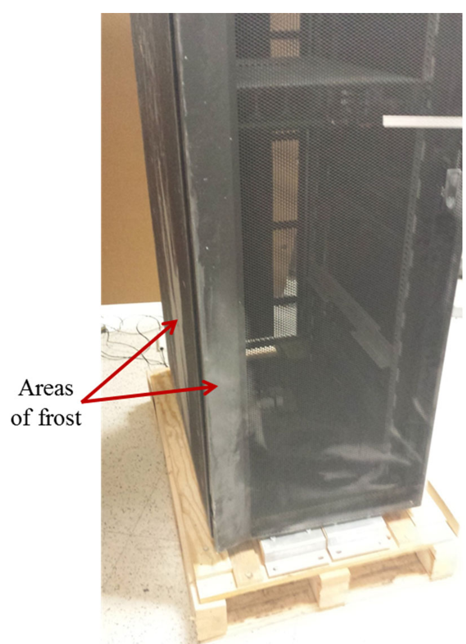

Figure 1 Frost on the covers of an IT equipment rack (also known as a cabinet or frame).

Cold Weather Shipping Background

IT equipment is cooled during transportation in the frigid weather, generally below the dew-point temperature in a humidified indoor environment. When the equipment is brought inside a heated building, the moisture of the warmer, higher dew-point indoor air makes contact with the cold IT equipment and condenses on the surfaces. This is the same phenomenon that occurs to people who wear eyeglasses. After being in a cold outdoor environment and entering a warmer indoor environment, the lenses fog up with condensate. The difference is that IT equipment has far more mass than eyeglass lenses. When the outdoor temperatures are extremely cold, it takes a long time for the IT equipment to cool down, but more importantly, it takes a long time to warm up or acclimate to the indoor temperature. If the IT equipment temperature is below the freezing point of water, condensate will freeze and form a layer of ice crystals on the IT equipment when exposed to warm, moist air. The amount of ice crystals will vary based on the temperature of the IT equipment and the dew point of the indoor air. This is a normal phenomenon that could be observed if the product packaging, including the polyethylene bag, foam, and cardboard is removed prematurely as equipment is rushed into data centers. The packaging acts as an interface or vapor barrier, allowing the equipment to acclimate with minimal data center air contact. With packaging on, the formation of condensate directly on and within the IT equipment is significantly less than if packaging is removed.

The Process of Condensation

Condensation is the conversion of a gas to a liquid, whereas *condensate* is the liquid formed by the process of condensation. For instance, a cold drink forms condensate on its exterior. See Figure 2.

The liquid water which is present on the outside of the glass comes from the air in the room. The amount of air that must pass by the glass such that the water vapor in the air can condense on the glass is less obvious. As a simple experiment, two glasses are filled with ice and water (see Figure 3). One glass is placed in a sealed plastic storage bag and the other is not placed in a bag. The tops of both glasses are covered to prevent moisture from escaping the glass.

After a period of exactly two hours, the glass without the bag has already formed a small amount of condensate. The bag with the glass inside is opened and has no visible condensate. See Figure 4.

There are two important results from the simple experiment. First, the glass that is inside the bag is dry. It undoubtedly has a tiny bit of condensate, but for the most part, there is no water on the glass. Second, the amount of ice melt that has occurred is very similar. Ice cubes were not weighed, but an equal number of ice cubes were placed in each glass at the beginning of the experiment.

The water that condenses on the cold IT equipment comes from the conditioned air inside the data center. Some sources for this moisture include humidification, air exchange with the outdoors, and humans. All data centers have some rate of exchange of indoor air with fresh air from the outdoors. During cold weather, the air that is brought into the data center is very dry. The dew point of the outdoor air cannot be greater than the outdoor dry-bulb temperature as any moisture above this level will condense outside. For instance, if the dry-bulb temperature outdoors is –10°C (14°F) and the relative humidity outdoors is 90%, the dew point of the outdoor air is –11°C (12°F). Nothing will condense on objects and surfaces that are cooled to –10°C (14°F) if the objects and surfaces are in the outdoor environment. If the outdoor air is brought inside and heated to 25°C (77°F) without any moisture added, the relative humidity would be 8%. This value is much lower than the relative humidity set point of most data centers. Moisture is typically added to boost the relative humidity. As a result, the dew point also increases. The same equipment on which condensate did not form while it was outside the building will have condensate form on it once it is brought into the humidified data center.

Limiting the exposure of the cold equipment to moist air is an effective method to prevent direct condensation from occurring on the equipment. If the cold equipment is kept inside a sealed or closed plastic bag until it has warmed

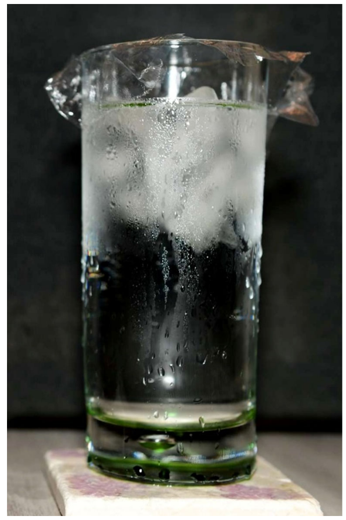

Figure 2 Condensate on the outside of a cold glass.

Figure 3 Initial state of glasses.

Figure 4 Glasses after two hours.

above the dew-point temperature, condensation directly on or within the equipment will be significantly reduced. In the experiment, the plastic bag around one of the glasses is sealed. For most IT equipment racks, the plastic bag is placed over the IT equipment and is open at the bottom. For most 1U-4U volume servers, the plastic bag completely encloses the IT equipment but is not sealed. Regardless of the whether the plastic bag is totally sealed, it is an effective method to reduce condensate.

IT Equipment Shipping Practices and Packaging for Transportation

IT equipment has historically been shipped by truck, including both dedicated carrier (where a truck and trailer are used solely for a single product sent to a single destination) and less than truckload (LTL), which consolidates other freight. These modes of transportation may have the transported product temperature controlled for part of the journey. Air cargo is also heavily utilized, particularly due to the high value of the products and high interest on the part of end users to receive the IT equipment and get it operational. Ocean shipment of IT equipment does not currently represent a significant portion of the total shipments of IT equipment. However, ocean shipment is increasing in interest due to lower transportation costs. Regardless of the mode selected, a substantial portion of the journey will be by truck for all local deliveries and for getting the product to and from the airport or seaport. Temperature controls are possible with all modes of transportation, but it is not the norm and, unless specifically arranged, cannot be entirely relied upon. Shippers can expect their products to be potentially exposed to temperature extremes from –40°C to 60°C (–40°F to 140°F) in the distribution cycle, depending on the mode, time of year, and region. Temperatures in the air cargo hold of an airplane are typically controlled to remain above freezing in the cargo positions, but equipment can still be exposed to freezing temperatures during ground transfers.

Racks, Cabinets, and Frames

When shipping LTL, dedicated carrier, or internationally by land, air, or sea, IT equipment racks (also called cabinets or frames) are shipped in a protective package on some type of wooden pallet to increase stability, to add protection against shock and vibration, and to facilitate safe handling in transit networks. As part of the protective packaging, the IT equipment racks are covered with a non-heat-sealed polyethylene bag to prevent dust and to protect against abrasion. Some packages also use cushions or other types of protection. The outer packages can range from cleated wooden crates to large corrugated cardboard boxes with transparent plastic stretch wrap. These types of packages are designed to protect the products against rough handling, including additional freight in LTL, air cargo, and other networks during transit.

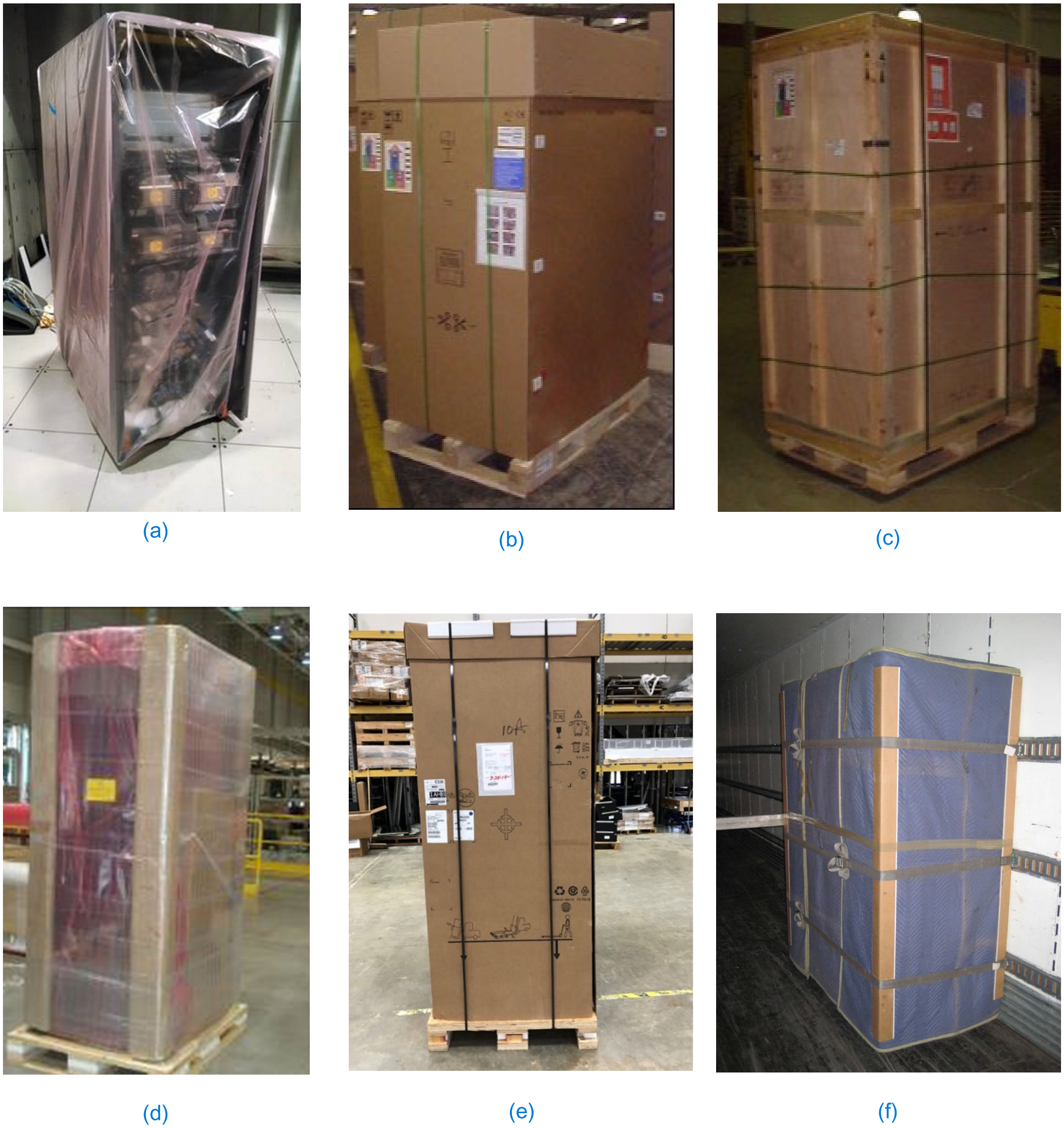

Figure 5 Primary IT equipment rack shipping methods: (a) interior polyethylene bag package, (b) corrugated pack with custom noncushioned pallet, (c) full wooden crate method, (d) clear view style with cushioned pallet, (e) corrugated pack with cushioned pallet, and (f) minimum pack method: blanket wrap (no pallet) padded van.

(a) (b)

Figure 6 Packaged 2U server (a) in poly bag and (b) with top cushions and accessories before the box is taped shut.

Some in-country domestic shipments utilize minimal packaging methods, which use little to no packaging and pallets. This method relies on carriers using dedicated truck and personnel (like a moving truck and moving personnel), relying on the caster wheels to roll the IT equipment racks on and off the truck trailers and into customer sites as well as data centers. Generally, this is reserved for hardware that has been designed to handle the shock and vibration during transit. The risk of damage is mitigated through personalized handling rather than packaging protection. Figure 5 shows several packaging methods depending on the origin and destination.

Smaller 1U-4U Rack Mount and Stand-Alone IT Equipment

Smaller IT equipment is typically packaged in a corrugated cardboard box. Inside the cardboard box, the IT equipment is wrapped with a non-heat-sealed polyethylene bag to prevent dust and to protect against abrasion. The IT equipment and bag are surrounded by fabricated polyethylene cushions. The amount and positioning of the cushions depends on the contents, including the IT equipment and ship group materials (e.g., mounting rails, media, and quick start guides). Figure 6 shows a 2U server as it is packaged for shipping. Figure 6a shows the server in its poly bag, which is neatly folded closed. The poly bag is not hermetically sealed. Figure 6b shows the server with its top cushions and accessories before the box is taped shut.

Individual boxes will ship alone. Multiple boxes that are part of the same order or ship to a single address come either on a half pallet or a full-sized pallet. All the boxes are assembled and banded to the pallet. The perimeter of the assembly is covered with stretch wrap and a corrugated sheet is placed on the top surface to prevent scuffing.

Other Packaging Considerations

It is also possible to provide specific environmental protection for highly sensitive cargo within its packaging. Silica gel packets (e.g., desiccant) can be added inside a package to absorb some moisture, but the packets tend to get overwhelmed relatively quickly in ambient conditions. Although the silica gel packets are effective at reducing moisture inside the packaging, the packs do nothing to protect the equipment from condensation once the packaging is removed. If acclimation procedures are not followed prior to unpacking, condensate can occur when the protective packaging is removed.

Many data centers ban the presence of packaging materials inside the mission critical space. The dust and dirt created by or brought in with the protective packaging may contaminate the environment, including, but not limited to the air-handling system and the air intake of the IT equipment. Some of the packaging is also highly combustible in the event of a fire.

Industry Studies on Low Temperatures and Acclimation of IT Equipment

Very few studies have been done to understand the IT equipment shipping environment and the acclimation time required for IT equipment to completely dry out after cold weather exposure. There is also a lack of information on low temperature extremes specific to truck and air cargo environments. However, some aspects of older studies offer clues about shipping climates. Until recently, most studies on temperature within the supply chain were focused on the “cold chain” discipline that is concerned with shipment of food, pharmaceuticals, and other perishable goods. These goods must be kept within a certain temperature range to remain consumable.

Even moving companies acknowledge that when shipping electronic devices in cold weather, care needs to be taken due to the risk of condensation (Bekins 2017). It is recommended to “always package electronics in completely sealed boxes” (Bekins 2017). Moving companies also recognize the need to allow components to safely acclimate after unpacking for at least 24 hours before energizing them.

Also, there are equipment vendors that suggest heaters should be used in electronic product enclosures (Kooltronic 2020). The heaters would introduce supplemental heat when ambient temperatures drop and the heat from working components is not present. During off-peak hours of operation or when the equipment is shut down, IT hardware temperatures could then be kept above the dew point, eliminating the threat of condensation. It is possible that this type of solution could be used for shipping, but is not recommended.

Shipping Studies

The Climates of the World study captures weather station data from approximately 800 worldwide locations, including outdoor temperature extremes as well as precipitation records (Hacia and Vitale 1972). The temperature extremes in the study do not directly correlate to the extremes found inside transportation vehicles but show temperatures that could be encountered temporarily when IT equipment is removed from transport vehicles or transferred to/from various locations in the transportation cycle. Data for average weather and extremes are listed in the study for 40 continental US cities and other countries from all continents.

"Thermal Study of a Transport Container" (Rodriguez-Bermejo et al. 2007) examines temperature variations within refrigerated or temperature-controlled ocean containers and is therefore not specifically relevant to normal truck and air shipping modes for IT equipment. However, one aspect of interest is the temperature will fluctuate within the containers and be affected by radiant energy in the form of solar heating of the ocean container. The same affects would be applicable to trucks and airplanes.

"International Safe Transit Association (ISTA) Temperature Project—Data Summary" inspects temperature and relative humidity in the LTL environment during the summer months of 2001 in the US across the southwestern states (routes from Dallas, TX to Phoenix, AZ) and is focused on high temperature extremes using data loggers (ISTA 2001).

"Ocean Container Temperature and Humidity Study" tracks temperature and humidity levels on ocean shipments from Netherlands to Japan and from Japan to the US as well as surface transport from Portland, OR to Memphis, TN (Leinberger 2006). This study is useful in that it covers an entire year. It includes low temperatures for the entire ocean and road trucking portions of the journey. One finding in this study is that the greatest extremes are found on the land portion of the journey (i.e., trucking) and not the ocean portion. The range of temperature is –29°C to 57°C (–21°F to 135°F) and relative humidity is 19% to 96%. Temperature and relative humidity variables mentioned in the study are dependent on the position of the product within the container (high/low, edge/center) and position of the container on the ship. Two terms from the study are "focus on the land" and "heat rises, mass stabilizes." For IT equipment, the large thermal mass of the product can help protect it from extreme conditions when temporarily exposed. Of course, this also causes the products to be vulnerable to condensation when taken from cold to warm and moist environments if adequate acclimation time is not allowed.

Recent Studies Focused on IT Equipment and Acclimation Time

An ISTA presentation (Green and Sanders 2016) investigates the root cause of condensation on IT equipment racks that are exposed to wintry conditions prior to being brought into a relatively warm and humid data center environment. The presentation also analyzes the results from a series of environmental chamber tests on IT equipment and establishes a comprehensive set of preventative practices.

In general, the root cause of visible condensate on IT equipment is acclimation procedures that are not followed as fully packaged racks are moved from trucks to indoor areas and immediately unpackaged. Vague guidance on the part of the IT equipment manufacturers is partially to blame.

A series of controlled experiments in large environmental chambers, capable of fitting a fully packaged rack, are used to study acclimation. The IT equipment is fitted with temperature and humidity sensors capable of recording temperatures as low as –40°C (–40°F). The test samples ranged from 578 lb to 1975 lb (261 kg to 896 kg), but fully configured racks can far exceed these values.

The findings from the presentation are as follows:

1. The outermost surfaces (IT equipment rack covers) act as both moisture sink and source due to their comparatively quick acclimation times.
2. After the transition from very cold to warm, frozen moisture on the outer and inner surfaces of IT equipment rack covers warm up quickly and introduce moisture back into the local environment.
3. Dense internal components acclimate the slowest. Internal components can be wet far longer than outer covers, which are dry. See Figure 7.
4. Exposure of an unpackaged IT equipment rack and its components to rapid airflow (forced convection warming) in the data center exacerbates the condensation. This process can give the illusion of accelerated acclimation by drying off visible external surfaces while introducing more moisture to colder internal components and surfaces.
5. The top cover of the IT equipment rack acclimates quicker than the bottom because of the falling boundary layer and condensate flowing down due to gravity.

Based on the findings, the advice is to allow the IT equipment rack to acclimate for at least 24 hours while packaged, even if only in a poly bag, to mitigate condensation. The condensate that forms on the IT equipment is not a cause for concern with respect to product quality unless it is still present when the equipment is connected to utility power. Condensate can be an excellent conductor of electricity and can bridge circuit traces or electrical components on circuit boards. IT equipment should not be connected to utility power and turned on prior to the completion of the acclimation period.

David et al. (2016) delves deeper into the experimental and numerical study of acclimation of a populated IT equipment rack. In the experimental portion of the

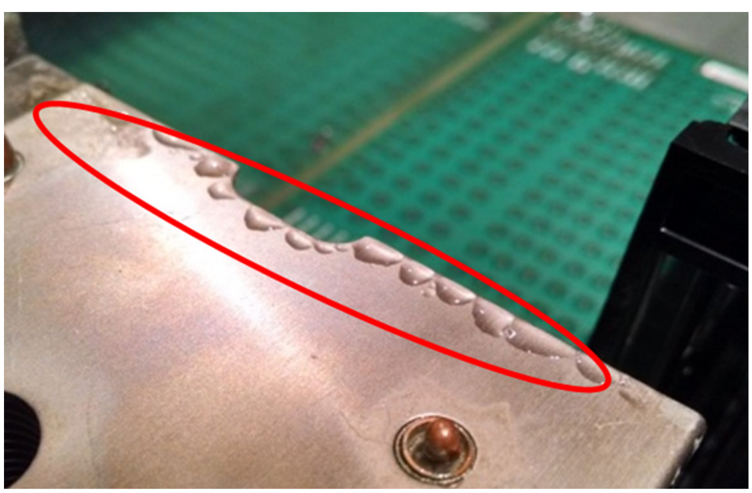

Figure 7 Visible condensate produced during acclimation.

work, a 2000 lb (907 kg) IT equipment rack with server and input/output (I/O) hardware is instrumented and chilled down to –27°C (–16.6°F) in an environmental chamber. Two tests are then conducted: (1) the rack is warmed to 35°C (95°F) and 85% relative humidity (rh) within the chamber itself, and (2) the rack is pulled out of the chamber and allowed to warm up to room conditions of 24°C (75.2°F) and 54% rh—conditions similar to that of a typical data center environment. In both tests, the rack is covered with a plastic bag as would be the case during shipping.

In Test 1, due to the high ambient humidity and forced convection within the chamber, a significant amount of moisture is found on the internal surfaces of the rack as well as on components as shown in Figure 7. This test leads to two findings and recommendations. First, a source of moisture is the forced air circulation around the rack inside the chamber during the heating process. Because the packaging bag is not sealed, forced air can easily make its way under the bag and into the rack. This process supplies a substantial amount of moisture to the rack's interior. It is recommended that during the acclimation process from cold to warm that the rack is not near sources of forced air convection such as air-conditioning units or perforated floor tiles. Doing so could result in significantly more condensate forming within the rack and thereby resulting in more time required to allow the rack to dry out before power is applied to the rack. Second, it is critical to check for moisture both outside (i.e. on the covers) and inside the rack. The acclimation process is usually deemed to be complete on visually inspecting the outside of a rack, but as testing found, a rack may appear to be dry on the outside but be wet on the inside. This is due to the quick warming of the outside covers that causes them to reach and exceed the dew point of the data center relatively quickly. However, the internal components can remain cold, below the dew point, for longer and continue to act as a moisture sink. It is important to check both the inside and the outside of the rack for condensate before deciding to power it on, especially if the rack had been exposed to cold weather. The IT equipment inside the rack can be checked by undocking power supplies that come out either the front or the back of the server, storage, or I/O drawer. If the IT equipment is on slide rails, the IT equipment can be pulled out and the top cover removed. Higher thermal mass components (e.g., processor heat sink, transformers) can be visually inspected for condensate.

Figure 8 shows the temperature and relative humidity profiles within various parts of an IT equipment rack, including the external covers, an I/O card installed in an I/O drawer, and within one of the processor drawers from Test 2. The components warm up much faster than in Test 1, as they are not being hampered by the thermal mass of the environmental chamber itself and follow the classic lumped capacitance thermal behavior model (Incropera and DeWitt 2002). Fitting to this model determines the time constants of the various elements in the rack, with the internal drawers (both I/O and processor) having a time constant of six to seven hours and the covers (based on measurements at multiple points on the side covers), approximately two hours. The paper finds that a racked system with covers shows two distinct behaviors: (1) fast responding covers and (2) much slower responding internal components. These times are mass and material dependent,

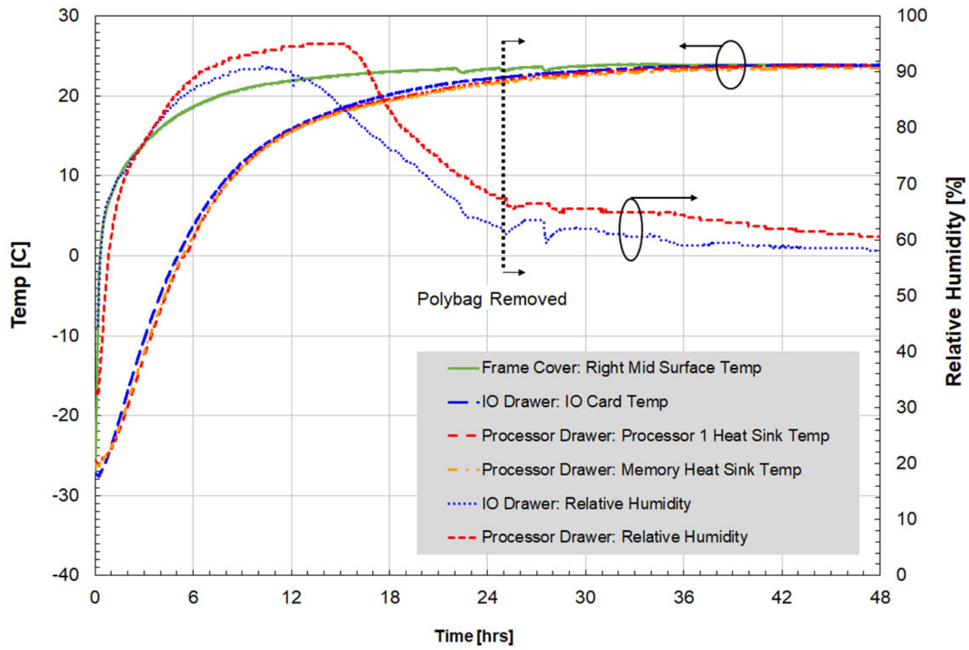

Figure 8 Temperature and relative humidity profile in a warming IT rack.

with heavier drawers or servers expected to take longer to acclimate to a new environment compared to a lighter or smaller drawer or server. The data also shows a complex behavior within the bagged rack during cooldown and subsequent warm-up with respect to internal moisture transport. The findings from this test are: (1) it is important to allow sufficient time for the system to acclimate, (2) outer covers can be warm and dry while internal components may still be cold and condensing, and (3) it is important to keep the IT hardware packaged and away from moisture sources while the temperature is below the dew point of the environment at the installation site.

The second section of the paper is on a modeling effort to capture the thermal and condensing behavior in a racked system. The model incorporates lumped capacitance thermal modeling of the internal components as well as evaporation and moisture diffusion models. Comparing the rate of evaporation with the rate of diffusion finds evaporation of condensed fluid to be primarily a diffusion limited problem. The model is compared to Test 2 data and the diffusion parameter is empirically tuned to match the behavior of the experimental data.

Three things are studied using the tuned model: (1) the mass of the IT rack, (2) the impact of removing the plastic bag at various times during the acclimation process, and (3) the impact of destination conditions. Raising the system mass increases the acclimation times, varying from 48 to 54 hours as the mass is increased from 1000 lb to 3000 lb (454 kg to 1361 kg). Taking the plastic bag off before the components have reached the external dew point can increase the acclimation times significantly. Compared to a dew-point approach time of approximately 14 hours, removing the bag prematurely at 6 hours leads to an acclimation time of 62 hours. Removing the bag at 18 hours results in a total acclimation time of 51 hours. Finally, for acclimation areas that adhere to the ASHRAE thermal guidelines, acclimation times at the various hot/dry corners result in the lowest acclimation times due to minimal condensation and high evaporation. It seems reasonable that a cold system will be ready sooner in a colder destination site, but this is not the case due to the much longer time required to evaporate off the condensed liquid. It is also found that, due to the large span in temperatures and humidity in the allowable ASHRAE envelopes (e.g., Class A2), the acclimation time can vary significantly.

The findings from the paper are as follows:

1. IT equipment racks exposed to cold weather and whose internal temperatures are below the dew point for the acclimation environment should be acclimated away from sources of forced convection such as air-conditioning units or perforated floor tiles. This is to avoid supplying excessive moisture into the system and minimize the occurrence of condensation within the rack, as well as to reduce the overall acclimation time.
2. IT equipment racks behave as two distinct thermal masses: covers and internal hardware. The covers respond much faster to changes in temperature than the internal hardware. Due to this effect, condensate verification should be conducted both inside and outside the acclimating rack to ensure it is safe to be powered on. IT hardware with the highest thermal mass (e.g., power supplies, transformers, heavy copper heat sinks) should be visually inspected.
3. Shipping packaging should ideally be kept on until the rack reaches the dew point of the environment in the vicinity of the rack. This protects both the inside and outside of the system from excessive condensation and reduces the total acclimation time. Keeping the packaging on also protects the system from dust and contamination that could lead to the formation of corrosives when mixed with liquid water.
4. Data center operators and installation personnel should be aware that the data center or staging environment can strongly impact how long a system is required to acclimate before being powered on. More acclimation time may be required for locations operating outside the recommended envelope of *Thermal Guidelines for Data Processing Environments* (ASHRAE 2015). Acclimation should be conducted in an environment similar to the final installation destination.

IT Equipment Manufacturer Shipping Tests

When extreme temperature conditions result in condensation during travel and delivery, the very first question from end users is, “Will this expensive and sensitive equipment be damaged?” The short answer is no. IT equipment manufacturers have many product design and test standards, including product shipping.

IT equipment manufacturers perform some level of life-like transportation compliance testing. The traditional testing is focused on shock and vibration of the various transportation modes along with handling of IT equipment in transit. Shipping and handling are the most visible and prevalent factors that affect transit of these types of products. For example, it is very noticeable if an IT equipment rack is destroyed in a tip-over event. However, product quality testing is also conducted to simulate less visible hazards like extreme temperature conditions to ensure the IT equipment can withstand these conditions.

Hot ship and cold ship are two psychrometric tests that most, if not all, IT equipment manufacturers perform on a product packaged in its shipping container. The product can be anything from a populated IT equipment rack of servers and storage to a field-replaceable component such as a processor chip or memory module. Hot ship and cold ship testing are intended to simulate a harsh transit environment. The hot ship test may be at a temperature up to 60°C (140°F) and the cold ship test may be at a temperature down to –40°C (–40°F). Relative humidity control is typically not used in the environmental chambers at the extremely cold ship condition due to the difficulty and cost of controlling the relative humidity when running a sub-zero compressor.

A typical test could be as follows. The packaged product is put into the environmental chamber. The soak period is set at a minimum of eight hours. After the soak period, the packaged product is removed from the chamber and allowed to acclimate in an ASHRAE-recommended product power off range outside of the chamber for a minimum of 24 hours. When unpackaging the product, a visual inspection of the internal components should be done to check for the presence of moisture. If moisture exists on the product after the acclimation period, the product must be allowed to acclimate until it is completely dry. Do not power on a wet product. Once the product is free of moisture, the product is plugged into the utility and the product is started. Exercisers and/or diagnostics are run for 30 minutes to ensure the product is operating correctly.

Acclimation Procedures and Guidelines for IT Equipment Racks

IT equipment manufacturers have cautionary statements about acclimation requirements in their product literature or available via technical support. These cautionary statements can be simple to comprehensive. A simple statement is typically up to a couple sentences long and provides the following guidance: "Server and storage equipment must be acclimated to the surrounding environment to prevent condensation. Leave the system in the shipping bag, if used, for up to 48 hours or until there is no visible signs of condensation to let it acclimate to the indoor environment" (IBM 2014).

Recent studies by Green and Sanders (2016) and David et al. (2016) have led to more informative guidance on acclimation of IT equipment as follows:

- Server and storage equipment must be gradually acclimated to the surrounding environment to prevent condensation.
- When server and storage equipment are shipped in a climate where the outside temperature is below the dew point of the destination (indoor location), there is a possibility that condensate can form on the cooler inside and outside surfaces of the equipment when the IT equipment is brought indoors.
- Sufficient time must be allowed for the shipped IT equipment to gradually reach thermal equilibrium with the indoor environment before you remove the shipping bag and energize the equipment. Follow these guidelines to properly acclimate your equipment:
    - Leave the system in the shipping bag. If the installation or staging environment allows it, leave the product in the full package to minimize condensation on or within the IT equipment.
    - Allow the packaged product to acclimate for 24 hours. If there are visible signs of condensate (either external or internal to the product) after 24 hours, acclimate the system without the shipping bag for an additional 12 to 24 hours or until no visible condensate remains.
    - Acclimate the product away from perforated tiles or other direct sources of forced air convection to minimize excessive condensation on or within the IT equipment.

With IT equipment that is very large and dense, the thermal mass significantly influences the acclimation time. Critical components buried deep inside the IT equipment must be given enough time to completely dry out or irreversible damage can occur. The informative guidance can be further expanded by providing acclimation time based on the thermal mass of the IT equipment, transportation

Table 1 Acclimation Time Based on Temperature Exposure and 3000 lb (1361 kg) Mass

Thermal Condition of Machine that Arrived at the Customer Site	Computer Room ASHRAE Class	Time to Acclimate, h: First with Shipping Bag ON	Then with Shipping Bag OFF	Total
Extremely cold, less than –20°C (–4°F)	Recommended	24	6	30
	A1/A2	30	12	42
Very cold, less than 0°C (32°F)	Recommended	18	6	24
	A1/A2	30	12	42
Less than computer room dew point	Recommended	12	6	18
	A1/A2	24	12	36
Greater than computer room dew point	Recommended	6	6	12
	A1/A2	6	12	18
Unknown/default	Unknown	24	12	36

environment, and dew point within an ASHRAE environmental class. See Table 1 for a product weighting 3000 lb (1361 kg). In general, the higher the relative humidity in the installation location, the longer it takes for the IT equipment to acclimate.

Because most cautionary statements about acclimation are buried in written documentation that is either shipped with the product or on the manufacturer's web site, these statements are not immediately visible to the end user. To improve visibility, acclimation guidance may be placed on IT equipment rack shipping packages. See Figure 9.

Figure 9 Acclimation warning on IT equipment rack shipping package.

Acclimation of Field-Replaceable Components

The results and guidance have been focused on racks with servers and systems weighing as much as a few thousand pounds. Smaller components that are commonly replaced or upgraded in the field, such as memory modules, disk drives, fans, PCIe cards, and processor modules, may also be subjected to very cold storage and shipping conditions. These smaller components, unlike bigger racked systems, are also less likely to enjoy expedited shipping and/or climate-controlled shipping resulting in long storage and transit times in standard non-climate-controlled conditions. This raises an important question: what are the acclimation requirements and best practices for smaller packaged components?

In general, acclimation best practices provided for larger systems still apply to smaller packages. Enough time should be provided to allow the temperature of the component to be installed, preferably still in its packaging (or at least in its internal poly bags or electrostatic bags), to reach the dew point of the installation environment. This could be conducted in a staging area with a similar environment as that of the installation site. When this temperature has been achieved, the packaging can be removed to allow any moisture trapped within the packaging and components to evaporate away. Once carefully inspected and confirmed to be dry, the component can be safely installed in the destination server or drawer.

The difference between acclimation of smaller components and larger servers and systems is simply time. Smaller components with less mass will typically acclimate faster than larger, heavier IT equipment. Nevertheless, this instinctive understanding can lead to underestimating how long a component can take to acclimate to a new environment. Two similarly shaped components could have different acclimation times if one component is significantly heavier than the other component. For instance, a server fan and heat sink are similarly sized, but the heat sink, which is heavier, takes longer to acclimate. Alternatively, components of similar mass could also yield different acclimation times if the shape of the component and packaging is different. A relatively flat component where one dimension is significantly smaller than the other dimensions, i.e., a memory module, will acclimate faster than a blockier component of similar mass. Finally, the quantity and layers of packaging can significantly influence acclimation times. Figure 10 compares the packaging for a single memory module and a single processor heat sink.

The colors in Figures 10a and 10c represent the following: tan is cardboard, salmon is foam, gray and blue are plastic bags, and green and black are PCB/components. Substantially more packaging is required to safely ship the processor heat sink due to its larger mass compared to the memory module.

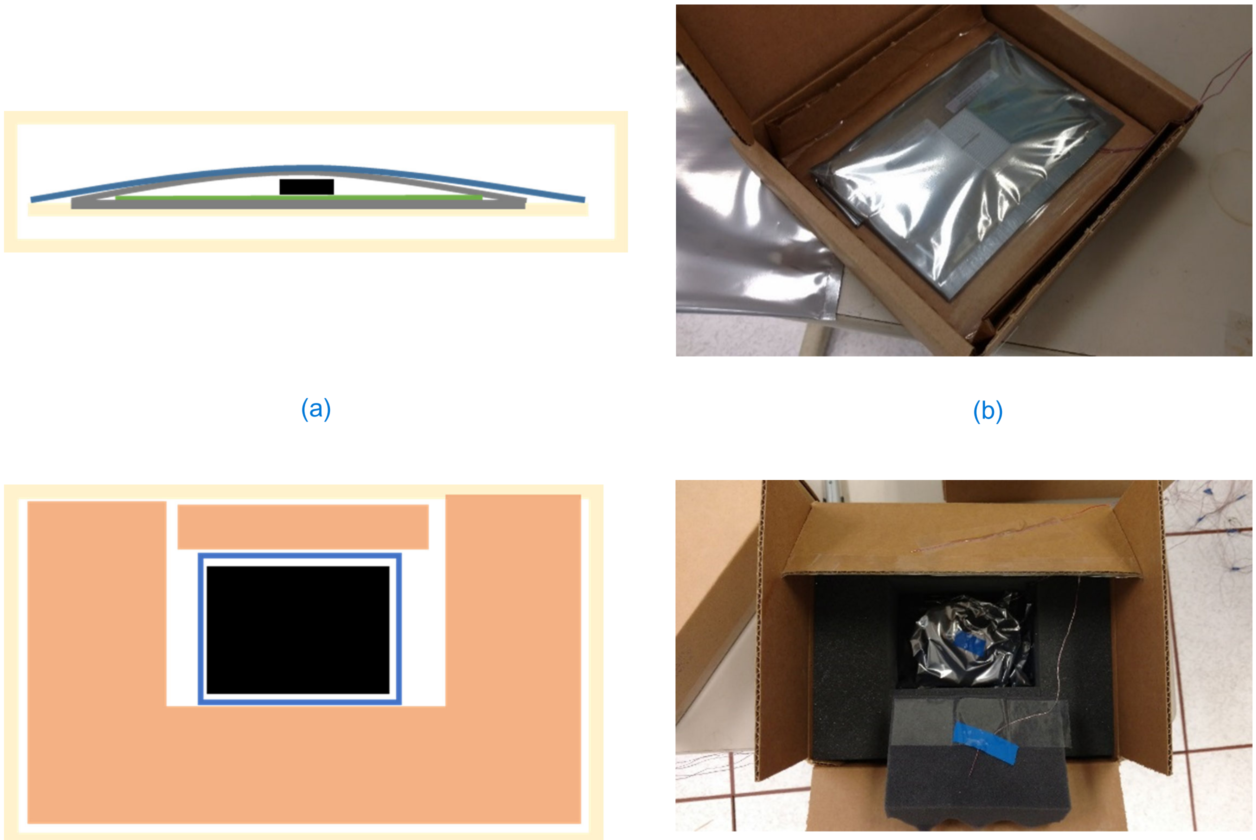
(a) (b) (c) (d)

Figure 10 Packaging for (a, b) a memory module and (c, d) a processor heat sink.

The thermal time constant is broadly defined as:

$$\tau = \frac{\text{heat stored}}{\text{heat transferred}}$$

The heat stored is a function of mass and heat capacity. The heat transferred is a function of conductive, convective, and radiative heat transfer off the surfaces of the object. For a box sitting on the floor, heat transfer occurs: (1) from the surrounding air to the box via natural convection and forced convection (if there is some air movement around the box) off the top and sides of the box and (2) with the floor via conduction through the surface with which it is in contact. Typically, as the surface-to-surface contact area with its low thermal conductivity of typical flooring materials and worktables is smaller than the surface area exposed to the air, convective heat transfer is dominant in determining the thermal time constant.

Experimental work is conducted on a variety of different components in their packaging to determine the effective thermal time constant. The boxes are instrumented with thermocouples at various points on the internal component and within the packaging. The instrumented boxes are placed in a thermal chamber and chilled down to –30°C (–22°F). Once steady state is reached, the box is removed and placed on a cart. The box can acclimate naturally to the room environment while tracking the temperature at the various points within the box. From the data, it is possible to extract the thermal time constant for the component.

The memory module shown in Figures 10a and 10b is the lightest package tested with a weight of 0.6 lb (0.3 kg) and yields an acclimation time (equal to 3x thermal time constants, or the time needed to reach 95% of the final temperature) of 1.2 hours. The heat sink package is the heaviest package tested with a weight of 3.5 lb (1.6 kg) and yields an acclimation time of 10 hours. A processor module was also tested. Unlike the memory and heat sink shipping packages, the processor shipping package has the smallest ratio of component mass to total mass (4%) due to the substantial amount of packaging provided to protect the processor during shipment. Due to the amount of packaging, the acclimation time of 3.3 hours is substantially higher than would be expected from the mass of the component itself. Therefore, total package mass and size is more important in determining acclimation time than the mass and size of the component being shipped when acclimation is conducted with packaging. Once the packaging is removed, the mass and shape of the component itself sets the acclimation time. In this case, it would be expected that the processor module with a mass approximately 5% of that of the heat sink would acclimate much faster to the environment than the heat sink. Removing outer layers of packaging such as the cardboard box and foam is recommended to minimize the necessary acclimation time. Internal poly bags or electrostatic bags, which add very little mass but provide a moisture barrier, should be kept on during the acclimation process to minimize condensation directly on the component.

Given the variety of components and packaging used in the industry, there is no simple rule that can be applied to determine the required acclimation time. Though multiple, relatively simple rules were determined for the small number of components tested in the study, the results could vary from one IT manufacturer to another based on packaging styles and acclimation recommendations (e.g., with full packaging, partial packaging, or no packaging). Thus, it is important for IT manufacturers to determine and provide guidance to their clients or service personnel regarding recommended acclimation procedures and times, in addition to the best practices as outlined, for smaller field-replaceable components.

Inspecting for Moisture

The amount of acclimation time could be a concern for some data center owners and operators. Unfortunately, there is no reliable process to inspect for internal condensation. Acclimation of IT equipment racks and field-replaceable components depends on several factors, including but not limited to the ambient temperature to the temperature inside the package and dew-point difference as well as IT equipment thermal mass.

In general, the IT equipment should not be unpackaged before the prescribed time has elapsed. This limits the amount of moisture from the room that can get inside the IT equipment and therefore limits condensation through restriction of air. By removing the shipping packaging too early, the moisture from the room condenses on the outside covers and inside the IT equipment. This increases the required acclimation time.

Summary

Shipping IT equipment in winter weather conditions is unavoidable in most places of the world. Arctic weather can be experienced deep into the northern hemisphere via a polar vortex from the North Pole. The main precaution with shipping in extremely cold weather is to allow for acclimation of the product when brought indoors. Acclimation time must be built into the data center installation schedule during the winter months. If acclimation time is not considered, external visible condensate on covers will most likely cause a product quality perception issue. Internal condensation can result in immediate or short-term product failures when powered on. Not adhering to the IT equipment manufacturer's acclimation time may result in significant install delays or, in the worst case, require product replacement that may not be covered under warranty.

Throughout the white paper, several terms have been used for the acclimation whitespace, including but not limited to acclimation area, receiving area, and staging area. In general, it is recommended that any unpackaging area is controlled to the ASHRAE thermal guidelines even though it may not be within the data center whitespace. For all ASHRAE thermal guidelines classes, there is a product power off temperature and relative humidity range.

References

ASHRAE. 2015. *Thermal guidelines for data processing environments,* fourth edition. Peachtree Corners, GA: ASHRAE.

Bekins. 2017. Moving in cold weather? Protect these 5 belongings. https://www.bekins.com/2017/03/01/moving-in-cold-weather-protect-these-5-belongings/.

David, M.P., J. Prisco, S. Spaulding, W. Green, R. Sanders, and B. Rawson. 2016. Environmental acclimation of computing systems. 15th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), Las Vegas, NV, 2016, pp. 791–98, doi: 10.1109/ITHERM.2016.7517627.

Green, W.J., and R.T. Sanders. 2016. Cold weather shipping and acclimation—Never let them see you sweat. Presented at the ISTA TransPack Conference, Orlando, FL, March 21–24.

Hacia, H., and C.S. Vitale. 1972. (revised by McKittrick, D.A. 1991). Climates of the World. Historical Climatology Series 6-4. Asheville, NC: US Department of Commerce and the National Oceanic and Atmospheric Administration.

IBM. 2014. Acclimation. https://www.ibm.com/support/knowledgecenter/POWER7/p7ebe/p7ebeacclimation.htm.

Incropera, F.P., and D.P. DeWitt. 2002. *Fundamentals of heat and mass transfer*. New York: J. Wiley.

ISTA. 2001. ISTA temperature project—Data summary. East Lansing, MI: International Safe Transit Association.

Kooltronic. 2020. Condensation and electronics. https://www.kooltronic.com/downloads/K1213.pdf.

Leinberger, D. 2006. Ocean container temperature and humidity study. Presented at the ISTA TransPack Conference, Orlando, FL, April 19.

Rodriguez-Bermejo, J., P. Barreiro, J.I. Robla, and L. Ruiz-Garcia. 2007. Thermal study of a transport container. Madrid, Spain: Sensors Technology Laboratory, National Center for Metallurgical Research, Spanish Council for Scientific Research (CENIM-CSIC).