

HOW THERMAL CONTROLS AFFECT DATA CENTER RELIABILITY

This Whitepaper takes an in-depth look at some of the smallest components used in data centers. With the importance of reliability in data centers large and small, we explore how thermal controls function and how to judge the potential reliability of the thermal controls sourced for equipment throughout data centers. This paper also shows ways to customize thermal controls to improve both performance and reliability in any type of application.

This Whitepaper should be read by:

- » Design Engineers for equipment used in modern data centers
- » Engineering and Production Managers for equipment used in data centers
- » Procurement personnel for equipment used in data centers
- » Personnel in data center owner organizations
- » Regulatory Agency personnel

This Whitepaper will explain:

- » How thermal controls provide both over temperature protection and temperature control.
- » How to spot potential reliability problems in the thermal controls you spec.
- » How to assess the potential reliability of the thermal controls you spec.
- » How to customize thermal controls to more precisely meet the needs of your application.

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Table of Contents

The 3 Most Important Words in Data Centers	4
How Thermal Controls Operate	5
Where Thermal Controls are Used in Modern Data Centers	6
The Components of a Typical Bimetallic Thermal Control	7
Important Thermal Control Design Considerations to Improve Reliability	8
How to Ascertain the Quality of Thermal Control Components	9
Using Customization to Increase Reliability	10
A Final Word About Reliability	11
About the Authors	11



With the incredible advances in AI and cloud-based computer programs data centers have come to dominate business worldwide. Data centers come in all sizes, but just looking at the hyper-scalers, alone, we see an average of ten new ones opening every month with over 500 currently in the planning stages. In total, the world expects to add 100 GW of new capacity between 2026 and 2030. The competitive nature of these facilities has forced data centers to focus on the reliability of every piece of equipment used inside them. This, in turn, has placed a premium on reliability for every equipment manufacturer who hopes to sell products into this exploding market. The purpose of this white paper is to help people like you understand how one of the smallest components used in data centers can have an outsize effect on overall reliability.



The 3 Most Important Words in Data Centers: Reliability. Reliability. And, Reliability.

Reliability has become the most important word in data centers because without it a data center becomes just another collection of used servers. While data center function is critical, they all depend on automation to keep labor costs as low as possible. In such an environment the reliability of products used in data centers is as critical as the center's overall function.

Out of the millions of parts that go into a typical data center, among the smallest are the thousands of thermal controls used in every area. As in the case of the proverbial "Princess and the Pea" these tiny thermal controls can cause a lot of headaches for data centers focused on delivering "Five Nines" performance (99.999% uptime) while employing highly automated and heat-sensitive processes.

"Five Nines availability means that data centers operating continuously around the clock can only afford 5 minutes and 15 seconds of downtime in an entire year. Extreme reliability is the golden fleece of the day.

After over 65 years spent totally focused on the design and manufacture of thermal controls, we have some special knowledge on what makes one thermal control more reliable than another. This white paper focuses on ways to ensure performance reliability in thermal controls that is commensurate with data center needs.



What does a thermal control do?

There are two types of thermal controls used in most data centers. First are those that provide short circuit and over-temperature protection. These type of snap action thermal controls sense an impending catastrophic failure and break the circuit before it happens. No other device is needed to sense problems and actuate a solution.

The second are those that maintain product temperature within a proscribed range. These open and close circuits as needed to ensure temperatures do not rise or fall too far. Creep-action thermal controls continually open and close circuits to maintain temperature within a narrow range. Again, no other devices are needed to both sense and actuate the steps needed to maintain temperatures.

There are a number of ways to sense temperature or current changes in an electrical circuit. Some are more cumbersome or less convenient than others. To judge the qualities of each, consider the steps involved in making or breaking a circuit in order to protect against catastrophic failures.

Step 1: Sense an overheat or overload situation

This step can be achieved using a sensing device such as thermistors, bimetallic controls or thermal fuses. Each can be set to sense heat build-up in the circuit or ambient environment, or to sense a surge in current flowing through the circuit.

Step 2: Actuate circuit changes

Sensing devices like thermistors must be attached to a controller system to actually break circuits and prevent catastrophic failure. Thermal fuses and most bimetal controls can both sense and break circuits when temperatures or circuit loads exceed calibration limits.

Step 3: Auto-reset circuit for continued operation

Thermistor and controller systems can reset circuits as temperatures cool or overload conditions change. Bimetallic thermal controls automatically reset themselves as circuit conditions drop back to acceptable conditions. Thermal fuse devices are one-shot solutions and impossible to reset so, also, do not allow continued operation.

The point of this exercise is to show why bimetallic thermal controls are the predominant type of controls used throughout modern data centers. They are the only type capable of sensing danger, activating a solution and then automatically resetting the circuit once conditions return to a normal range. As in most things, the simpler the better. The fewer components required to sense and actuate change, the better.



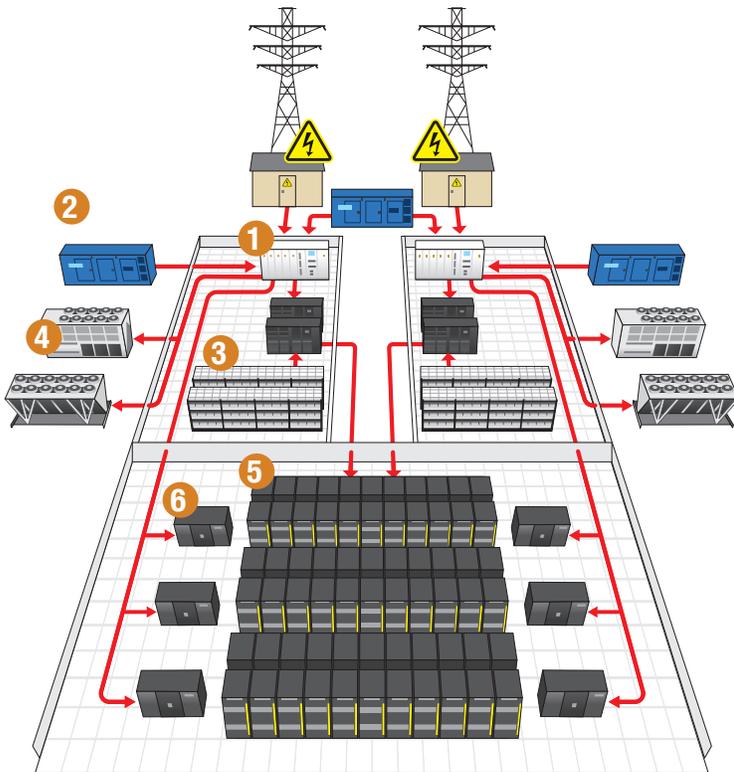
There are also two different basic bimetallic thermal control configurations: Cantilever and Disc-Type. Because most cantilever type thermal controls have the circuit run through the bimetal arm they are influenced by changes in both circuit and temperature. For this reason they provide the most benefit on lower voltage circuits.



Disc-type thermal controls are designed so that the bimetal discs only react to temperature making them suitable for use on larger load applications.

Where Thermal Controls are Used in Modern Data Centers

The short answer is, everywhere. At least everywhere there is an electrical circuit, and especially circuits that could cause problems if they overheat or develop short circuit conditions. The fact that there are so many different types of circuits in any data center means you should understand how different types of thermal controls are used in different applications. The fact there is so much reliance on the reliability of every piece of equipment used in a data center means you need to pay particularly close attention to the way thermal controls are built and their suitability for any particular application. This is a classic case of the tiniest component being the ultimate thing standing between catastrophic failure and continuing, efficient operation. Here is a quick overview of where thermal controls are used in a typical data center layout.



1. Main Incoming Power Distribution

In this area thermal controls are primarily used to provide overheat protection. 1/2" disc controls are often used since the bimetallic wings do not conduct circuit flow but, rather, react to heat build-up. Other preferred thermal controls include those with a shunted design where the bimetal, once again, does not carry the circuit, but will break the circuit when heat rises above a safe temperature.

2. Back-up Power Generation

Bimetal thermal controls help battery-powered back-up power generators simplify circuit design by combining sensing and activation functions in a single device. This eliminates the need for redundant and costly controllers that convert data from sensors into open or closed circuits. With bimetal controls the bimetallic element immediately reacts to changes in either power or temperature and automatically make or break the circuit to ensure safety in NiCad and Lithium-Ion batteries, alike. The small size and limited power draw of bimetal devices make them an ideal solution for these applications.

3. Uninterruptible Power Supply System (UPS)

When power step-down takes place at the rack level, snap-action thermal controls are used to sense overloaded or short circuit conditions. However, creep action thermal controls are used to control temperatures within a narrow range. In both instances, bimetal thermal controls can immediately sense and solve both temperature and circuit-related problems without oversight from humans or downstream components. This is a valuable characteristic in a room filled with server racks providing critical operations.

4. HVAC and Water-Cooling Systems Used to Control Data Center Climate

Heat is a constant villain in any data center simply because of the massive amounts of heat generated by newer chips. Refrigeration units often use disc-type thermostats to regulate high and low operating temperatures. These units also have heater circuits to keep ice from forming. Bimetal controls with their fast operating characteristics play an important role in regulating these circuits, as well. Water metering systems make similar use of bimetallic controls.

From industrial scale chillers to normal HVAC heating and air-conditioning systems, bimetallic thermal controls play a vital role in both controlling temperature and preventing dangerous overcharge conditions. They are especially prevalent in preventing short-circuit conditions in blowers and motors used throughout HVAC systems.

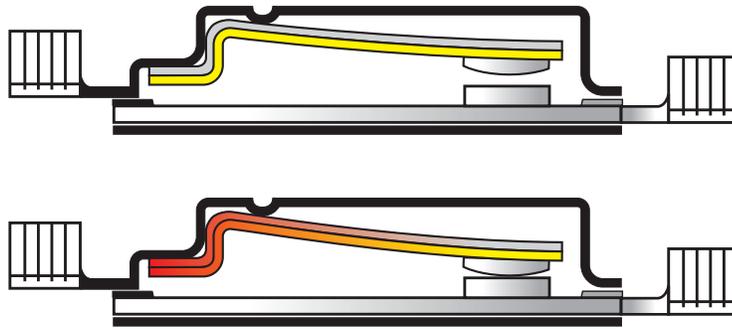
5. Server and Data Storage

Mechanical bimetallic thermal controls routinely play two key roles in protecting server-level circuits. First thermal controls, primarily creep-action, provide board-level overheat protection. Snap-action devices are also used on incoming power circuits to provide reliable short circuit protection.

6. Lighting & mechanical building components, including security

A wide variety of bimetallic thermal controls are used in common data center lighting systems, including ballasts, recessed lighting and the transformers used in lighting circuits. Most often these devices are used to provide over-temperature and short circuit protection

The Components of a Bimetal Thermal Control and How They Operate



Bimetal thermal controls are deceptively simple devices. There are only five basic components, however each can be customized in a number of ways to more precisely meet application needs. In the next section we will discuss ways you can determine the quality of each component used in the thermal controls you procure.

1. **Case:** Depending on the particular model, cases can be made of folded-over metal, drawn nickel or drawn plastic. Cost and the need for isolation from circuit current is most often the determining factor. Drawn cases can be potted to protect against ambient environmental conditions.
2. **Bimetal Arm:** Bimetals are made by bonding two different metals that expand at different rates when heated, causing the strip to bend as temperature rises to open or close a circuit. When current flows through the element, metals with higher resistivity generate more internal heat, making the strip bend faster. Because bimetal responds to both external temperature and the heat created by electrical current, it can reliably sense and react to changes in both.

Bimetal arms can be easily changed in order to better meet the needs of any particular application.

3. **Contacts:** Silver-based contacts are welded inside the case. When the arm deflects upon reaching the circuit-breaking temperature, the two contacts part, breaking the circuit. When the temperature returns to a normal range and the bimetal arm moves back, the contacts touch to reset the circuit.
4. **Insulation:** Generally this is Nomex or some other type of thermal insulation to protect bimetallic arms from reacting to ambient temperatures or electrical discharge in the surrounding area.
5. **Calibration:** Using both mechanical means and bimetal selection, a thermal control can be made to react faster and more precisely to rapid temperature changes, assuring the circuit is opened before anything harmful happens or closed when conditions are proper.
6. **Terminals:** The critical point where a thermal control becomes part of your circuit. There are a wide variety of terminal designs available, however, consideration must be given to both the security of the connection and their positioning in order to allow easy mounting in tight spaces.
7. **Manufacturing system:** Although you may not know a company's manufacturing process, the manner of their quality control procedures and the ultimate performance of their products in real world conditions will provide insights into their attention to detail during the manufacturing process. At Portage Electric Products we employ Full Batch Reliability Testing on the theory that statistical testing will only tell you how many out-of-spec parts you will receive while Full Batch testing ensures every thermal control you receive will reliably perform as promised.

The purpose of this section was to help you understand how thermal controls work so you can judge the future reliability of the thermal controls sourced for different data center equipment. However, it should also help you understand the final section where we will discuss ways you can customize bimetallic thermal controls to improve performance in your particular application.

Important Thermal Control Design Considerations to Improve Reliability

Form follows function. When it comes to the design of the thermal controls you are sourcing, certain design features that will play an important role in determining long-term reliability. The two most important components of any **bimetal thermal control** are the bimetal arm and the **contacts**. If either of these fails, the device can no longer reliably make or break the circuit.

Bimetallic Arms

Visually bimetallic arms look similar across manufacturers. The real differences show up in **material quality** (discussed in the next section) and the **ability to customize** the bimetal to suit specific applications. Very few manufacturers allow customization of the bimetallic element, itself. **PEPI® thermal controls**, however, offer access to hundreds of bimetal options, allowing you to select the precise material best suited to your application's temperature, load and cycling requirements.

Contacts: Size and Construction Matter

Unlike bimetal arms, contacts show visible differences between manufacturers, primarily in size and construction.

Contact Size

When it comes to contact size, **bigger is better**. Thermal controls experience high cycle rates throughout their lifetime, especially **creep-action controls**, which frequently cycle to maintain a stable temperature range. Each cycle causes wear. Larger contacts provide:

- » More consistent electrical connection over time.
- » Greater tolerance for minor misalignment between the bimetal arm and fixed contact.
- » Longer life and more reliable performance under repeated cycling.

Contact Material

The composition of the contacts is not always obvious at a glance, but it has a major impact on performance and reliability. In an effort to cut costs, many manufacturers have shifted away from solid silver contacts to silver-tin alloys or thin silver plating over tin.

This creates several problems:

- » **Tin tarnishes faster** than silver.
- » Tin causes **uneven wear**, reducing contact consistency.
- » Tarnish and uneven wear both degrade electrical performance.

The ideal material is **coin silver** which offers the best combination of conductivity and wear resistance. If the thermal controls you're sourcing don't use coin silver contacts, as found in PEPI® thermal controls, you're likely going to face reliability issues down the road.

How to Ascertain the Quality of Thermal Control Components

There are really three parts to the pursuit of reliability in thermal controls. First is the quality of the components used in every device. Second is the ability of a device to be customized to more precisely meet the needs of any particular application. **In data centers, where reliability is critical, customization is an important way to ensure maximum reliability** and operation more precisely in line with application needs.

Component Quality

There are four key components you can observe when trying to figure the potential reliability of any bimetallic thermal control: (1) Bimetallic arm. (2) Contacts. (3) Insulation. (4) Calibration.

Bimetal Arm

As mentioned earlier, there are two sides to any bimetallic. The Low Expansion Side (LES) and High Expansion Side (HES). When thermal control manufacturers receive a reel of new bimetal they should quickly run tests to make sure the resistance, dimension and grain consistency are within specs.

Measuring camber is akin to checking the warp in a wood 2x4 purchased at your local lumberyard. We specify a maximum of 9/32 camber over a 3 foot length of bimetal. Any more than this will create repeatability problems.

Measuring resistance will determine the integrity of the bimetal.

Contacts

This is the easiest place for a customer to ascertain the quality of the thermal controls they are sourcing since quality is a function of the manufacturers specs. First is the overall size of the contacts being used relative to the size of the thermal control. The smaller the contacts the more prone they will be to misalignment, especially as they wear through repeated cycling.

The second thing to look at is the amount and type of silver used in contacts. Tarnish will affect performance, so be sure that coin silver is being used. This is the silver alloy with the least likelihood of tarnishing. However, many manufacturers have lately begun to use contacts with silver/tin alloys or only a thin layer of silver painted onto nickel contacts in a mad search for pennies of savings. The predictable result is contacts that fail to perform as expected causing costly problems.

Insulation

When preventing heat penetration, thicker is better. But, in a search to cut manufacturing costs, many thermal control suppliers have turned to epoxy-coated insulation. This provides the necessary thickness, but with a lower flash point meaning it will not reliably prevent arc ignition. A preferred material is straight Nomex™ without any coating that will provide a higher flash point required for optimum safety.

Calibration

The only consideration with calibration dimples is precision. The only way to measure this is to look at a manufacturer's overall reputation for precision and reliability. However, you should pay attention to the plus/minus variations listed in the manufacturing specs.

The real reliability assurance is the quality checks used in the manufacturing process. Statistical Process Controls will only tell you how many out-of-spec parts you should expect. So, at Portage Electric, we utilize Full-Batch Testing to ensure every part is within spec. To our way of thinking, it is the only way to offer the level of reliability required in modern data centers.

Using Customization to Increase Reliability

There are actually two different types of thermal control manufacturers. The first uses mass production processes designed to favor low manufacturing costs over real world reliability. The second uses lower volume manufacturing processes and superior components to favor reliability over cost reductions.

Given the need for ultimate reliability in data centers, you are probably better off sourcing components using thermal controls manufactured using the later process. An added benefit is that these type of manufacturing systems make it possible to customize components to create thermal controls better suited to any particular application.

There are also two ways a thermal control can be customized. First is changing components in order to make them more precisely match the needs of a particular application. This could include wiring devices together to create thermal control harnesses capable of coordinating the protection of multiple circuits. Second is modifying the device to meet environmental challenges, including moisture, high or low temperatures, dust and more.



Customizing components

Here are the basic ways you can customize a thermal control to more precisely meet application needs:

1. Change operation temperature and calibration

Set the make/break temperature precisely where it's needed for your application.

2. Change bimetallic element

There are hundreds of different combinations available to more precisely meet the sensitivity and derating needs of an application.

3. Customize mounting brackets or add factory-attached leads

Either way you'll simplify installation while ensuring installation suited to your needs.

4. Electrically isolate the thermal control

Using sleeves, bubble packs and other methods, the thermal control can be isolated from both the circuit and environmental conditions that may lead to nuisance tripping.

5. Create harnesses

Many applications require multiple thermal controls wired together into a harness configuration to coordinate the protection of multiple circuits.

Modifying thermal controls to meet environmental challenges

There are an unlimited number of possibilities. For instance, potting the thermal control has become popular for equipment used in liquid direct-to-chip cooling systems. Other customization options might include some type of encapsulation to, again, protect against environmental challenges. There are a wide range of encapsulations available, including tubing and bubble cases.

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A Final Word About Reliability



Perhaps the most important ingredient in predicting reliability is the manufacturer behind the thermal controls, itself. Thermal controls may be small components, but they play an outsized role in protecting mission-critical equipment -- especially in environments like data centers where uptime is everything. To most large manufacturers they are a sideline to a wide range of electrical devices they manufacture.

At **Portage Electric Products**, thermal controls have been our **sole focus**, for over 65 years. This singular commitment has given us a front-row seat to every challenge these devices can face in real-world applications. While new materials, evolving environmental requirements, and emerging technologies continue to introduce new variables, our decades of experience have taught us how to customize thermal controls to meet those challenges head-on.

About the Authors

Phillip Warrick has been head thermal control engineer at Portage Electric for over 40 years. If there is anything he doesn't know about thermal controls, it probably isn't worth knowing.

Doug Carey is a long-time associate at Allied Enterprises a supplier to many of the major data centers currently in operation or in the planning stages. Allied's full portfolio of products includes products for power management, thermal management, and integrated rack solutions from leading brands, including Liebert®, Portage Electric Products, Inc. (PEPI®) Chloride®, Geist™, NetSure™, Vertiv™ and Energy Labs. Allied also supplies engineering and consulting services to data center builders and owners.

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