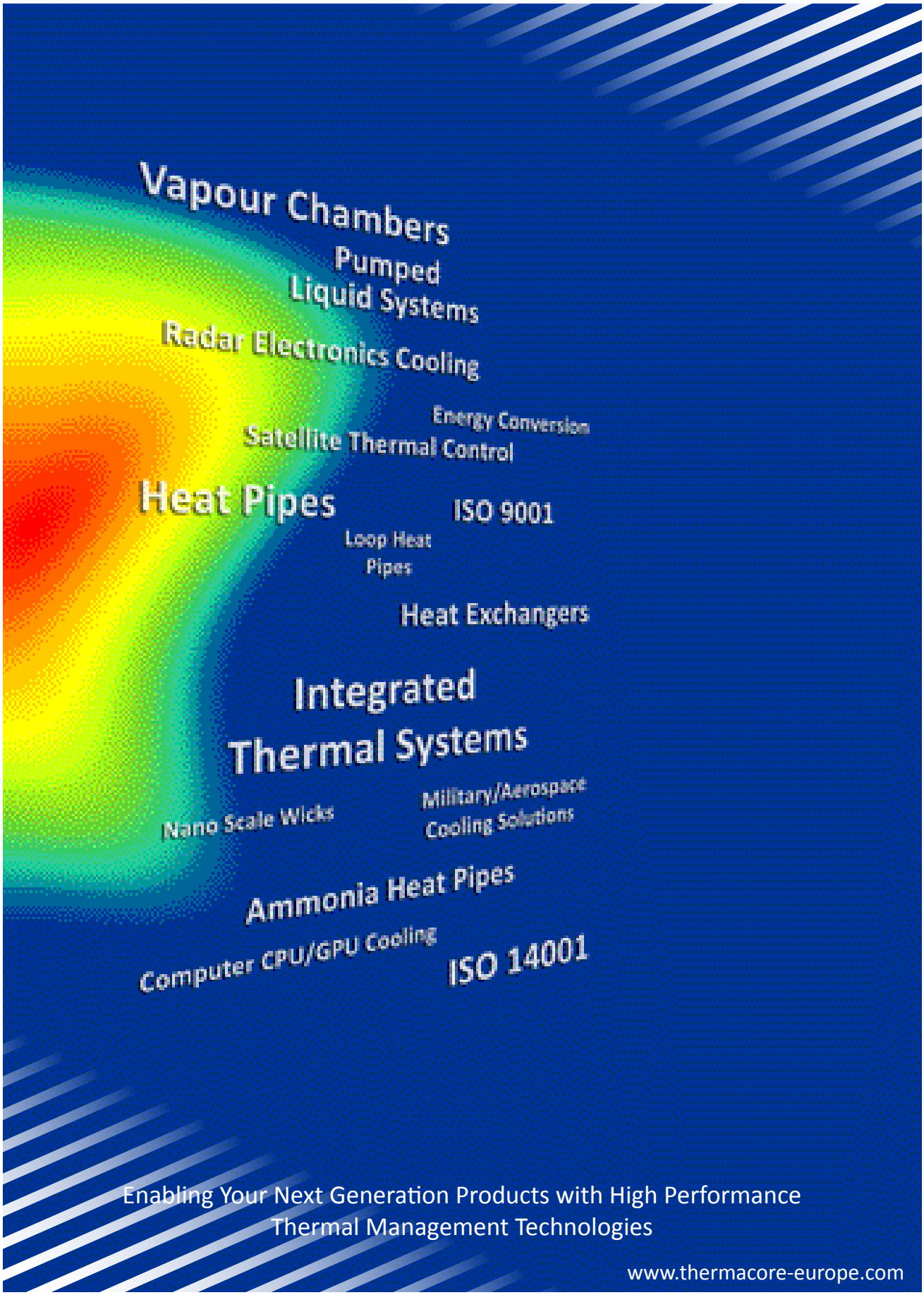
THERMACORE EUROPE

Thermal Management Solutions



Enabling Your Next Generation Products with High Performance Thermal Management Technologies

www.thermacore-europe.com

HIGH-PERFORMANCE, CUSTOM SOLUTIONS

Thermacore Europe leads the industry in the design, development and production of custom thermal management solutions for Original Equipment Manufacturers (OEMs) and Contract Manufacturers worldwide. Maintaining a tradition of excellence in heat transfer technology, we have the technical expertise and manufacturing capabilities to solve the most demanding thermal management challenges.

The Thermal Solution Technology Leader

With over 100 patents and 400+ man-years of engineering expertise, we develop and retain the most experienced and dedicated engineers in the industry. Thermacore Europe's Research and Development activities have a proven track record of moving technology from concept to fruition. Our international presence, industry leadership and problem solving skills will ensure your thermal needs are met in a timely and cost effective manner.

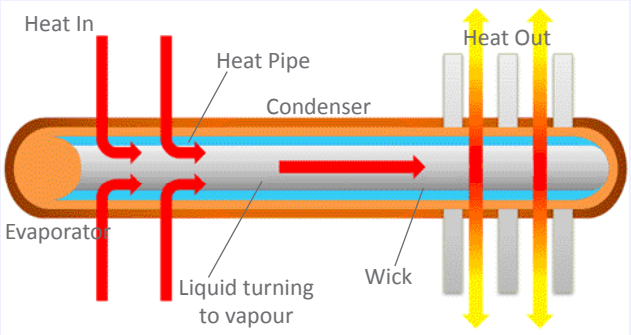
Masters in Two-Phase Heat Transfer Technology

Our reputation has been built on developing custom thermal management solutions using compact, highly efficient two-phase technology. We have almost 40 years of experience designing, developing and manufacturing heat pipes and heat pipe based thermal solutions for many industries including military, medical, telecoms, aerospace, energy conversion, power electronics, test equipment, transportation, industrial controls, consumer and automotive.

Superior Quality and Reliability

Thermacore Europe is committed to providing customers with the highest level of product quality and reliability. This is ensured through extensive thermal and mechanical analysis of the application requirements and validation testing. Thermacore Europe can evaluate product thermal performance in our thermal lab, test product mechanical performance under various environmental conditions e.g. shock and vibration, freeze/thaw, salt fog and perform failure analysis to understand product deficiencies.

Two Phase Cooling - Heat Pipes



A heat pipe is a two-phase heat transfer device with an extremely high effective thermal conductivity. It can be cylindrical or planar and the inner surface is lined with a capillary wicking material. The heat pipe is evacuated and backfilled with a small quantity of a working fluid such as water, nitrogen, ammonia or sodium. Heat is absorbed in the evaporator region by vapourising the working fluid. The vapour transports heat to the condenser region where the vapour condenses, releasing heat to a cooling medium such as air. The condensed working fluid is returned to the evaporator by gravity, or if working against gravity, by capillary action created by a "wick structure."

Heat pipes have a lower total thermal resistance than solid conductors, enabling efficient and even heat transfer. An important element of the heat pipe is the "wick structure." While we design and manufacture heat pipes with various wick structures, we specialise in a "sintered powder metal" wick structure that allows the heat pipe to provide the highest heat flux capability, greatest degree of gravitational orientation insensitivity, and freeze/thaw tolerance. Since establishment, Thermacore has pioneered and developed "sintered powder wick technology" and is the technology leader in the industry.

Heat pipes are completely passive heat transfer systems; they have no moving parts to wear out and require no energy to operate. Heat pipes offer low-cost packaging flexibility because they can be manufactured in a variety of shapes and sizes. Their light weight and compact size also make them the ideal choice for space constrained applications. Heat pipes can be manufactured to survive freeze-thaw conditions.

HEAT PIPE ASSEMBLY TECHNOLOGIES

Multiple Heat Pipe Technology

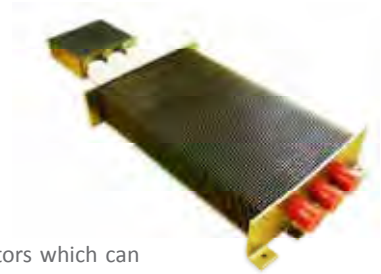
Therma-Sink™ uses heat pipe technology to move the heat from an attachment plate at the heat source to a location within the package where enough space is available for adequate heat removal. Fins are stacked on the heat pipes to provide adequate surface area for heat dissipation to the air. Designed for applications with limited space directly above the hot component (such as Blade Servers), multiple Therma-Sinks™ can be used to transfer heat to a common airflow. Thermal resistance is minimised within the assembly through the use of a thermally conductive epoxy or solder, efficiently transporting heat from the hot component to the fin stack for dispersal. Therma-Sink™ can be located above, below or on the same level as the heat source making a wide variety of design configurations possible. Therma-Sink™ assemblies are typically made of aluminum or copper.

Embedded Heat Pipe Technology

Embedding heat pipes into a heat sink is an effective way to greatly enhance the performance of an existing heat sink with minimal design changes. Embedded heat pipes extend overall heat sink operation with little to no system updates, providing improvement in your existing heat sink. Heat pipes inserted into the grooves of a heat sink base may reduce a heat sink's thermal resistance by up to 50%. This allows embedded heat pipes to provide necessary improvements to your existing heat sink where needed. Embedded heat pipes may also allow an aluminium heat sink to be implemented where, previously, an expensive and heavy all copper solution was used.

High Power Heat Pipe Technology

Thermacore Europe manufactures several Therma-Charge™ products for cooling power semiconductors, typically used in motor drive assemblies, with heat dissipation requirements ranging from 100's of Watts to over 10,000 Watts. Standard heat pipes are embedded in a metal plate under the power semiconductors and extend from the plate to a remote fin stack. Heat from the electronics is absorbed by the heat pipes and transported to fins which are cooled by natural or forced convection. Power electronics, such as IGBTs, can be mounted on both sides of the plate affording good installation flexibility.



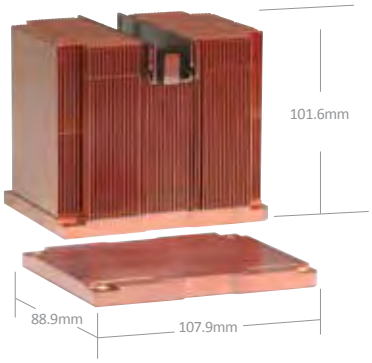
Isolated Therma-Charge™ units are electrically isolated by using ceramic insulators which can insulate several thousand volts of electricity. Various sizes and configurations of the Therma-Charge™ and Isolated Therma-Charge™ units are possible and custom specifications are available.

Tower Heat Pipe Technology

In a Therma-Tower™ the base is an integral part of the heat pipe. By having wick structure in the base, a significant thermal interface between the heat source and the air is eliminated, and higher heat flux loads can be handled. The vertical arrangement of cooling fins along the outside of the heat pipe results in maximum heat dissipation with the smallest footprint. Fine Pore Wick covers walls and bottom of heat pipe for maximum heat transfer and permits operation in any orientation.

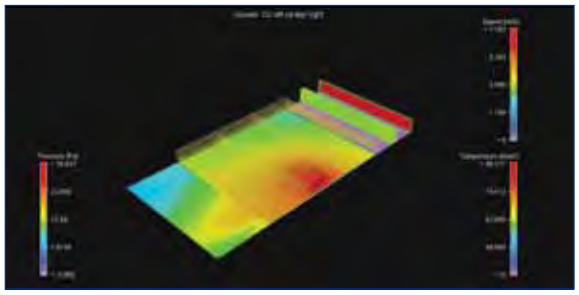
For more detailed Therma-Charge™ information, please see our Power Electronics brochure that can be found at: www.thermacore-europe.com

HEAT SPREADER TECHNOLOGY



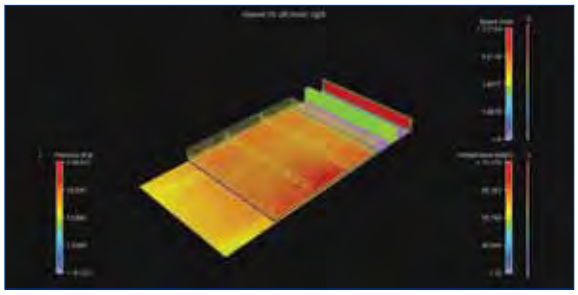
Therma-Base™ or Vapour Chamber Technology

Therma-Base™ is a planar heat pipe, or vapour spreader, used as the base of a heat sink. A Therma-Base™ delivers higher thermal performance than a traditional, or heat pipe embedded, heat sink by alleviating spreading resistance found in heat sink constructions. Therma-Base™ achieves superior performance via two-dimensional spreading, enabling lower device temperatures and greater component reliability. Therma-Base™ has an enhanced capability to accept higher heat fluxes than a traditional aluminum or copper surface. Its smaller size improves system packaging and provides quieter operation through less air flow. Therma-Base™ passes shock and vibration testing and thermal cycling (freeze/thaw), operating at any orientation.



All Copper Base Heat Sink = 0.423 °C/Watt

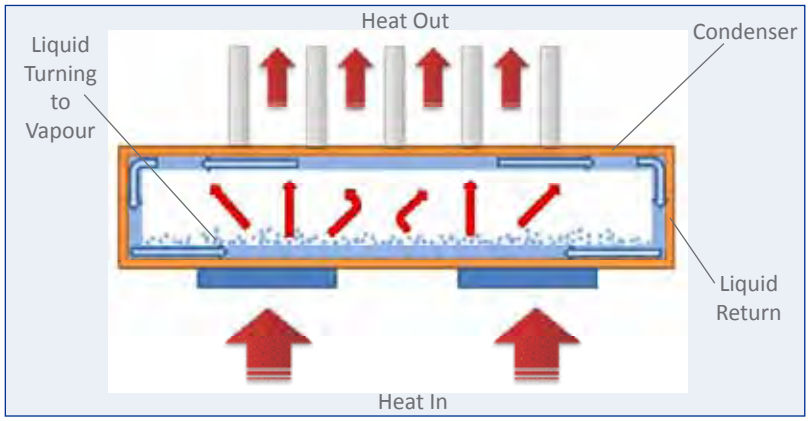
vs.



Therma-Base™ Heat Sink = 0.307 °C/Watt

Therma-Base™ Advantages

- Highest performing heat spreader in the industry (allows 3D heat spreading)
- Effective thermal conductivity between 5,000 W/mK to 10,000+ W/mK (vs. 401 W/mK pure copper and 1,200 W/mK graphite)
- Application improvement of over 30% in high flux, poor spreading applications
- Over 350 watts/cm^2 heat flux capability
- Can be engineered to withstand increased internal pressure (Working temperatures up to 150°C)
- Various sizes possible, Thermacore Europe has experience producing vapour chambers as large as 431.8mm wide by 762mm long
- Patented Thru-Hole Technology allows both straight and threaded holes through the highly conductive vapour space region for ease in design of attachment hardware
- Thermacore Europe vapour chambers have been successfully thermally cycled from -40°C to +85°C
- We have over 50,000 hours of vapour chamber continuous life testing
- We have shipped over 500,000 vapour chamber heat sink assemblies



Applications

- Computer CPU and GPU Cooling
- Desktop, Server, and Mobile Computing
- Military and Power Semi-conductor Cooling
- IGBT's, MOSFETS, SGT's, Thyristers
- Telecom Applications – RF Amplifiers
- Low Profile Applications – Blade Servers
- High Temperature Applications (>100°C)
- High Structural Strength Applications
- High Clamping Force Applications

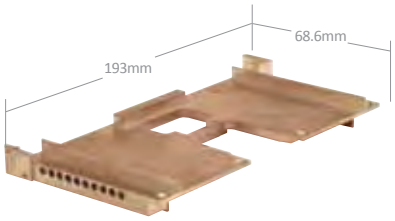
Thin Therma-Base™

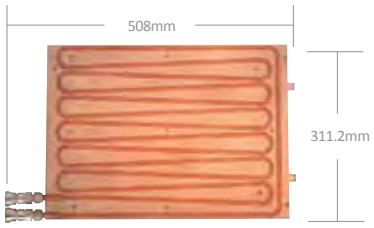
- Credit card thickness available in copper and titanium
- Heat pipe thermal performance is 100 times better than same mass solid copper plate and 50 times better than same volume of solid copper plate
- Operation insensitive to orientation and locations of the heat input and heat removal areas

COLD PLATE TECHNOLOGIES

Heat Pipe-Assisted Cold Plate Technology

Thermacore Europe use heat pipes embedded in an aluminum plate to provide the necessary high-efficiency heat transfer in space and weight constrained applications. By using heat pipes, the cold plate has the weight of aluminum with an effective thermal conductivity more than four times that of copper. It is capable of operating in harsh environments including high altitude, extreme temperatures and humidity, shock and vibration.



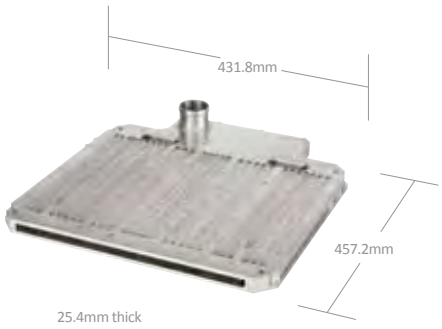


Custom Embedded Tube-in-Plate Liquid Cold Plates

Our bespoke embedded tube-in-plate liquid cold plate technology is engineered to match the thermal/mechanical performance, pressure drop and dimensional requirements of the application. Our customised solutions consist of copper or stainless steel tubes pressed into a channelled aluminum or copper extrusion or machined plate. These cold plates are cost-effective and offer good heat removal for low-to-medium watt densities. Typical applications include power electronics, RF generators and transmitters, semiconductor processing equipment and uninterruptible power supplies.

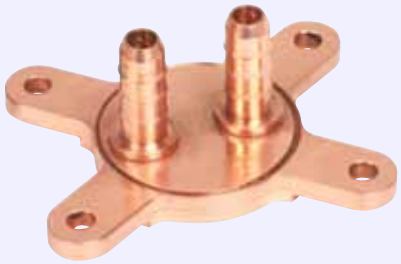
Vacuum-Brazed Cold Plate Technology

Thermacore Europe's Vacuum-Brazed Cold Plate technology is engineered to match the thermal/mechanical performance, pressure drop and dimensional requirements of the application. We customise the internal flow configuration to maximise thermal performance and minimise cold plate pressure drop. The cold plates can include embedded heat pipes and be manufactured in various sizes and shapes. Our vacuum-brazed cold plates can include unique surface finish requirements and hole locations for mounting. We have designed these cold plates for various fluids including air, water, water/glycol and PAO.



Liquid Cooled Cold Plate Technology

We can manufacture pumped liquid cold plates as part of a complete system to cool high-power semiconductors requiring high rates of heat removal with low fluid flow. These liquid cold plates incorporate vertical fin technology (e.g. microchannel technology) or for higher performance Thermacore Europe's powder metal technology. Thermacore Europe's custom liquid-cooled assemblies are designed specifically to our customer's unique thermal/mechanical requirements.



Liquid Cooling System (LCS) Technology

The Thermacore Europe Liquid Cooling System (LCS) is a sealed system that utilises pumped single phase liquid to cool computer microprocessors. The liquid cooling system uses a pump to circulate a thermally conductive liquid that removes heat from the processor using Thermacore Europe's Liquid Cold Plate technology and rejects it to the ambient air flowing through a liquid-to-air heat exchanger.

Thermacore Europe has incorporated its patented sintered powder metal technology into the cold plate component. Microchannel cold plates can be used for applications with lower performance requirements. The all-aluminum, liquid-to-air heat exchanger allows for higher heat flux capability to maximise heat transfer efficiency by dissipating excess microprocessor heat into the local ambient air.

AVIONICS THERMAL CONTROL TECHNOLOGIES

Aircraft Thermal Control Trends and Challenges

The More Electric Aircraft (MEA) architecture removes the hydraulic system and replaces it with wires, motors and electronics. A more electric architecture will reduce weight and fuel consumption and require less maintenance, resulting in a more efficient and cost-effective aircraft. As the MEA approach is implemented, electronics and motors are being moved closer to the components they control. As a result, critical electronics and motors are positioned in remote locations throughout the aircraft where their thermal control is more difficult. Thermacore Europe's custom thermal solution technologies help to enable the MEA architecture through improved cooling of these distributed electronics and motors.

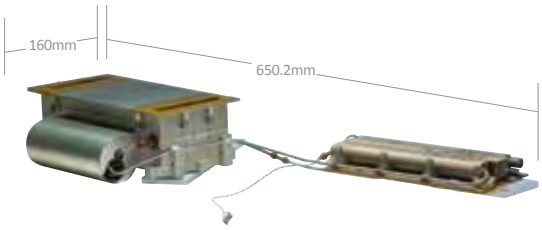
Heat Pipes for Avionics

Thermacore Europe Heat Pipes are qualified for use on aircraft. Currently our heat pipes are used to cool critical components on next generation fighter aircraft. In addition to providing improved thermal performance over competing graphite conduction solutions, our heat pipes used on the F-35 JSF application had the additional benefit of being lower cost than competing solutions.

Loop Heat Pipes for Avionics

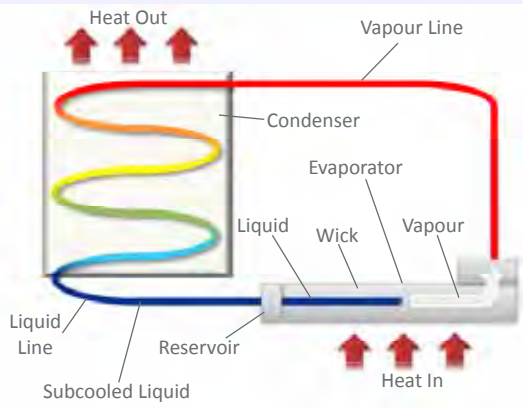
Over a period of several years, the Navy, Air Force and NASA helped us to qualify loop heat pipes (LHP) for aircraft thermal control applications. This qualification process included thermal performance testing, high-g spin table testing, flex fatigue testing, shock/vibration testing and freeze/thaw testing. As a result of this work, Thermacore loop heat pipes are being implemented into aircraft thermal control applications. The most notable use of an LHP is on the F-16 to cool an electro optical targeting POD. We delivered over 100 production LHPs for this use to provide long distance heat transport while providing shock and vibration isolation between the heat source and heat sink under 9g environmental conditions. Other suitable aircraft applications for LHPs include:

- Actuator-mounted electronics cooling
- Wing and cowl anti-icing using engine waste heat
- Avionics Cooling



Loop Heat Pipes

LHPs provide effective heat removal over long distances without sensitivity to gravity. These unique passive two-phase heat transfer systems are bendable, flexible and routable and have the ability to operate as thermal diodes and prevent backward heat leakage. Loop heat pipes can have multiple evaporators to accommodate dispersed heat sources and can include passive/active thermal regulation.



Advantages

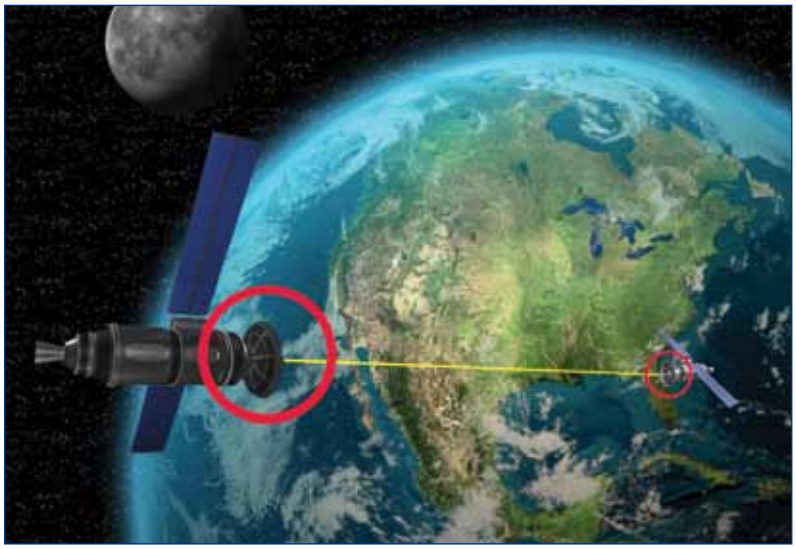
- Dissipates several watts to multi-kilowatts
- Long distance heat transport (Up to 75 ft. / 23m)
- Broad operating temperature range
- Transport lines can be made flexible
- Flex fatigue resistant (>7.5M flex cycles)
- 9g operating condition capable
- Shock and vibration (34g random) qualified
- Freeze/thaw survivable

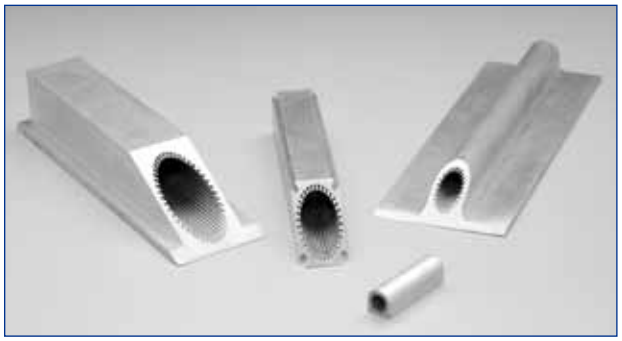
AEROSPACE THERMAL CONTROL TECHNOLOGIES

Satellite Thermal Control Trends

With the ever-increasing demand for national, international and military space-based communications and the evolution of space electronics (miniaturisation, complexity, and integration), satellite thermal control subsystem must accommodate significant increases in waste heat dissipation. As a result, thermal control of satellite and spacecraft electronics is a significant issue that requires advanced thermal management solutions.

To enable effective cooling of spacecraft electronics, Thermacore Europe offers a variety of Heat Pipe and Loop Heat Pipe technologies to provide efficient and low mass thermal solutions.





Heat Pipes for Aerospace Applications

Thermacore Europe Heat Pipes for Aerospace applications include Constant Conductance and Variable Conductance (VCHP) axially grooved ammonia and copper-water heat pipe systems. Our copper-water heat pipes are qualified for use on spacecraft and have been successfully used on the Navy Windcat Microwave Radiometer Satellite.

Additionally, our Axially Grooved Ammonia Heat Pipes can be integrated into the radiator panels of the satellite thermal control subsystems. Thermacore Europe and our radiator panel supplier partners can provide these heat pipes embedded in a structural honeycomb panel.

Loop Heat Pipes for Aerospace Applications

As more and more electronics are being packaged into satellites, providing adequate thermal control through radiation heat rejection with limited surface area becomes more challenging. Heat rejection radiator panels that can be stowed for launch and then deployed from the satellite on orbit are required. Thermacore Europe's LHP technology makes heat rejection through deployable radiators possible. Our solutions are capable of transporting and rejecting heat loads from 100's of Watts to greater than 2000 Watts.

LEADING EDGE TECHNOLOGIES

Thermacore Europe originally developed copper-water sintered wick structure heat pipes for the Military and Aerospace market. We used this development to benefit our commercial OEM customers by enabling their next generation products.

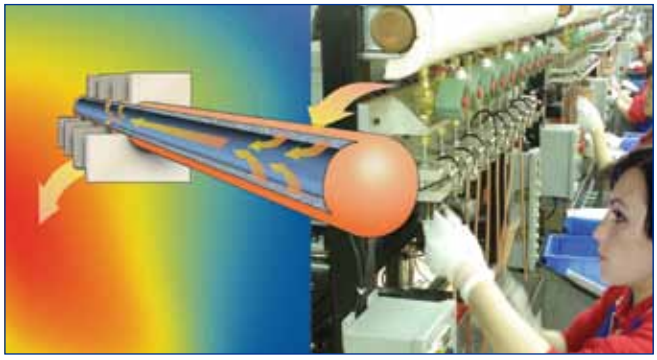
At the same time, commercial adoption and repetitive, high volume manufacturing of these advanced products helped to drive down the cost of the product, which benefits the sector with reduced costs. Maintaining this technology development cycle is part of our heritage, and an important enabling process for all of Thermacore Europe's markets and our commercial OEM customers.

New Technology Development

To support this "High End Technology to Mass Production" business model, we have a proven track record of new technology development which serves as a catalyst to keep ourselves at the forefront of emerging cooling technologies and applications. Thermacore Europe remains active in new thermal technology development and the application of that technology for the most challenging thermal problems. We develop solutions and underlying technologies to meet the needs of prime contractors as well as FP7 Projects, DARPA, DOD, DOE, NASA, and NSF. A few of these emerging technologies are:

- Nanoscale Wicks
- CTE Matched Solutions
- Advanced Materials
- High-Temperature Heat Pipes
- Advanced Air Cooled Solutions
- Leading Edge Heat Spreaders
- High Performance Pumped Single and Two-Phase Cooling
- New and Improved Modelling Methods and Tools

Concept → Mass Production

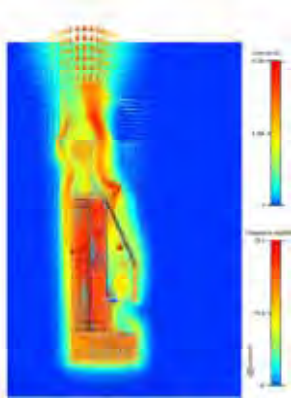


High Heat Flux Heat Pipe Technologies

The heat flux capability of a heat pipe is determined by the boiling limit in the heat pipe evaporator structure. Axial grooves, mesh screens and sintered powder wicks are commonly used in wicking structures, providing capillary pumping to return liquid to the evaporator. The evaporator wick structures also serve as extended surfaces for evaporation or boiling heat transfer enhancement. The performance data in the table shown is based on test results for copper/water heat pipes and other single- or two-phase devices.

Wick Structure Technology	Heat Flux Capability
Miniature, axially grooved wicks	Up to 20W/cm²
Mesh screen wicks	Up to 40W/cm²
Inverted-meniscus wicks	Up to 200W/cm²
Sintered wicks	Up to 350W/cm²
Graded wicks	Up to 250W/cm²
Combined pulsating and capillary transport structure	Up to 250W/cm²
Graded wicks with secondary liquid feeding wick	Up to 300W/cm²
Bi-dispersed wicks	Up to 1,000W/cm²
Porous metal with single phase helium flow	Up to 11kW/cm²
Porous metal with single phase water flow	Up to 12kW/cm²

ANALYSIS, TESTING, AND MANUFACTURING CAPABILITIES



Design and Analysis

We can import your CAD drawings and input your parameters to run the thermal or mechanical analysis that best meets your needs efficiently. From thermal analysis to mechanical design, CAD modelling to CFD analysis, our first class design team is ready to provide the thermal solutions to fit your component, board and system level requirements.

Thermal Lab and Calorimeter/Test Cells

Our Thermal Lab quantifies the performance of cooling devices. Parts are evaluated on their ability to meet the specifications required. Efficiency of the component can be checked before and after an event, such as a structural test or a life test, to investigate degradation in performance.

Calorimeters or Test Cells create a stable environment with a variety of moving gases and fluids. A component's thermal efficiency can be tested with controlled temperature, pressure and flow levels.

Temperature Shock and Cycle Testing

Thermacore can also perform thermal shock and cycle testing that subjects a product to alternating extremes of high and low temperatures in order to observe changes in product characteristics and failure occurrence caused by different materials and their thermal expansion coefficients.

Life and Reliability Testing

Thermacore Europe has been performing heat pipe and LHP life testing on a variety of material systems and heat rejection conditions for almost 40 years. Material systems and heat rejection conditions include copper-water, copper-water sintered powder, aluminum-ammonia, inconel-sodium, forced convection and liquid cooling. With over 300,000 hours of life of continuous, on-going life testing on copper-water-sintered power heat pipe systems, we have developed a proven set of manufacturing processes that control product life and reliability.

No other heat pipe manufacturer can make this claim

In addition to the rigorous life and reliability testing Thermacore Europe performs on heat pipe systems, Thermacore Europe is also performing life testing on single phase, pumped liquid systems.

Quality Control

Thermacore Europe is committed to a continuous improvement philosophy and is certified to both ISO 9001 and ISO 14001 standards. Thermacore Europe is currently seeking AS 9100. As part of our commitment to quality assurance, we utilise Statistical Process Control (SPC), lean manufacturing techniques and the latest measurement equipment such as CMM's and optical comparators in our manufacturing processes. We routinely manufactures product that meets the European Union RoHS Compliance requirements.

Manufacturing Capabilities

Thermacore Europe has extensive manufacturing capabilities to produce custom, high performance thermal solutions. Manufacturing equipment capabilities include machining centers, clean and sintering ovens, vacuum brazing ovens, manual and robotic welding (TIG, MIG, Plasma, Inert Gas) customised assembly equipment, and bespoke thermal test stations for 100% final thermal validation testing. In addition, Thermacore Europe has an experienced staff of manufacturing engineering and management personnel.

HEAT EXCHANGERS

Heat Exchangers for Enclosure Cooling

The trend toward greater miniaturisation of electronic components and assemblies has increased the capability to get more electronics into enclosed cabinets. Resultant increase in heat loads have placed greater demands on cabinet cooling to ensure that electronics are protected, while performing as intended.

Thermacore Europe offers a family of compact, high-efficiency, cabinet-cooling heat exchangers that are capable of meeting the increasing thermal requirements found in computer, communications and military applications. These heat exchangers are capable of meeting NEMA standards and various environmental conditions frequently found in the communications and military applications.

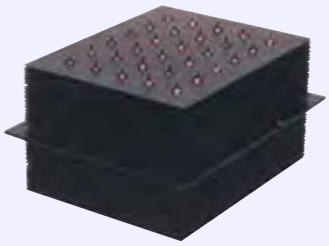
Reliability, thermal performance, cost and size are four governing factors in choosing heat exchangers for cooling electronic enclosures. Combined with lower maintenance cost and greater reliability, Thermacore Europe heat exchangers are the ideal solution for many cabinet-cooling applications.

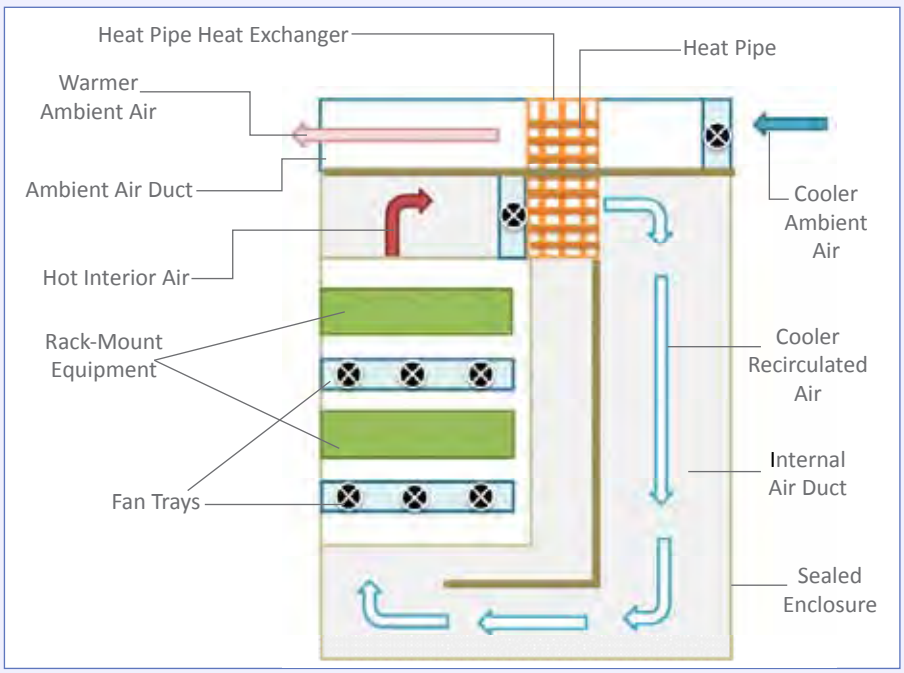
The key to optimal heat exchanger operation lies within its design, therefore Thermacore Europe has the ability to custom manufacture each unit according to specific application requirements, based around four types of heat exchanger core technologies. These heat exchanger core technologies include: heat pipe based cores, air-to-air impingement cores, liquid-to-air cores and air-to-air cross flow heat exchanger cores. The heat exchanger core technologies are described below and on the following page.

HEAT EXCHANGER CORE TECHNOLOGIES

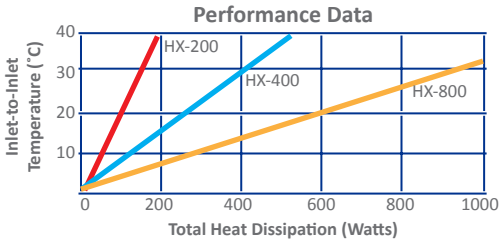
Heat Pipe Core Technology

Heat pipe core units can be a flexible thermal management system used to assure efficient cabinet level thermal management. Fin stacks can be tailored to accommodate different power loads and different air velocities in the ambient and internal loops. All heat pipe core units provide a NEMA 4 and NEMA 12 compliant seal to separate the two air streams. Thermacore Europe engineering can design the appropriate heat pipe core for each customer's application with a broad range of core sizes available.





HEAT EXCHANGER CORE TECHNOLOGIES



Performance Data:

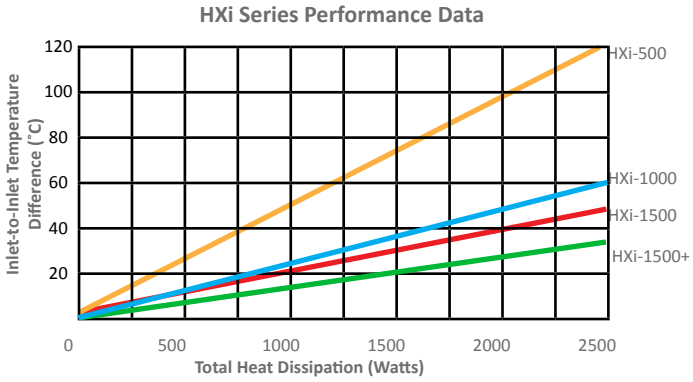
Model	Performance	Weight
HX-200	4.8 W/°C	2.7 lbs.
HX-400	13.2 W/°C	6.8 lbs.
HX-800	32.0 W/°C	15.1 lbs.

HX Series™ Compact Heat Exchangers

Thermacore Europe's HX™ Series is designed to provide economical cooling for enclosed electronic equipment with high heat loads. This series uses passive heat pipe technology with energy-efficient cooling fans for economical operation and high operational reliability. Their versatile mounting design allows for placement on doors, side, top or back of the enclosure. HX™ Series is an air-to-air heat exchanger that utilises two-phase heat pipe technology for performance, reliability and cost effectiveness. The HX™ maintains the integrity of NEMA 4 and NEMA 12 enclosures by utilising a flange and a closed-cell neoprene gasket between the unit's interior and exterior heat exchanger. Product design can easily be scaled to larger or smaller capacity configurations and can be equipped with either AC or DC fans. HX™ heat pipe heat exchangers are easily adaptable for custom applications and can be mounted externally, partially recessed or captured within ductwork.

HXi Series™ Air-To-Air Heat Exchangers

Our HXi™ Series air-to-air heat exchangers are designed primarily for cooling indoor and outdoor electronic enclosures. The HXi™ Series uses a double-sided impingement technology to achieve significantly improved heat transfer performance while reducing heat exchanger size. Comparative tests verified that a HXi™ heat exchanger is capable of dissipating twice the heat load of many other types of heat exchangers of a comparable size. Thermacore Europe's patented design makes the HXi™ Series heat exchanger a low-cost and high-performance alternative to conventional heat exchanger technologies. There are fewer moving parts for greater overall reliability. Standard units are available with 2, 4, 6 or 8 fans. Custom optional features such as alarms and temperature controls are also available. Units are UL recognised and meet Bellcore GR-487-CORE, NEMA 4 and NEMA 12 requirements.

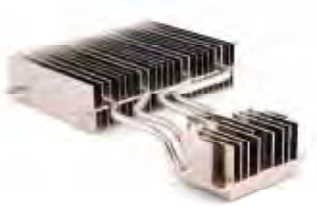


Liquid-To-Air Core Technology

Thermacore Europe's 5300 Series high-pressure heat exchanger is a high performance liquid-to-air heat exchanger. It is designed to provide effective cooling in a closed-loop cooling system where heat dissipation is too great for natural or forced air convection systems, or where heat must be dispersed at a distance from the components being cooled. Typical applications include cabinets, CT scan equipment, and industrial process equipment.

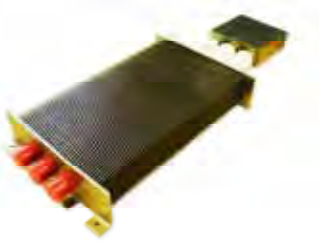
For more detailed heat exchanger information, please contact Thermacore Europe (details on back page) or visit our website: www.thermacore-europe.com

THERMACORE TECHNOLOGIES



Therma-Sink™

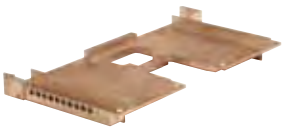
Therma-Tower®



Therma-Charge™

Embedded Heat Pipe

Therma-Base®

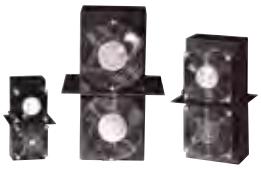


Heat Pipe Cold Plate

Custom Embedded Tube-In-Plate
Liquid Cold Plates

Vacuum Brazed Cold Plate

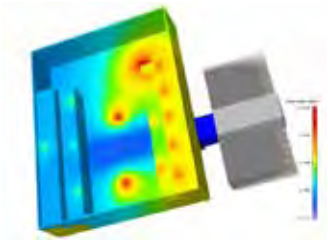
Liquid Cooling



HX™ and HXi™

Liquid-to-Air Core

Loop Heat Pipes



Thermal Analysis

Mold Cooling

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