industry: **various**
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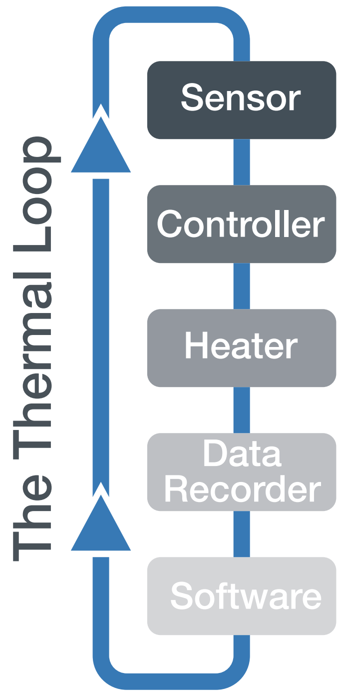
The Thermal Loop:

An Introduction to the Unifying Concept Behind *Watlow's* Products and Processes



Introduction:

Watlow® has a large portfolio of products, sold across a number of industries and used in a wide variety of applications. It also provides deep expertise on a number of topics related to thermal systems and their control. With recent acquisitions, that portfolio and that expertise has only grown.

A large portfolio and deep expertise is a good thing for our clients and partners, but there is a danger as well: It is all-too-easy to lose sight of the underlying value that we offer. If there isn't a unifying idea, model, concept or metaphor to organize and make sense of what we do, people will get lost in the details…and many opportunities will be missed as a result.

For ***Watlow***, the underlying concept behind everything we do is that of the thermal loop. Every product we offer, and every project we work on, is ultimately about the creation and control of a thermal loop in some application. This paper, the first in a series, will focus on the three foundational components of the thermal loop - the heaters, the sensors and the controllers. In subsequent white papers we will further explore how a thermal loop can be enhanced through new technologies such as data acquisition and cyber security. Once you understand this basic concept, it will help you see where ***Watlow's*** specific products, projects and expertise fit into the bigger picture.

What Is the Thermal Loop, and Why Do Our Customers Care?

A thermal loop is a kind of system designed to precisely control temperature. This could be the temperature of an object (or a solid), a fluid, a gas, or a space. Precise control of temperature requires more than simply heating—it also requires accommodating for the effects that the heater or heaters have, and then adjusting the system accordingly.

When ***Watlow*** talks about "the" thermal loop, it simply means that there is a single, abstract idea behind the the design of any application or thermal process.. Think of it this way: There are hundreds of things a person could do for a living. While each job is different, we can all still understand the concept of a career. In fact, thinking about how you want your career to proceed will heavily influence the jobs you take. In a similar way, thinking about the thermal loop will influence how you think about the individual parts of the system, and how they might work together.

Parts of the Thermal Loop

A typical thermal loop has:

- One or more **heaters,**
- An electrical **power supply,**
- A **power controller,**
- One or more **temperature sensors** and a **high limit** safety sensor
- A **high limit controller**
- A **process controller**
- A **data recorder**

The electrical power supply provides the energy needed for heating, while the power controller regulates and "smooths" that power output. The heating elements heat the material(s) in question. The process temperature is sensed with the temperature sensors, sending a signal to the process controller, which adjusts the power output to maintain the desired temperature for the specified duration. Finally, the safety limit sensor sends a signal to a limit controller if the process temperature travels outside of a defined safe level to immediately kill the power effectively shutting down the entire process.

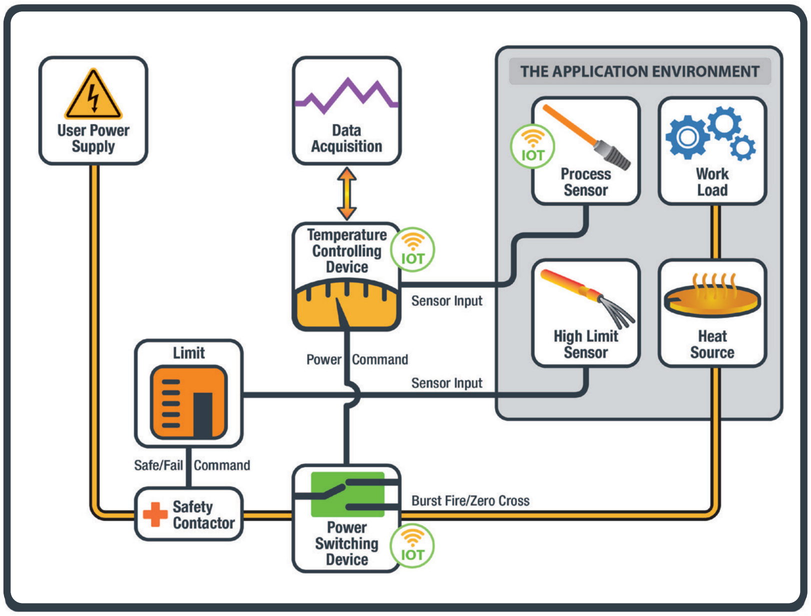


Diagram of a typical thermal loop and it's associated components.

In some cases, a single component can play multiple roles. For example, with high temperature coefficient of resistance (TCR)
materials, it is possible for a single component to act as both a heater and a sensor, which cuts down on the total number of components and wires needed in the system.

Altogether, these parts create a system known as a thermal loop that can maintain process temperatures automatically through time.

What the Thermal Loop Does: An Everyday Metaphor

Consider, for a moment, the thermostat in your home. It senses the temperature of the air in the space and adjusts the action of your boiler, furnace, or heat pump accordingly. If it is an older thermostat, it will "sense" mechanically by means of two metal strips that expand at different rates with changes in the temperature. A more modern thermostat will use electronic sensors. In both cases, the thermostat determines the difference between the current temperature and the set point and sends a signal to adjust accordingly.

A home thermostat is a simple example of closed loop temperature control. Contrast it with other appliances in your home, such as your cooking range. You can adjust the temperature of the range, but this has to be done manually: The system does not detect temperature or adjust itself. It provides heat only. There is no "loop" to speak of (or rather, the user is a big part of the loop).

In between these two examples might be your toaster. The average toaster has an open coil wire that serves as the heating element, and the output of that heating element can be adjusted. But the toaster is not sensing temperature either; it merely has a spring that adjusts the time that the heating element is on. So, while the toaster needs far less manual input, it is still an "open loop" system.

What makes the thermostat different, then, is that it is actually sensing its environment and making adjustments as that environment changes. A homeowner could theoretically set a thermostat and leave it for months, never having to actively direct or control the system—but the system would maintain the same temperature range all during that time.

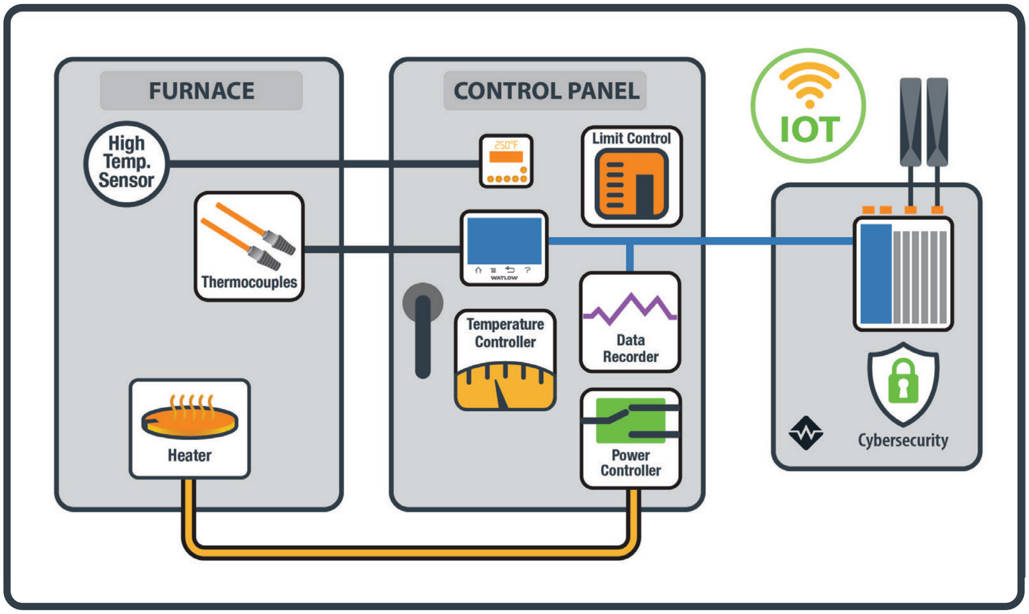


Diagram of how a thermal loop can be enhance through new technologies like Industry 4.0 and cybersecurity systems.

Now imagine if these components could review and analyze temperature variations through additional sensors that know when you are home or when weather conditions change dramatically. Storing and learning this information through complex new algorithms could enable the system to respond in a predetermined way essentially providing a smarter thermal loop. This is where Industry 4.0 (or I4.0) concepts begin. You can access more of ***Watlow's*** thoughts around I4.0 ***here***.

Complicating the Example—Or Why Thermal Control is So Difficult

Thermostats are nothing new, and the basic principles of controlling heat sources and maintaining temperatures have been around for decades. What more can ***Watlow*** add to the science and engineering of thermal control?

Think back to the traditional thermostat example. It is true that it can sense temperature and adjust accordingly. (That is what makes it a closed loop.) But if you have ever lived in a house or apartment with one, you know that they are severely limited.

For example, there can be a significant temperature variance between different parts of the house. If the thermostat is located in a cooler downstairs hallway, it might register that the house is at ideal temperature, even though the upstairs rooms are actually many degrees warmer. Or, conversely, the thermostat might overheat the house, shooting past the ideal temperature by several degrees.

So why do these things happen? There are many factors that play out in these scenarios:

- There is a large and noticeable temperature gradient in the house. (This is common in two-story houses since hotter air rises and cooler air settles. But poor insulation, exposure to the sun and other factors can be at play, too.)
- The thermostat is in one place, and can only read the temperature at that one place.
- Most homes have only a single thermostat; adding more would mean breaking into the walls to add appropriate wiring.
- The thermostat only allows for "on" and "off" control of the system; there is no "half on" as the house comes to temperature.

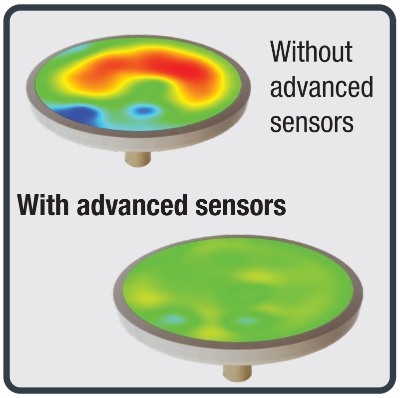
Hot and cold zones commonly experienced in a typical residential home.

Watlow does not offer solutions for home heating systems. But the problems seen with traditional thermostats are a good parallel for understanding the challenges that industries face when it comes to process heating and thermal control. For example:

- Many processes require precise heating but do so in interfering, environments (a blast furnace in a glass factory, for example). The process itself might introduce more or less ambient heat at specific locations. Getting a uniform temperature is thus trickier.
- Temperature sensing needs to be done in multiple zones, not just one place. For example, a surface for creating semiconductor chips might need to be divided into several dozen zones so that strict temperature uniformity can be achieved at each point (much like having a thermostat in every room of your house).

Industrial metal forming furnace operations can significantly influence ambient heat conditions.

- Adding sensors and controllers traditionally call for more wiring. Reducing the number of wires while still maintaining precise control is crucial for many applications.
- Heaters are typically controlled by consistently monitoring and varying the power being provided. If power can be controlled in a more precise manner, then heaters can be better controlled and heater life can be extended. This often requires going beyond simple "power on/power off" switches and introducing advanced forms of power control.



Thermal uniformity on semiconductor pedestals through ***Watlow's ATS technology***.

Why Creating a Thermal Loop Requires Systems Thinking

Why do we talk in terms of "thermal loops" at all? Why not just talk about heaters, sensors and power controllers themselves?

Granted, naming the parts of the thermal loop and understanding their features is easier. But remember, these individual components are just that: Components.

Understanding the thinking that goes into choosing the right components, and putting them together, is a far greater challenge. This is where ***Watlow's*** deep bench of expertise comes in.

The Right Recipe for the Right Application

Imagine that you want to cook a meal that will impress your dinner guests. You could go out and buy the best ingredients available. Maybe you get the most select cut of Kobi beef, spend money on the most expensive spices (maybe saffron and truffle oil?) and hunt to find the purest bottled spring water to use. Even though each ingredient is somehow "the best," you cannot just dump them all in a pot and expect the dish to come out well.

In fact, it will probably taste horrible. The flavors, though individually very good, might not mix well together. Or one flavor might overwhelm the others. There might be a sequence and timing to adding the ingredients, too. On the other hand, more pedestrian ingredients, carefully chosen to combine and highlight each other, can create a superb dish with the right recipe.

Your dinner guests' tastes matter, too. That Kobi beef might impress your boss and his wife, but what if you are throwing a birthday party for young children? Then pizza and birthday cake would be more appropriate. What if someone is vegan? Then both the beef and the pizza are out, and you need to think of something vegan friendly.

Closed loop thermal systems are a lot like dishes in this way. The ingredients matter, but so does the recipe and the end state you are trying to achieve. Each application, and each customer, has its own "recipe" that works for them.

Systems Thinking vs. Component Thinking

This is why systems thinking is so important. Even if you find that "best" component—the best heating element, the best sensor, the best power controller—it does not mean that you have found the best component for that particular application and system. In fact, the problem that a potential customer is facing might not even be an issue of the right component at all, but rather the way in which the entire system has been engineered.

For example, here are some issues that can arise in a thermal loop that are more "systems problems" than problem with any one component:

- Temperature sensors that are either too close or not close enough to the heating elements, giving a skewed picture of the temperature on a heater surface or within a heated space.
- Small fluctuations in temperature at the heating surface lead to "hot spots" which, over time, can result in scorched material accumulations that can foul up the equipment. The effect is not noticed until the equipment fails.
- The power needs and input to the system fluctuate over time, leading to inconsistent heating even when sensors are recording the correct temperature. Or they draw too much power and become a safety hazard.
- Space for heaters and sensors (and their wiring) is limited; components that can fit in the space must work in concert to keep temperature within a narrow range.
- A particular application calls for rugged equipment, including a rugged control panel. The panel will be difficult to access and maintain, and so must be built to maximize uptime with minimal intervention.
- A particular application generates a large amount of data from its sensors, but there is nothing analyzing that data to look for patterns that might indicate the need for equipment maintenance, adjustments to process stages, run times, energy utilization, etc.
- Data needs to be recorded and/or transferred because the application is part of a process in a highly regulated industry. There needs to be an adequate "audit trail," even when everything is working as it should.

These are just a few examples of the kinds of "systems" problems that ***Watlow*** has dedicated itself to solving over the last few decades.

What Are Typical Applications Where the Thermal Loop Matters?

There are many industries and applications where the control of thermal processes matter: Semiconductor processing, energy generation, materials processing, medical devices, foodservice equipment and more. Found within each of these industries are sensitive processes that require varying levels of temperature regulation.

For example, when a manufacturing process molds and shapes metal, the equipment needs to maintain a temperature above a certain threshold—but an exact temperature may not be necessary. But another process that involves melting plastic may need to keep temperatures within a very strict range, lest the material starts to burn or foul the equipment.

Currently, some of the applications where ***Watlow*** is solving complex thermal problems include:

- Respiratory devices
- Analytical equipment (sample heating)
- Exhaust fixing/heating (for factories and for diesel engines)
- Oil and gas processing
- BPA processing
- Concentrated solar/molten salt
- Gypsum processing
- Pedestal heating in semiconductor processing
- Food processing (dairy)
- Pharmaceuticals
- Heat treatment for aerospace parts

The Thermal Loop in Highly Regulated Industries

Some industries are highly regulated—think pharmaceuticals, medical devices, aerospace, food processing. In these industries, it is not enough to have precise control of the temperature for a given application; there also needs to be a record showing the performance of the system. For example:

- Pharmaceutical companies need to be able to prove the safety and authenticity of their products, and so have a stringent audit process in place. This includes recording temperatures used in their manufacturing processes.
- Manufacturers of airplanes must often heat treat various metal parts. Thus must be done within a precise temperature range, and manufacturers need a record of what that range was throughout the heat treat process to comply with industry regulations.
- A dairy farm that produces milk must ensure that it is safe to drink, meeting all regulations set down by the FDA and other entities. Every part of that process is controlled and recorded.

Non-compliance in these cases often means hefty fines and item recalls. Even if the equipment used is high performing and well controlled, there needs to be ways to easily access and accurately measure, monitor, record, and protect the various fine-tuned processes in question. Thus, data logging and monitoring are also very much a part of the thermal loop.

New drug therapy testing

Aerospace manufacturing

Dairy production

Questions that Demonstrate Thermal Loop Thinking

So what does it look like when a ***Watlow*** team member is demonstrating "thermal loop thinking?" It could be as simple as asking a different set of questions when trying to solve a problem or make a sale. For instance:

- Do we have the right component parts for this application?
- Do we have enough of each part to get the job done?
- How might the components fail, given the application environment? How costly is that downtime?
- How much space does each component take up? Are there space constraints that might suggest components with a smaller footprint?
- How much power does each component require? How much power would they leave for other, non-thermal-loop components?
- Do the components "talk" to each other appropriately? Are they updating in real time?
- How quickly can the system react to outside changes in temperature? How quickly does it need to react?
- Who needs data from these components? How and when do they want to receive that data? How crucial and timely is it for them? Are there compliance issues involved?
- What will be needed to set up the system? What other components might need to adjust when, for example, switching to an electric heater?
- How is overall safety guaranteed?

These questions are merely a guide and are certainly not exhaustive. With a little work, one can imagine how they could be made to illuminate a particular problem at hand. To take just a few examples:

- A customer asks for a new power controller to replace one that has malfunctioned. Is the power controller that they have the one that is most appropriate for the application? Was there something about the system's setup that caused the power controller to fail prematurely? How important is it to control the load on the system overall? How important is it to log the data about power consumption?
- An engineer asks why a heating element is not getting their oven up to temperature. Before recommending a larger heating element, ask: Is the sensor too close to the heating element? Is the power supply sufficient to reach the target temperature quickly enough? What can show the time course of the temperature change and inform the solution?
- An energy plant is being forced to move away from fossil-fuels, and so is interested in electrification of all processes. Before they invest in all-electric heaters, it might help to ask: How will these heaters be controlled and monitored? Is there space in the control room for an appropriately sized control panel? Or is a smaller one needed? What will the load be like once the heaters are turned on? (Who talked to the power company about this?) Is there a way to minimize the footprint of the heaters and control panels to make room for future expansion?

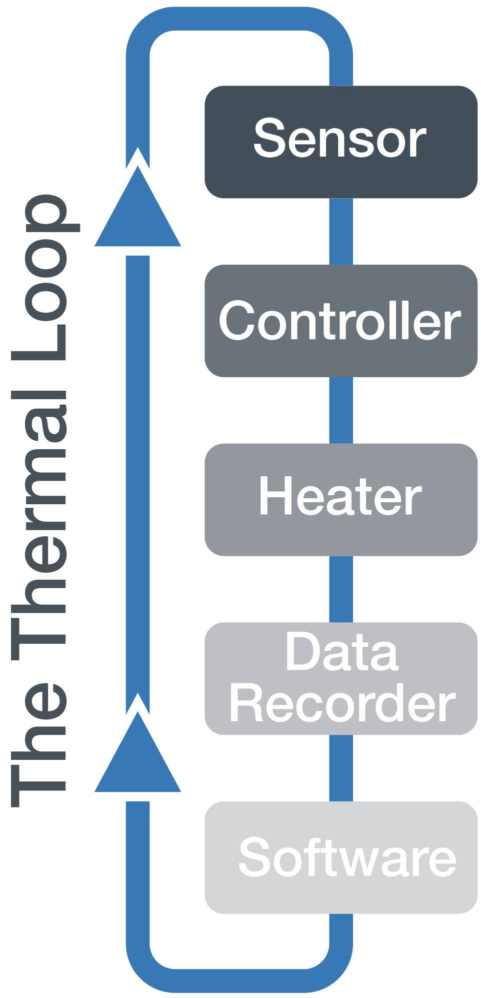
Again, the answers to the questions are going to be application specific and site specific. This is even more reason why these questions need to be asked in the first place. The better that ***Watlow*** can understand the application and its requirements, the better it can create a thermal loop that is consistent, sustainable, automated and that lends just the right degree of control.

Big Picture Takeaways

The thermal loop is an abstract idea that gives structure and organization to what ***Watlow*** does and how we do it. By thinking through the thermal loop for a given application, you will be better positioned to find various opportunities and solve complex thermal problems for ***Watlow*** customers.

Thinking through the thermal loop requires understanding the components of the loop (heater, sensors, power supplies, power controllers and process controllers). But more than that, it requires systems thinking: Considering how the various components need to work together to achieve their effect, and how those will be embedded in an application to achieve various goals.

Helping clients achieve their goals—whether a more efficient process, or lower carbon emissions (decarbonization) or better control within a confined space—often starts with an analysis of the system. This is where ***Watlow*** can apply its expertise and bring best practices to bear on our customers' applications. Once we can demonstrate our value in this way, we become a trusted partner for that customer from that point forward.



Further information is available at: www.watlow.com