Thermal Stress Testing: Breaking Old Habits
When to assess quality and reliability test resources

Thermal chambers have found a place in the psyche of test, quality, and production engineers—and for good reason. Chambers have been a staple for testing and conditioning materials and electronics for many decades.

First developed as passive conditioning tools, chambers have become standard fare for all types of temperature testing. They come with different sizes, configurations, and performances. Today, many test regimes involve dynamic measurements in which each device in a batch needs wire and cable connections running from the devices in the test chamber out to monitoring equipment on the outside of the chamber. In addition to cabling issues, the need to reduce test time continues to play a major role in allocating test resources. These are just a few instances where fixed-dimension chambers are poorly suited for the task. However, chambers are so prolific they often stand in as a “good enough.”

When is “good enough” no longer acceptable? The answer is when reducing time or early notification of failures has a real financial effect. Looking beyond tradition is hard, and there is a cost, but in some cases the benefits far outweigh these difficulties. This article discusses the challenges in temperature testing and when it’s time for an alternate approach.

What they do well

Thermal chambers are the standard for electronics and materials testing, widely adopted as a temperature conditioning tool in the absence of dynamic test requirements. Their advantages include:

- Different-size volumes are available, from half a cubic foot to walk-in rooms.
- Lengthy testing such as burn-in can easily run for hours and days.
- Unit under test (UUT) can be batched together in one test run.

Where they are limited

In some situations, thermal chambers are less effective due to:

- Reduced efficiency and uniformity when the chamber is not sized to the UUT
- Insufficient test bandwidth limits ability to test in parallel
- User access limitations due to predesigned chamber configurations

Here are three reasons why an alternative thermal source should be considered:

- When test throughput needs to increase
- When the UUT requires improved uniformity
- When chambers can’t be reconfigured to meet test requirements

Temperature forcing: an alternative approach

So what is an alternative to traditional chambers? Broadly defined, it is a system that uses compressed air, refrigeration, and heaters to control the temperature of an air stream. Precisely controlled air then
flows into an enclosure that contains the UUT. The industry calls this method by several names, but we'll use “temperature forcing.” (See figure 1.)

Figure 1. Temperature-forcing block diagram and physical system

Thermal chambers and temperature-forcing systems both use air convection to change the temperature of a UUT. Because air is a poor conductor, it needs sufficient flow to move a thermal mass. Therefore, it’s critical to optimize enclosure size to the UUT.

A note on context: Chamber users are accustomed to manufacturer specifications for air transitions only. These numbers ignore an important thermal load inherent in chambers: the metal walls of the enclosure. In fact, UUT temperature lags far behind air temperature because the energy absorbed by chamber walls is much greater than the effect of air. Examples used in this article include the load presented by an enclosure, air volume, and the UUT itself.

The examples in figures 2 and 3 include the mass of an enclosure and the UUT. They compare chamber and forcing-system transition times for a cooling from +150°C to −40°C using a 200 g aluminum mass UUT.

Figure 2. The UUT reaches −40°C in 43 minutes (4.4°C/min). Transition rates of 4° per minute are best case for batch-sized chambers, which includes the chamber walls, chamber air, and low-heat UUT.

In figure 2 the chamber UUT transitions to −40°C in 43 minutes. The forcing-system UUT makes the same temperature transition in 3.3 minutes.
How? The interchangeable enclosures of a forcing system are matched to the UUT size, which avoids having to cool excess volume and mass from the enclosure itself (discussed below).

Bringing the UUT to a precise temperature is another major difference between the two systems. Temperature forcing provides UUT control, which uses the UUT temperature as feedback to control the system. This allows a UUT to quickly reach a known, precise temperature.

![Temperature Profile 200 g Aluminum Mass in Forcing System](image)

**Figure 3.** Cooling transition time for UUT using a temperature-forcing system. It is 13 times faster than the UUT in a chamber (as seen in figure 2). Heating profiles would show even faster transitions.

**Reduce mass to increase speed**

Chamber mass is inescapable. Most chamber walls are made of stainless steel, and as such absorb heat. So much so that the work that goes into temperature transitions can be far less from the UUT or the volume of air around it. Rather, it is the energy and time needed to move the chamber mass itself.

In an effort to limit heat loss, chamber manufacturers make thick-walled enclosures. This really improves efficiency for test periods over many hours or days. However, if it is transition speed that you’re after, then the opposite needs to happen: You must reduce mass.

Low-mass enclosures and UUTs are optimal in temperature forcing. High-velocity air forced into a nonconducting enclosure, which absorbs little energy, produces an instantaneous change in the thermal environment around the UUT. The mass of a 2 lbs temperature-forcing enclosure has significantly less temperature load compared to the 50 lbs of a small chamber (as seen in figure 4).

![ATS Series](image) ![Enclosure](image)

**Figure 4.** Relative mass of enclosures for a temperature forcing (~2 lbs) system and a small chamber (~50 lbs).
If you test UUTs of varying size and mass, then chances are you won’t be using a chamber ideally suited for each one. The old habit of using chambers for everything, along with budget constraints, could likely result in making due with the equipment you already own. But there is no getting around it: Thermal mass and volume matter. If test time and cost are important, then adding thermal capacity will likely provide an economic payoff.

**Batch vs. individual device testing**

Chambers are great for applying thermal stress on multiple UUTs at the same time. However, there are two instances when a chamber batch is actually counter-productive.

The first instance occurs with temperature cycling time, where we’ve already shown the difference between temperature forcing and chamber systems. A chamber batch load will only increase ramp time. Realistically, the cycling time for a chamber batch of 10 printed circuit boards (PCBs) such as those seen in figure 5 will be longer than 30 minutes. The total cycle time for a temperature-forcing system, testing one at a time, for the same 10 PCBs will be 3–13 minutes to achieve the same result. That is, 20 to 80 seconds per board, for 10 boards.

![Temperature Profile of Populated PCBs using Forcing System](image)

**Figure 5.** Temperature profiles of various-mass PCBs with cooling curves for UUT to reach –40°C. Again, temperature forcing affects a thermal environment in seconds as opposed to minutes using a chamber.

The second instance has to do with the fact that a primary goal of any production test step is to identify problems with the manufacturing process *early*. The problem with batch testing is that many devices may get to this stage only to find that defects crept in from the previous manufacturing steps. Here, the costs of rework or scrap can be significant. By comparison, if you can individually build and test, you confirm quality right then and there, and more significantly, have the ability to correct a problem before building subsequent devices.

When does it make sense to look at temperature forcing? Thus far, we’ve shown how it can minimize thermal load to increase transition speed, as well as identify quality issues. But other issues factor into total test time and cost, such as user access and floor space, which is discussed below.

In general, the lower the percentage of time spent transitioning to temperature, the more likely a chamber is the correct system. However, for tests that are a few seconds to an hour or so in duration, temperature forcing should be considered.
Workflow considerations

Chambers are configured with doors, windows, lights, and ports to accommodate general test setups. Attaching cables and wires to the UUT can be cumbersome and lengthy when working around the confines of a chamber. Setup time can affect workflow effectiveness.

Setting up a test with temperature forcing works just the opposite of thermal chambers. Attaching and removing measurement and stimuli to the UUT is done in the open, separate from the thermal system. With setup completed the forcing-system enclosure is brought to the test site—manually or pneumatically.

Forcing-system enclosures of various types and sizes are interchangeable, allowing efficient and flexible test environments.

Figure 6. Temperature forcing can also accommodate batch testing with small-mass devices while maintaining high capacity. Air flow can be direct (left) or indirect toward the walls of an enclosure (right).

Finally, chambers are relatively fixed-location tools where test subjects are moved from another location to the chamber. Conversely, temperature-forcing systems are mobile, rolled to another part of the lab or production floor. This type of thermal system can move to the UUT, allowing greater operational flexibility and user convenience.

What are the right conditions to break old habits to improve testing?

Regardless of whether you use a chamber or forced-air system, here are a few key questions and answers to help you quantify when current thermal testing challenges your time and cost goals. Some can be achieved with chamber modifications. Temperature forcing can be applied to many types of test requirements. You can use the table below as a check list against your current system of temperature testing.

<table>
<thead>
<tr>
<th>Ask these questions</th>
<th>Analysis and improvement</th>
<th>Benefit</th>
<th>Equates to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the test fixture allow proper air circulation around the UUT?</td>
<td>UUTs should be 2–4 in. from walls, or UUT orientation restricts flow (if using a chamber). Redesign fixture, but consider cost.</td>
<td>Reduces time to reach uniformity</td>
<td>Time $________</td>
</tr>
<tr>
<td>Is thermal capacity sufficient to bring UUTs to specified temperatures in an acceptable time?</td>
<td>Thermal capacity of system should be much greater than test temperatures. Evaluate replacement system.</td>
<td>Reduces time to reach set point</td>
<td>Time $________</td>
</tr>
</tbody>
</table>
Does it make sense to perform single or batch testing?

<table>
<thead>
<tr>
<th>Use single UUT when cycle times are short and failures can be identified. Evaluate replacement system.</th>
<th>Faster overall testing and quicker isolation of problems; reduces retest and rework time</th>
<th>Time_____ $_______</th>
</tr>
</thead>
</table>

Is test setup or access hampering workflow?

<table>
<thead>
<tr>
<th>Reconfigure system to remove obstacles. Modify chamber or evaluate replacement system.</th>
<th>Reduces time to start and transition tests</th>
<th>Time_____ $_______</th>
</tr>
</thead>
</table>

Can thermal test be done at the UUT, or is floor space at a premium?

<table>
<thead>
<tr>
<th>System mobility for space needs, multiuse test sites, or production integration. Add wheels to chamber or evaluate replacement system.</th>
<th>Multiuse testing with same equipment or in-situ testing</th>
<th>Time_____ $_______</th>
</tr>
</thead>
</table>

Summary

Ensuring the quality of devices and materials typically requires a range of precision thermal environments to accommodate the product life cycle, including conditioning, verification, calibration, reliability testing, failure analysis, and quality audits.

Traditional chambers are used every day to support testing requirements, but they may be slow to perform or have other issues. For instances when “time is money”—i.e., during setup or a test run—and the size and mass of a UUT is small, then there’s value in realigning thermal test resources with the goals of the business.

Improving productivity includes an analysis of enclosure size, thermal properties, user access, use of floor space, and control functions. Hopefully, this article will help you identify when “good enough” is not adequate, and breaking the cycle of habit opens new paths to improving quality resources.

ABOUT inTEST Thermal Solutions

inTEST Thermal Solutions (iTS) specializes in the design and manufacture of thermal environments for electronics temperature testing and conditioning, as well as industrial process cooling systems. Thermal equipment includes mobile temperature systems, thermal chambers and platforms, and process chillers. We are recognized for expertise on precise control of extreme thermal environments, -185 to +500°C, and rapid transitions between desired temperatures. The ITS family includes three temperature-related corporations Sigma Systems, Temptronic and Thermonics. ITS is the Thermal Products Segment of inTEST Corp, Mount Laurel, New Jersey, USA.