JouleForce™ Microchannel For Electronic Cooling Testing and Design

A Molecular Based Framework For Heat Transfer

By: Scott Davis, Inventor, CEO Forced Physics LLC

Table of Contents

I. A Molecular Based Framework For Heat Transfer

Consider the energy efficiency of an integrated circuit. Every Joule of electrical energy delivered to the transistors and other components that make up ICs is converted into heat. During the early days of Moore's Law, a doubling of transistors on an integrated circuit was complemented by a proportional reduction in the power used to power the transistors (Dennard Scaling). This early trend ensured that the heat densities of IC's remained manageable and about the same as before. By the early 2000's though, fabricators encountered new scale related challenges that rendered Dennard Scaling obsolete. Since that time, silicon scientists and engineers have been creative in finding solutions to the array of challenges that ever increasing electronic speed and complexity create.

Today, the AI hardware stack includes GPUs, TPUs (ASICS), NPUs, and high-speed networking equipment. By parallelizing the workload at the IC level, the AI hardware stack accelerates the two main phases of AI operation, training and inference. Both of these phases are accelerated by circuitry that parallelizes the computationally intensive mathematical operations, such as matrix multiplications and tensor operations, both of which are fundamental to machine learning (ML), deep learning (DL), and neural networks.

Specialized ASICS in high-speed network switches provide efficient communication and high-speed data transfer between the large numbers of GPUs, TPUs and NPUs. The ICs used for high-speed operations are typically transistor dense and are fabricated with the smallest process nodes available (2nm and 3nm). While every effort is made to have the operations be energy efficient, the sheer speed of learning and inference operations requires high frequency operation of the IC elements. The combination of transistor density and high frequency operation of the ICs used in the AI hardware stack results in their notoriously high heat densities.

AI systems, especially those performing large-scale training or inference, rely on high-speed interconnects (e.g., copper using PCIe or proprietary interfaces) that are most effective over short distances (about 5 meters). Clustering components and entire servers into dense racks connected by short-range, high-speed links is the standard for optimal performance.

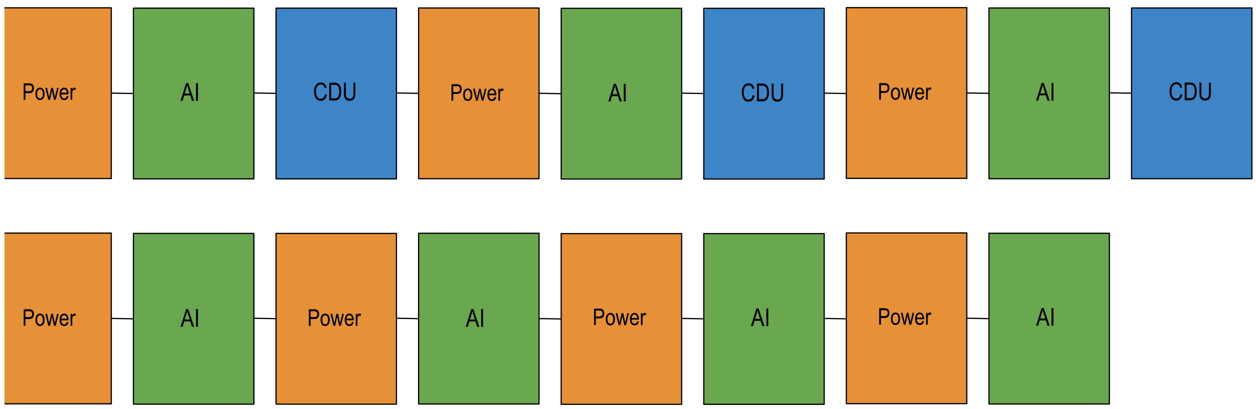
By 2029, the NVIDIA roadmap indicates the development of 4 kw GPUs that can be deployed in 1 MW racks. This AI architecture advancement will undoubtedly provide substantial gains in AI operational performance and capability and will be further advanced by the number of racks that can be included in a cluster.

The Open Compute Project (OCP) Strategy

The OCP strategy for racks with NVIDIA GPUs is to "fit" 250 4 kw NVIDIA GPUs into a single OCP rack and to remove the power components and Coolant Distribution Units (CDUs) that are normally housed in the same rack with the AI hardware stack. The solution utilizes alternating "in-row" side racks. One 2 MW capable side-rack provides 1 MW of power to two adjacent AI racks and another side-rack provides 2 MW of coolant distribution to its two adjacent AI racks. Single width 2 MW CDU racks decrease the number of AI racks that can be clustered in a row within 5 meters of each other by 33%.

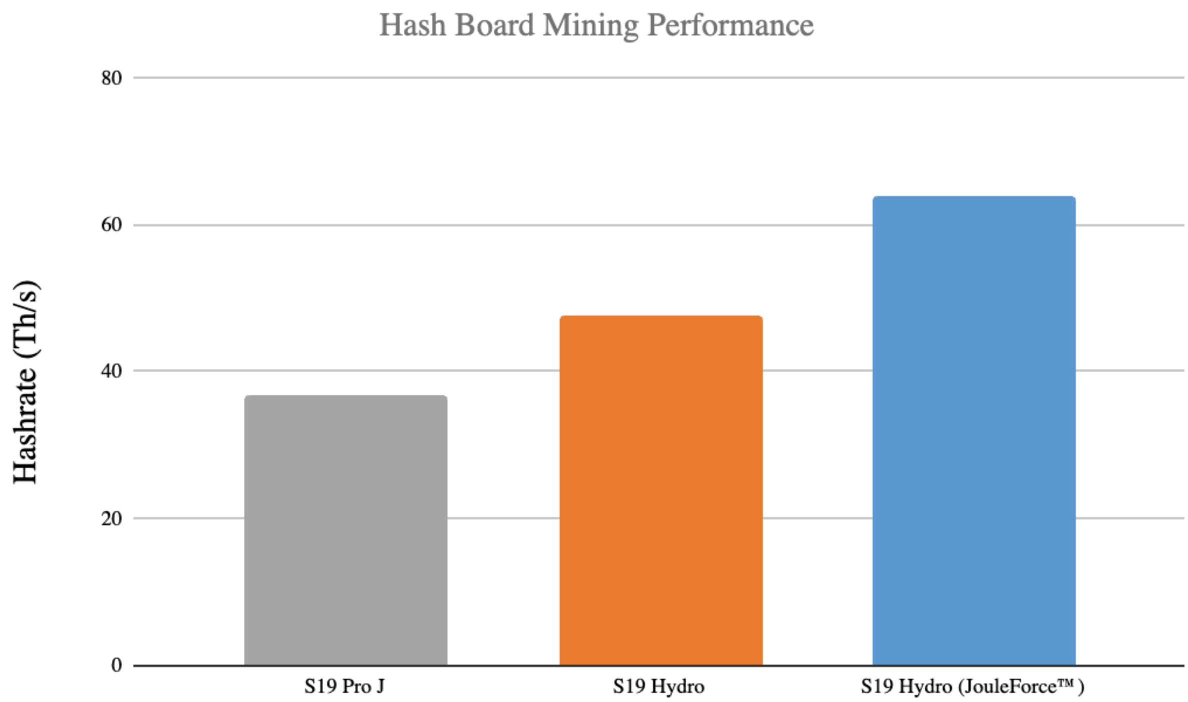
1.1 Cooling AI Hardware Without CDUs With JouleForce™

The diagram below illustrates the number of AI racks that can be clustered together with and without CDU side-racks.



Today, even the best direct-to-chip liquid cooling solutions require CDUs and the space that they occupy.

Forced Physics offers an electronic cooling product **JouleForce™** that doesn't require liquids or the use of CDUs. JouleForce™ technology converts the random motion of air molecules into an orderly coherent beam that removes heat from power dense surfaces at an unprecedented rate. It is currently used to cool the ASICs on the Bitmain S19 Pro+Hydro miner. S19 miners equipped with JouleForce™ MC4ECs experience a 33% increase in their advertised operating frequency beyond the advertised maximum frequency using direct-to-chip liquid cooling. In addition, an S19 system using JouleForce™ has been operated at full power, without throttling, outdoors in Scottsdale Arizona in 112 degrees Fahrenheit. Graph from this demonstration available below. Entire white paper on this subject available upon request.



II. The History of JouleForce™

JouleForce™ theory was initially presented to researchers at DARPA and the Army Research Laboratory (ARL) in Adelphi, Maryland. The idea of a "new" air-based physics that could contend with the inevitable rise of high power density electronics compelled DARPA and ARL to fund JouleForce™ research via a 3 year Cooperative Research and Development Agreement at ARL in Adelphi, Maryland and at a DARPA program facility, the MEMS and Nanotechnology Exchange in Reston, Virginia.

The program succeeded in developing a proof-of-concept MEMS device that converted room air molecules in a state of random motion into a collimated beam. The collimated beam was created inside a series of geometrically correct microchannels that were fabricated at ARL using MEMS technology. Today, aluminum substrates form the series of geometrically correct microchannels at a fraction of the cost of the earlier MEMS devices.

2.1 About JouleForce™ Technology

JouleForce™ uses specific microchannel geometry that "programs" the motion of air molecules at the molecular level. Upon entry to the microchannels, air molecules lose their random motion and instead transform into collimated beams. Beams form as a result of a series of most probable collisions that occur between the air molecules and the substrate.

Temperature at the Molecular Level

At the molecular level, a molecule's temperature is proportional to its velocity in each direction (x, y, and z). The faster a gas molecule flies (translates) in a direction, the hotter that molecule is, in that direction. The average air molecule in random motion has the same speed, and temperature in every direction.

As air molecules enter Forced Physic's MC4EC (Micro Channels For Electronics Cooling) their intermolecular and surface collisions result in collimated beams of air molecules. The collimated beams exhibit a lower (colder) most probable flight velocity towards the surface (surface normal) and a proportionately faster (hotter) most probable velocity parallel to the microchannel's length, than random motion would dictate.

Billions of "cold" surface collisions per second extract heat energy from the rapidly vibrating (hot) surfaces of the MC4EC. MC4EC geometry ensures that energy extracted from the microchannel surfaces is converted into additional surface parallel (x-axis) velocity in the direction of flow. Translational energy in the direction of flow is not a source of energy transfer to the surfaces of the MC4EC.

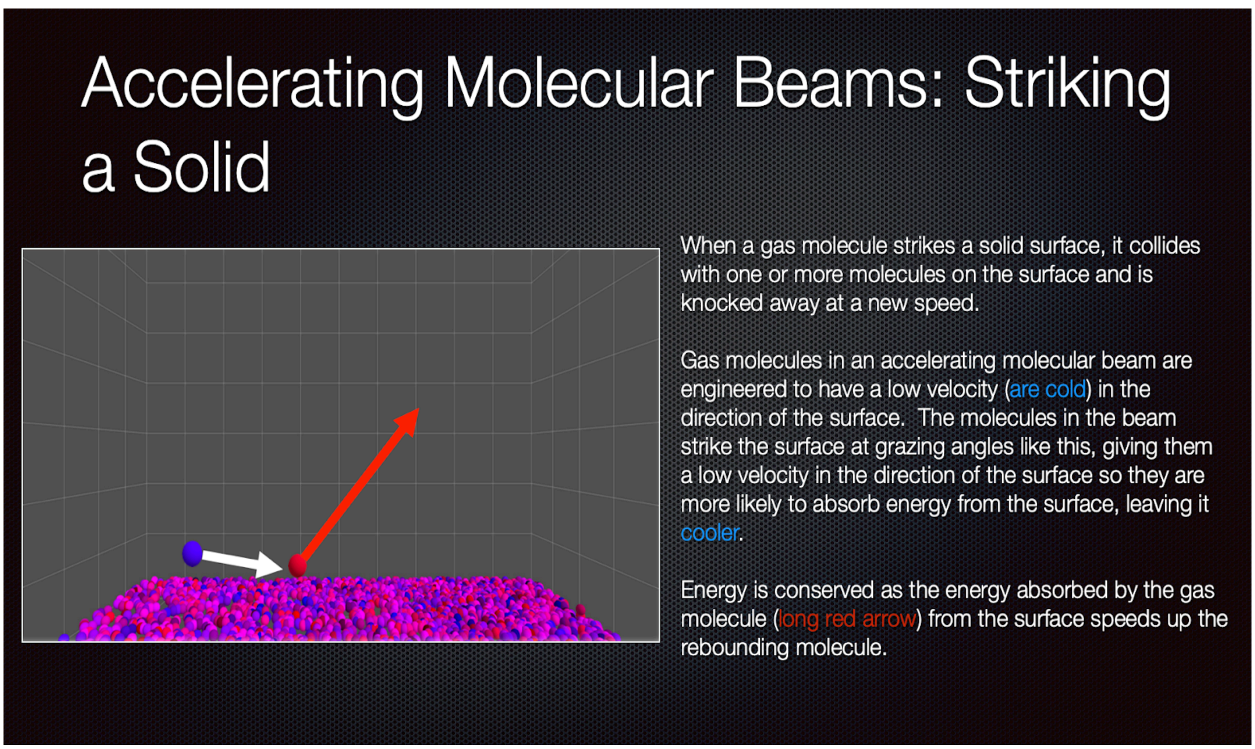


Illustration of a cold molecule colliding with a heated surface and absorbing thermal energy from the substrate on impact.

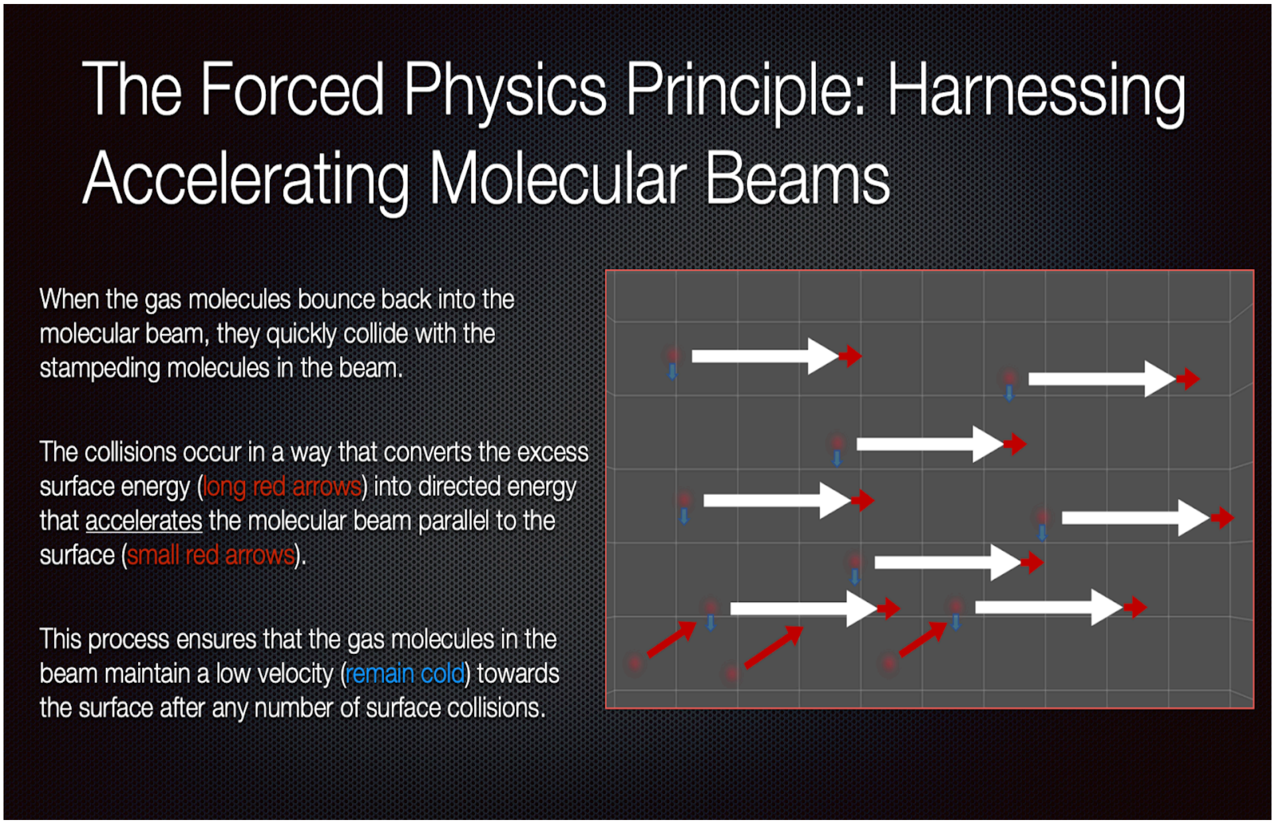


Illustration of how the energy gained from each molecule accelerates the molecular beam

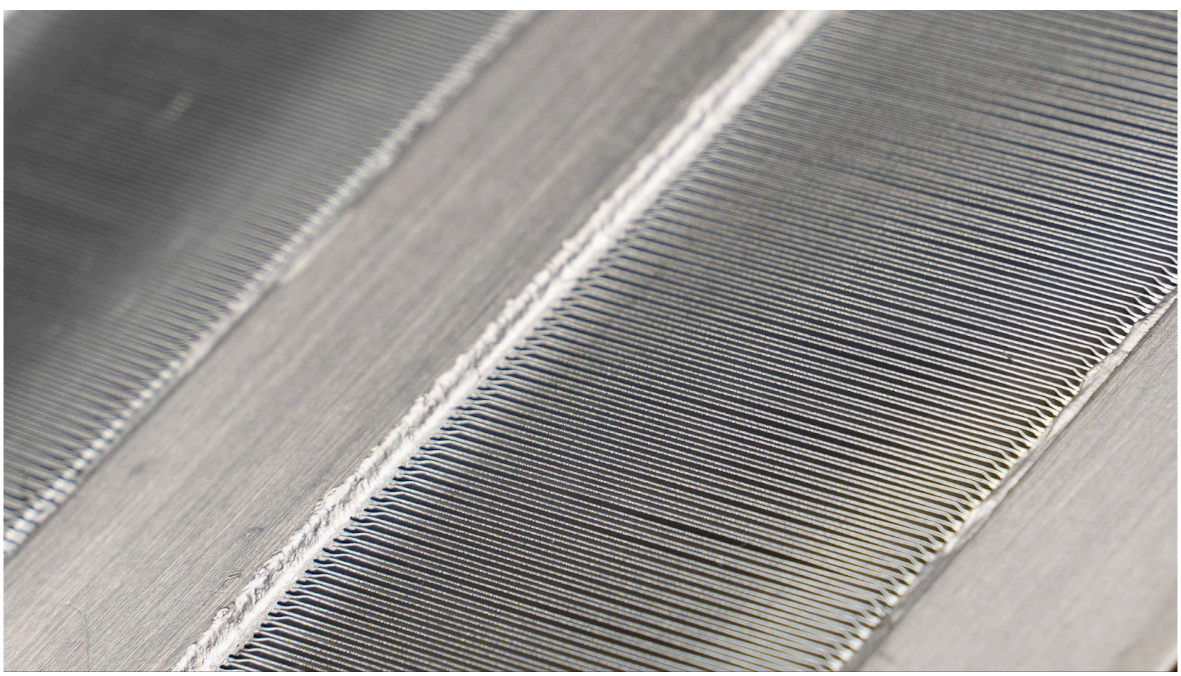


Image of the microchannels (the gaps within the aluminum substrate)

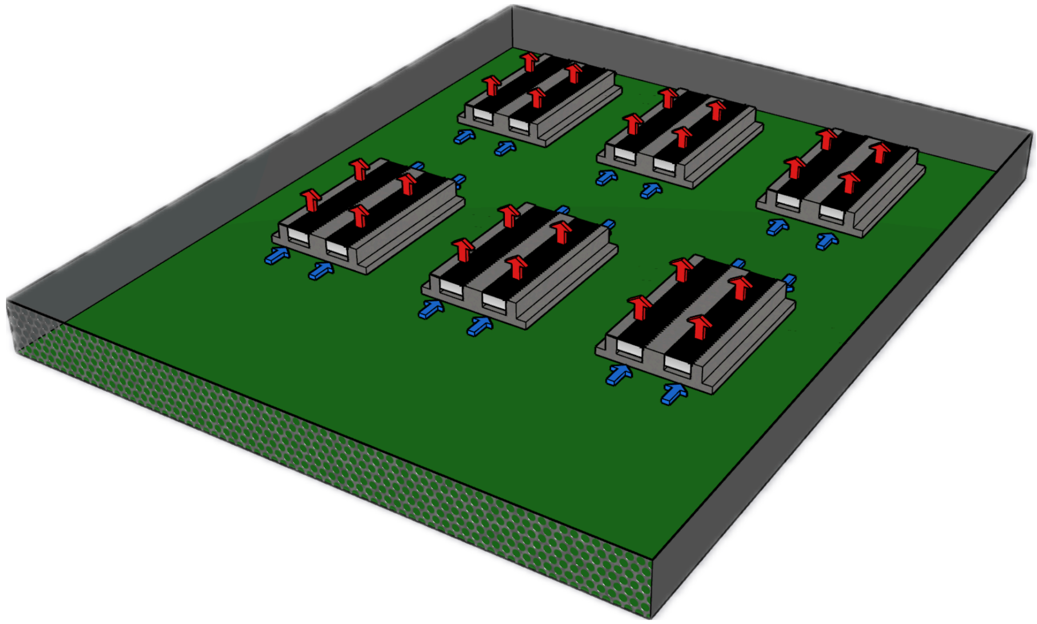
III. JouleForce™ MC4EC Airside Economization Cooling

Introduction
Forced Physics provides an entry level suite of open-source reference designs, based on the MC4EC product. Forced Physics desires that the Open Compute Project and other communities expand this suite to develop a sustainable framework for heat transfer that can be utilized by the entire market.

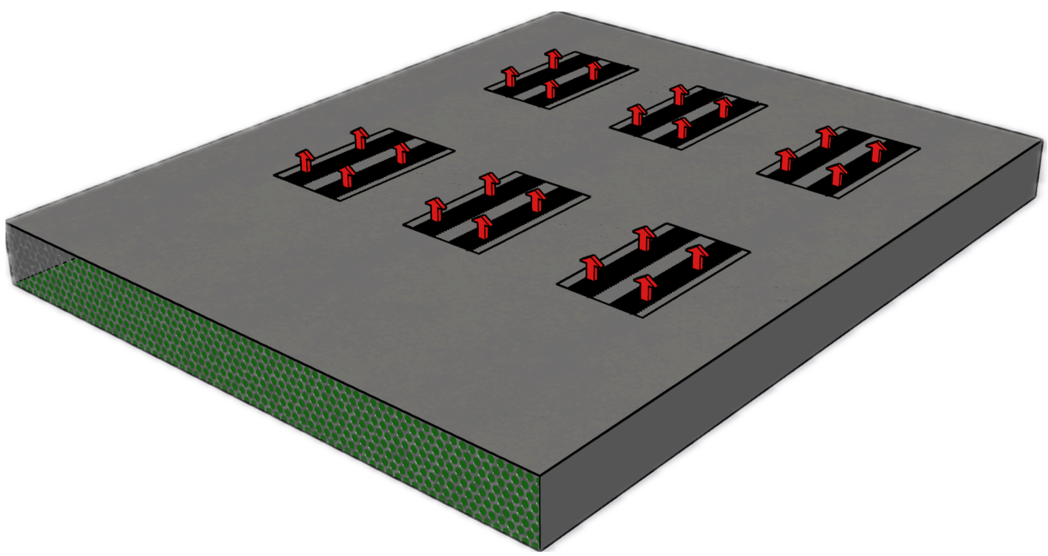
What makes MC4EC a Sustainable Heat Transfer Solution?
MC4EC based systems work without water, refrigerants, or compressed gasses associated with traditional methods. MC4EC based systems only require unconditioned air in any climate, as a cooling fluid.

Even the most power dense electronics can be effectively, efficiently, and economically cooled using MC4EC heat exchangers. The entire mechanical and electrical design space benefits by fewer moving parts and more IT energy utilization than can be accomplished with direct-to-chip liquid cooling in AI learning and AI inference facilities. For example, there is no requirement for air conditioning from compression or evaporative chilled water based systems. MC4EC based AI facilities will measure “all-in” MPUEs of < 1.02 even in hot climates.

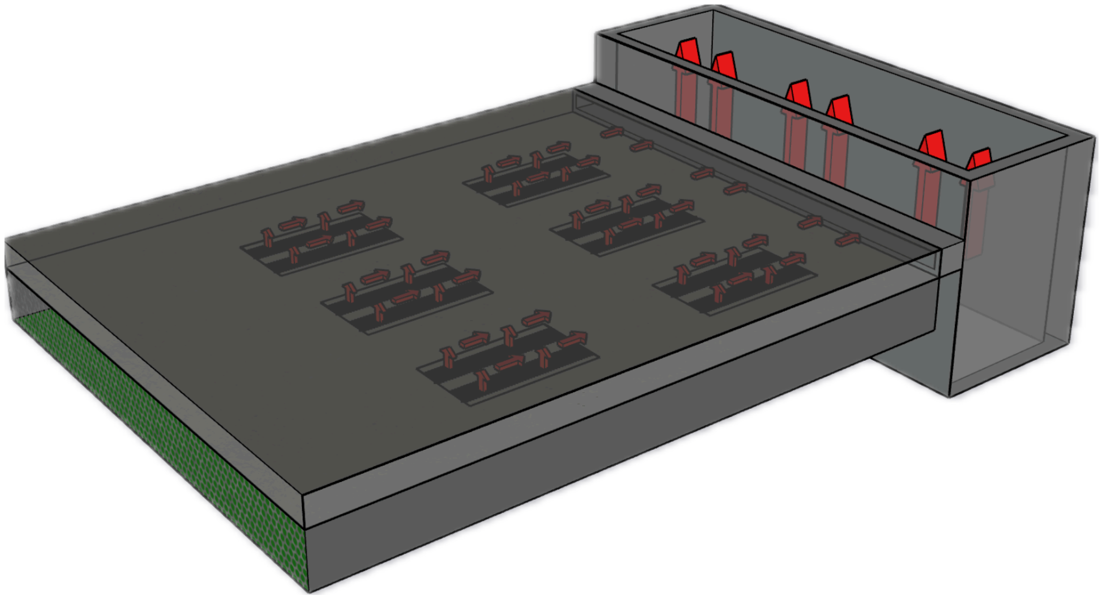
Forced Physics DCT designed SP5 socket JouleForce™ Array (JFA) with the microchannels within the aluminum substrate in a custom designed vapor chamber



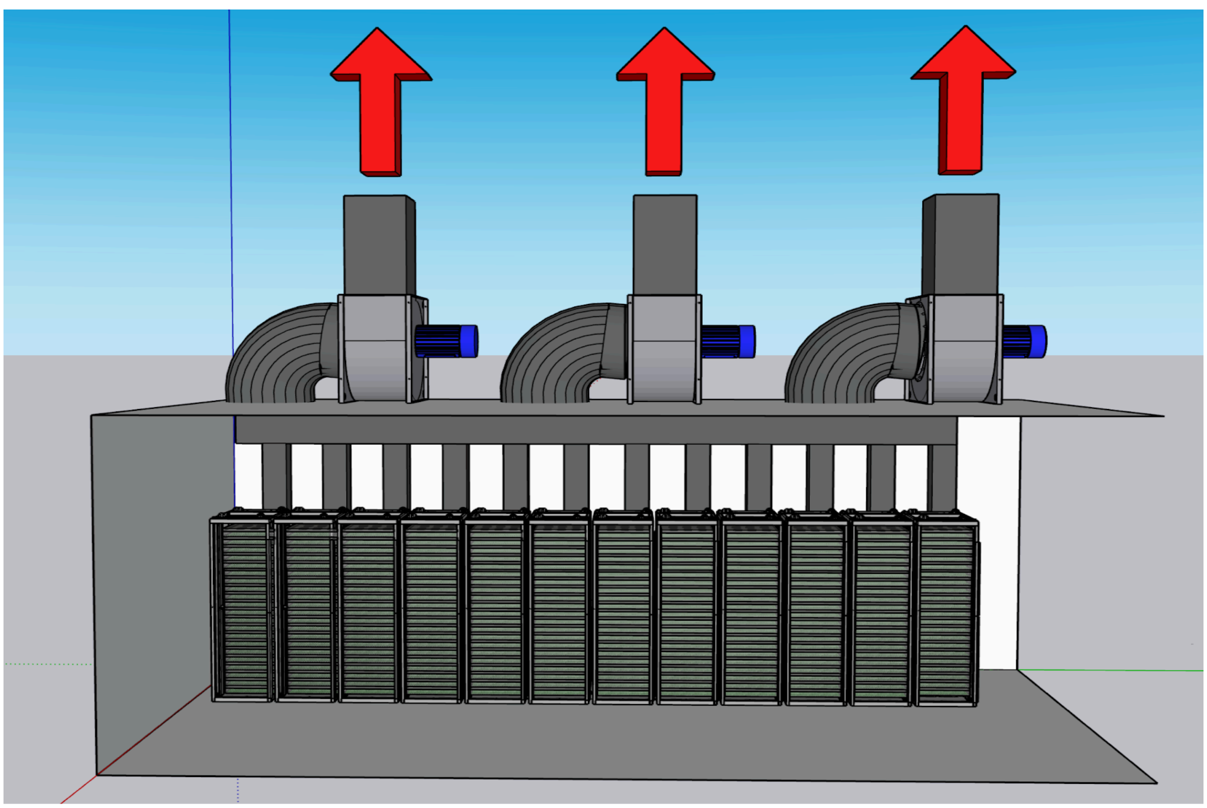
Example Illustration of 6 SP5 JFAs on an example server board. Arrows indicate airflow, blue arrow show ambient air, red arrow indicate air heated via energy transfer within the microchannels.



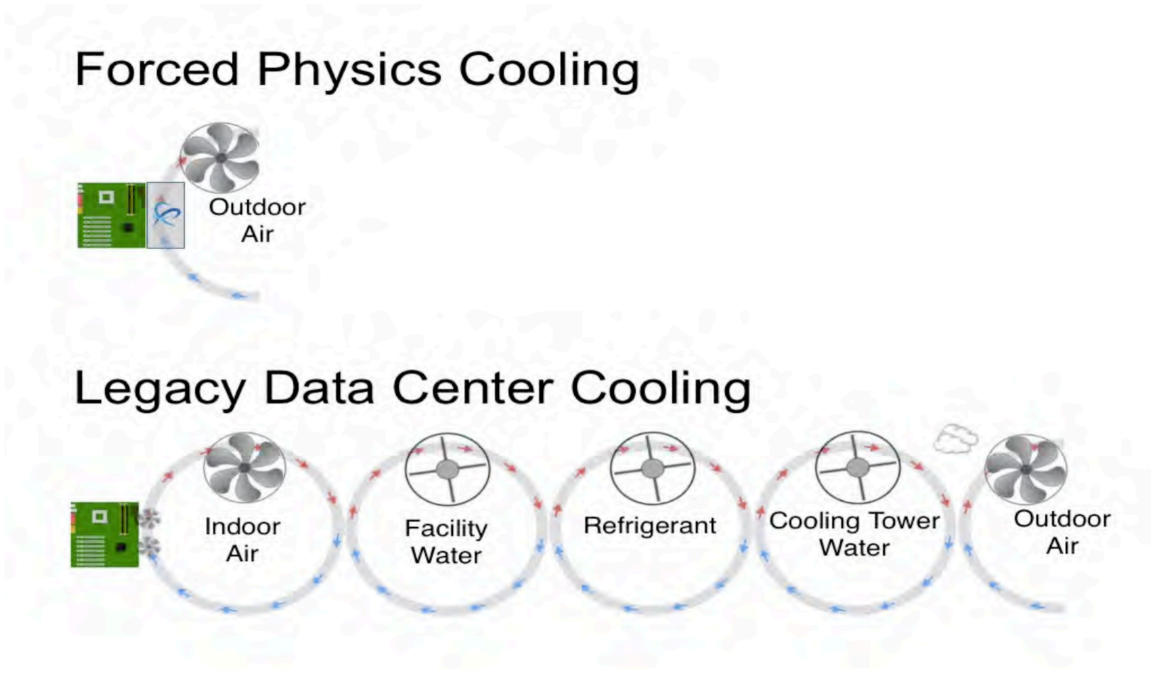
Example Illustration of an adapter plate mounted on six SP5 JFAs to seal the exhaust of the cooling devices.



Example Illustration of an air plenum on top of the adapter plate, mating from rear of enclosure to a central rack duct where heated air is pulled by a blower. Duct location (rear or side) can be configured to match the client's rack architecture. Ducts are shown semi-transparent to reveal the airflow path.



Example reference design of racks with servers, ducting and blowers within a data center, the blowers are on the roof and the heated air is released into the atmosphere and immediately equilibrated upon contact with outside air, the heat from the racks is removed completely.



The above illustration highlights the simplicity of heat removal using JouleForce™ technology.

The intent of these open-source reference designs is to provide the market with energy efficient, cost effective, and sustainable solutions that span the full design space, from server socket to facility. Forced Physics' core deliverable is the MC4EC microchannel technology, provided in configurations that are sized to the client's application requirements. In addition, Forced Physics can connect clients to a global ecosystem of suppliers and partners that support implementation, including heat exchanger reference designs and, if desired, end to end data center architecture support.

Server Socket MC4EC Heat Exchanger Reference Designs

A successful server socket design is conformal to the dimensional parameters provided by the server OEM. Vapor chambers and other heat spreaders need to be designed to:

1. Accommodate the MC4EC stacks required for active heat transfer from the GPU / CPU/ voltage regulator / etc.
2. Fit within the bounds of socket's x and y dimensions.
3. Accommodate inlet and outlet air ducting
4. Accommodate TDP of GPUs / CPUs currently in use / perhaps on the socket's road map
5. Fit within the bounds of the server's height (z) dimensions

Need More Physics?

A white paper, an AI generated simulation, and a slide deck that describes the physics behind MC4EC are available upon request.

About JouleForce™ Arrays
Each MC4EC is small (12.5 mm x 27 mm x 0.3mm) and will remove up to 2 watts of heat energy. Electronic components are cooled with tightly stacked MC4EC arrays soldered onto CPU/GPU socket compatible vapor chambers or other heat spreader material. The number of MC4ECs in an array(s) is matched to the heat output of the electronic components.

A fan or blower is used to induce unconditioned airflow into the array of MC4ECs that in turn remove heat generated by the electronic component. Heat energy is convected in a plume of hot exhaust out of the data center.

Guideline to Laboratory Tests of JouleForce™ AMD SP5 Socket Heat Exchanger
Both tests proposed in this section are routinely performed by heat transfer engineers on heat exchangers to characterize their performance. Conventional thermal engineering mathematics is used to ensure confidence in the validity of test results. The test results will serve to validate the performance claims regarding the JouleForce™ heat exchangers and its theory of operation.

These tests are suitable for professional thermal engineers and academics that desire to attain an understanding of and confidence in the performance of JouleForce™ heat exchanger technology.

Test Equipment and Set-Up
Note: the equipment set-up is the same for the static (no airflow) and active (using airflow) tests. The airflow system is **powered off** during the static test.

Device under test

- JouleForce™ SP5 heat exchanger
- Thermal interface material
- Intel design thermal test bed (SP5 socket dimensions used for this test)

Vacuum connection hardware

- Adapter to connect JouleForce™ SP5 heat exchanger to vacuum hose
- 2 inch steel wire reinforced vacuum hose with KF 50 fittings (connects JouleForce™ adapter to blower)

Air supply

- Blower, AIRTECH vacuum, model BN20160524

Power and heat load

- DC power supply capable of 1000 W output
- Ten resistive heaters, HotWatt PN H120 125 48 01, wired to the power supply

Instrumentation and data acquisition

- Four high precision temperature sensors with data acquisition and applicable connectors (Perfect Prime Datalogger Thermometer used)
- Flowmeter, Sierra QuadraTherm
- Differential pressure gauge, Fluke 922
- Ambient temperature sensor (either integrated with the pressure gauge or measured using one of the temperature sensors)

Performance Analytics

Proper analysis of JouleForce™ MC4ECs begins with the characterization of a single MC4EC (Microchannel for Electronics Cooling) microchannel under its operating conditions. Analysis of the MC4ECs performance is conducted stepwise:

1. Determine the number of MC4ECs in the array
2. Determine the heat load on each microchannel = W/MC4EC
3. Determine the airflow rate per watt of heat load = SCFM/W
4. Measure the array scale airflow based on SCFM/W = SCFM/microchannel array
5. Determine the airflow rate per microchannel = SCFM/MC4EC
6. Measure the ΔP needed to achieve SCFM/microchannel array = Inches of H2O
7. Convert SCFM to Sm^3/s
8. Convert Sm^3/s to kg/s
9. Convert Inches of H2O pressure differential to Pascals
10. Determine the “Ideal Fan Power” P_{fan} (W) required for the array = (m^3/s x Pa)
11. Determine the fan power overhead % (fan motor inefficiency, duct and plenum losses)
12. Determine the “All-In” P_{fan} for array scale airflow = (m^3/s x Pa) + overhead (W)
13. Calculate “All-In” MPUE
14. Calculate $T_{Inlet\ Required}$

Test Overview

A DC power supply provides output power to a series of resistive heaters embedded in an Intel designed thermal test bed. Two high precision temperature sensors that are embedded in shallow grooves on the top side of the Intel design thermal test bed serve as proxy junction temperature sensors on a CPU/GPU. The temperature sensor situated in close proximity to the inlet side (underside airflow ducts) measures the ambient air temperature.

The blower, differential pressure gauge, flow meter, and the exhaust temperature sensor do not serve a purpose during the static test.

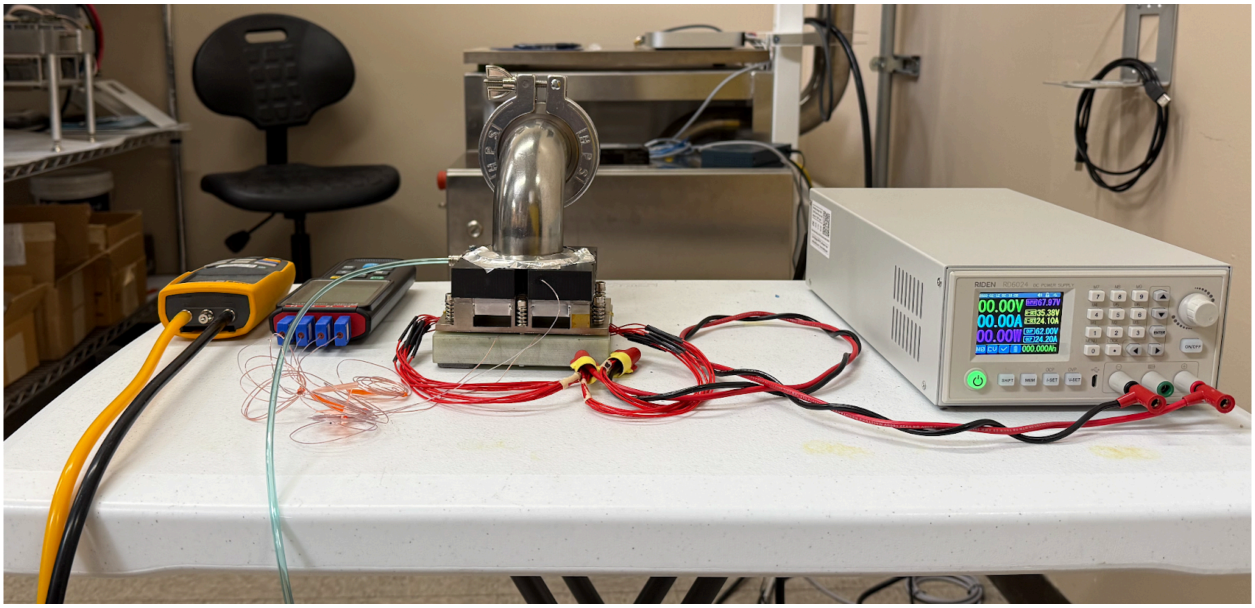


Image of the SP5 JouleForce Array (copper and aluminum device in foreground - center) mounted on an Intel designed test bed (underneath the JouleForce Array) with embedded resistive heaters (connected to red wires) and precision temperature sensors, with the DC power supply on the right and the pressure gauge plus temperature readouts on the left.

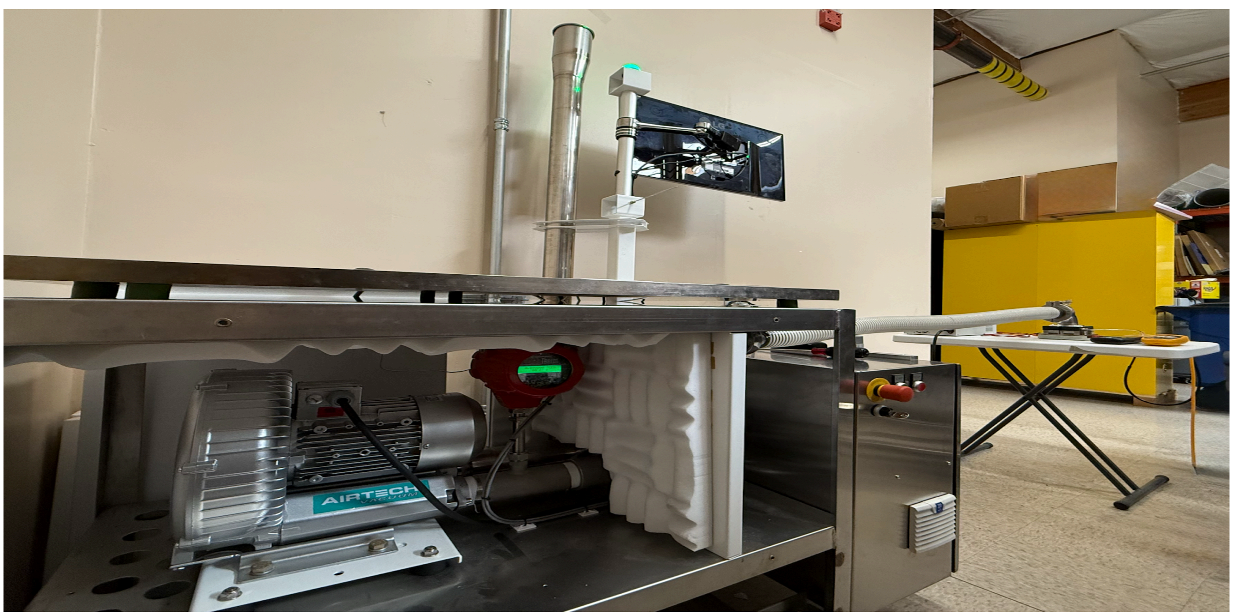


Image of the airflow portion of the test setup, showing the hose connecting the JouleForce Array (on the small table) to the Airtech vacuum blower, the Sierra QuadraTherm flow meter, and the exhaust pipe.

Equipment Staging

- The top of the aluminum test bed is affixed with the supplied fixture so that it is in good thermal contact with the bottom surface of the JouleForce™ heat exchanger.
- The AIRTECH vacuum, model BN20160524 blower is affixed with the supplied fixture to the top (exhaust side) of the JouleForce™ heat exchanger.

- The ⅛” tubing is connected to the differential pressure gauge
- The airflow meter is affixed with the supplied fixture and sealed to the exhaust side (top) of the JouleForce™ heat exchanger.
- A high precision temperature sensor is placed approximately ¼” above the exhaust side of the JouleForce™ heat exchanger MC4EC microchannels
- The JouleForce™ heat exchanger / Intel designed thermal test bed assembly is placed in a temperature-controlled environment with an adequate supply of “Target Ambient Temperature” air.
- An air duct creates a sealed airflow path between the blower inlet (low-side) to the exhaust side of the JouleForce™ array of microchannels.
- The differential pressure gauge is configured with an airtight fluid interface to sense the duct pressure and its second fluid channel detects the ambient pressure.
- The blower is configured to induce an airflow from the inlet side of the JouleForce™ heat exchanger microchannels at a temperature that is consistent with the environment that the equipment would be operating in. As the air passes through the microchannels, heat is removed from the solid microchannel surfaces that are in thermal contact with the heat source.
- Two high precision temperature sensors that are placed approximately ¼” above the exhaust side of the JouleForce™ heat exchanger microchannels sense the exhaust air temperature.
- A data acquisition system (Perfect Prime Datalogger Thermometer) is connected to the temperature sensors, flow meter, differential pressure gauge, and a power supply.
- The “static” thermal resistance (°C/W) of the JouleForce™ heat exchanger system is determined before the “active” convective heat transfer rate (Q) test is performed.
- The static test provides the inputs necessary for the calculation of the junction to ambient thermal resistance, R_{JA}, of the JouleForce™ heat exchanger system at its target Junction temperature at a particular ambient temperature. The idea is to determine the amount of power needed to raise the embedded temperature sensors from ambient temperature to the target junction temperature.
- The static thermal resistance is calculated and deducted from the total heat transferred by the active test of the JouleForce™ heat exchanger system. That is, a portion of the power supply set- point (W) needs to be allocated to the heat that is transferred by radiation and natural convection (Q”).
- The balance of the heat energy (W) transferred to the ambient air can then be attributed to the convective heat transfer rate (Q) of the system during active (blower on) operation.

Static System Test

The static (fan-off) test provides the inputs necessary to calculate the junction to ambient thermal resistance (R_{JA}) of the JouleForce™ heat exchanger system at its target junction temperature and user-selected ambient temperature. The purpose is to quantify the input power needed to raise the junction temperature from the ambient temperature to the target junction temperature.

The power associated with the static thermal resistance ($R_{\theta Q"JA}$) (i.e. attributable to radiation and natural convection (Q”)), is calculated and deducted from the total heat transferred during the (fan-on) “Active System Test”. The remainder is the net active convection heat transferred (Q) by the JouleForce™ heat exchanger system.

Static Test Procedure

1. The static test is performed on the JouleForce™ heat exchanger test system with the airflow system and all sensors attached, without powering on its airflow system. The active test is performed in a temperature-controlled environment with an adequate supply of Target Temperature air.
2. The voltage and amperage of the power supply are set to provide power to the resistive heaters embedded in the Intel designed thermal test bed. Power is increased until the Intel designed thermal test bed Junction temperature achieves steady state at $T_{Junction}$, the target temperature of the electronics (e.g. GPUs, CPUs) 85°C.
3. Using the ambient temperature, $T_{Ambient}$ (°C), set-power, P_{Set} (W), and $T_{Junction}$ (°C) as inputs to Junction to ambient thermal resistance equation:

$$R_{JA} = (T_{Junction} - T_{Ambient}) / P_{Set}$$

Active JouleForce™ Heat Exchanger Test

The second test will be performed with the airflow system powered on. The power supply will be set to provide desired power to the embedded heaters in increments of 50W starting at 100W. The airflow system will be adjusted to provide the airflow quantity to maintain the embedded heaters at a steady-state $T_{Junction}$ = 85°C.

Active Test Procedure

1. The blower is energized to induce a $T_{Ambient}$ = Target Temperature°C airflow from the inlet side of the JouleForce™ heat exchanger microchannels.
2. Initially, the blower speed/frequency is set to its maximum pressure differential / flow rate. This ensures that the JouleForce™ heat exchanger test system overcools the Intel design thermal test bed.
3. The resistive heater power supply is enabled to desired power (P_{Set}).
4. The blower speed / frequency is adjusted downward until steady-state $T_{Junction}$ = 85°C.
5. Sensor data is collected once the average of the two embedded temperature sensors provide an average $T_{Junction}$ = 85°C. The sensor data collected includes: exhaust temperature (°C), pressure differential (Pa), volumetric airflow (SCFM), Junction temperatures (°C), Ambient air temperature (°C), and Ambient air pressure (Pa).

The data acquisition system (Perfect Prime Datalogger Thermometer) connected to the temperature sensors, flow meter, differential pressure gauge, and a power supply provide the necessary data to calculate static (Q”) and active (Q) convective heat transfer.

In addition to (Q”) and (Q), the collected data facilitates the calculation of:

- Mechanical Power Usage Effectiveness (MPUE)
  = (P_{Set} (W) + Standard Cubic Meters /s x Pa (W)) / P_{Set} (W)
- Air Usage Effectiveness
  = $T_{Junction}$ / T_{out}
- Required Inlet Air Temperature ($T_{Inlet\ Required}$) (°C)
  = $T_{Exhaust}$ - (Q / (kg/s x Cp)

About MC4EC Empirical Evidence and Testing

This document provides empirical evidence of the theory of operation gathered from a series of tests on a productized MC4EC heat exchanger designed to extract waste heat from an AMD SP5 CPU socket.

The tests were performed in the Forced Physics facility in Scottsdale, Arizona. A DC power supply connected to an Intel designed thermal test bed with four (4) embedded resistive heaters and two temperature sensors was used as a proxy for an AMD SP5 socket. The test bed allowed for 50 watt incremental testing up to AMD’s thermal limit for the SP5 socket (500W).

The MC4EC tests were performed over a range of input power and junction temperatures that were held at a steady state prior to data collection to ensure data accuracy.

Additionally, air mass flow (kg/s), ambient air pressure (Pa), differential pressure (Pa), MC4EC exhaust temperature (°C) and ambient temperature (°C) data were collected simultaneously.

The collected data was analyzed to provide information regarding:

- Junction Temperature (°C)
- Heat transfer rate (J/s,W)
- Applied energy efficiency (P_{Set} + Fan_{Power} / P_{Set}), MPUE) for data centers
- Heat exchanger effectiveness ($T_{Exhaust}$ / $T_{Junction}$)
- Required inlet temperature (°C)

The heat transfer equation $\dot{Q} = \dot{m} \times Cp \times (Tout - Tin)$ was used to calculate the required inlet temperature as empirical evidence that supports the theory of operation.

Empirical Evidence of the Theory of Operation

The following summarizes collected data from one of the MC4EC performance tests:

Radiation and Natural Convective Heat Transfer
Junction temperature = 85.8°C
Ambient temperature = 23.3°C
Q" = Power required for JouleForce™ AMD SP5 compliant heat exchanger to achieve junction temperature = 18.432W

Active Convective Heat Transfer
Junction temperature = 85.8°C
Ambient temperature = 23.3°C
Airflow = 10.84 SCFM, 0.00614 kg/s
Exhaust temperature, T_{out} = 77.4°C
Cp air = 1005 J/kg · K
Q = Power required for JouleForce™ AMD SP5 compliant heat exchanger to achieve junction temperature = 400W, subtracting Radiation and Natural Convective heat transfer = 381.568W

Required Inlet Air Temperature
Applying the heat transfer equation $\dot{Q} = \dot{m} \times Cp \times (T_{out} - T_{in})$

Rearranging to solve for the inlet temperature (Tin):
$T_{in} = T_{out} - \dot{Q} / (\dot{m} \times Cp)$

Substituting the given values into the equation:

$\Delta T \approx 381.568 / (0.00614 \times 1005) \approx 61.835°C$

$T_{in} \approx 77.4°C - 61.835°C$
$T_{in} \approx 15.565°C$

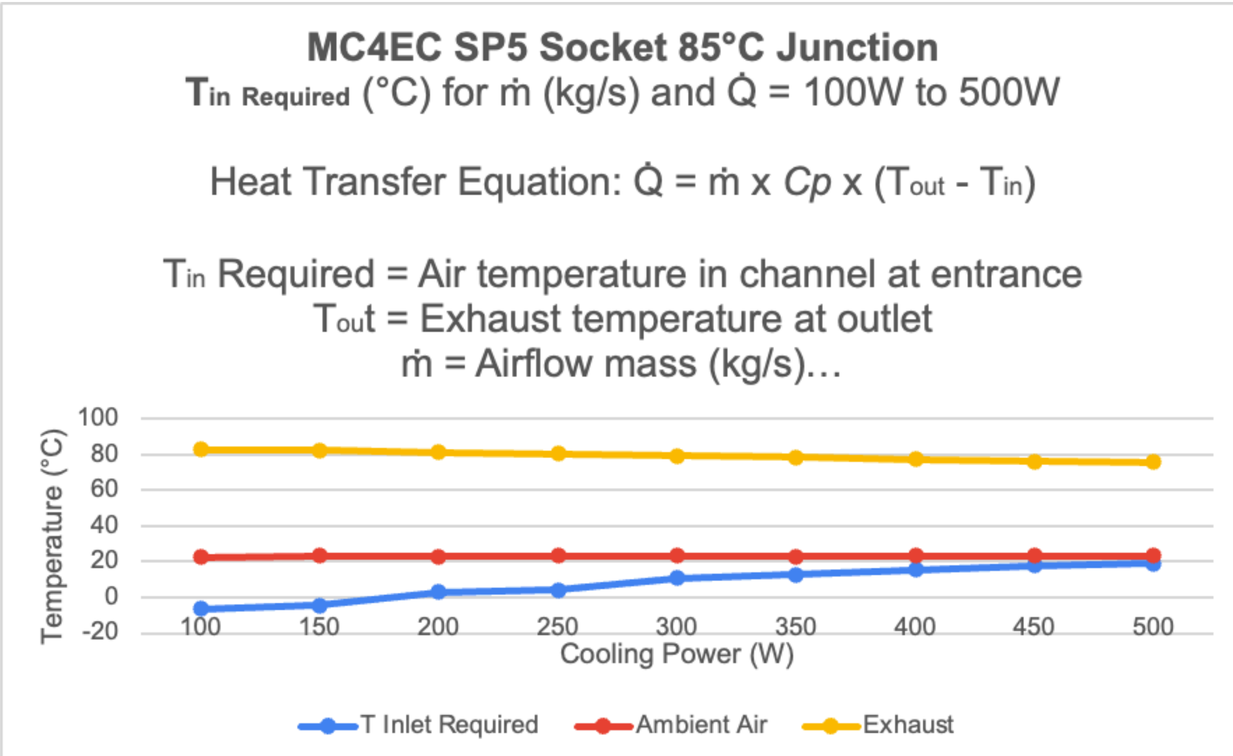
Where $\dot{Q}$ = active convective heat transfer rate (J/s, W), $\dot{m}$ = mass flow rate (kg/s), K is temperature in Kelvins, T_{out} = Exhaust temperature, $T_{in} = T_{Inlet\ Required}$ air temperature

The difference between $T_{Inlet\ Required}$ of 15.565°C and $T_{ambient}$ of 23.33°C = -7.765°C.

Given that all of the inputs to the heat transfer equation are known, except for the inlet air temperature, the calculated inlet air temperature is the only quantity that can precisely satisfy the equation. Hence, the empirical nature of the proof where, substituting in all values:

$$381.568W \approx 0.00614 \text{ kg/s} \times 1005 \text{ J/kg} \cdot \text{K} \times (77.4°C - 15.565°C)$$

Besides providing the necessary empirical evidence and mathematical proof to substantiate the theory of operation of the MC4EC, sub-ambient inlet air temperature requirements extend the ambient temperature range to hot climates, enhance their air utilization (effectiveness) and increase the energy efficiency of JouleForce™ heat exchangers.



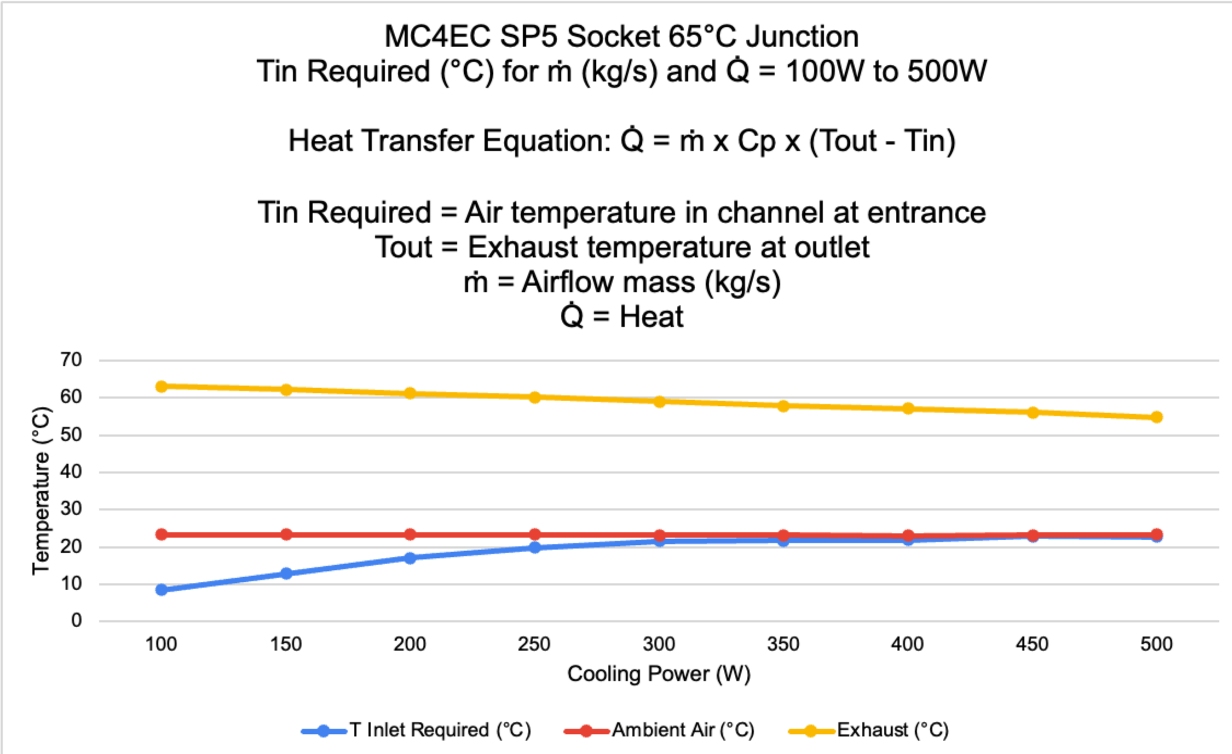
The Significance of $T_{\text{Inlet Required}}$

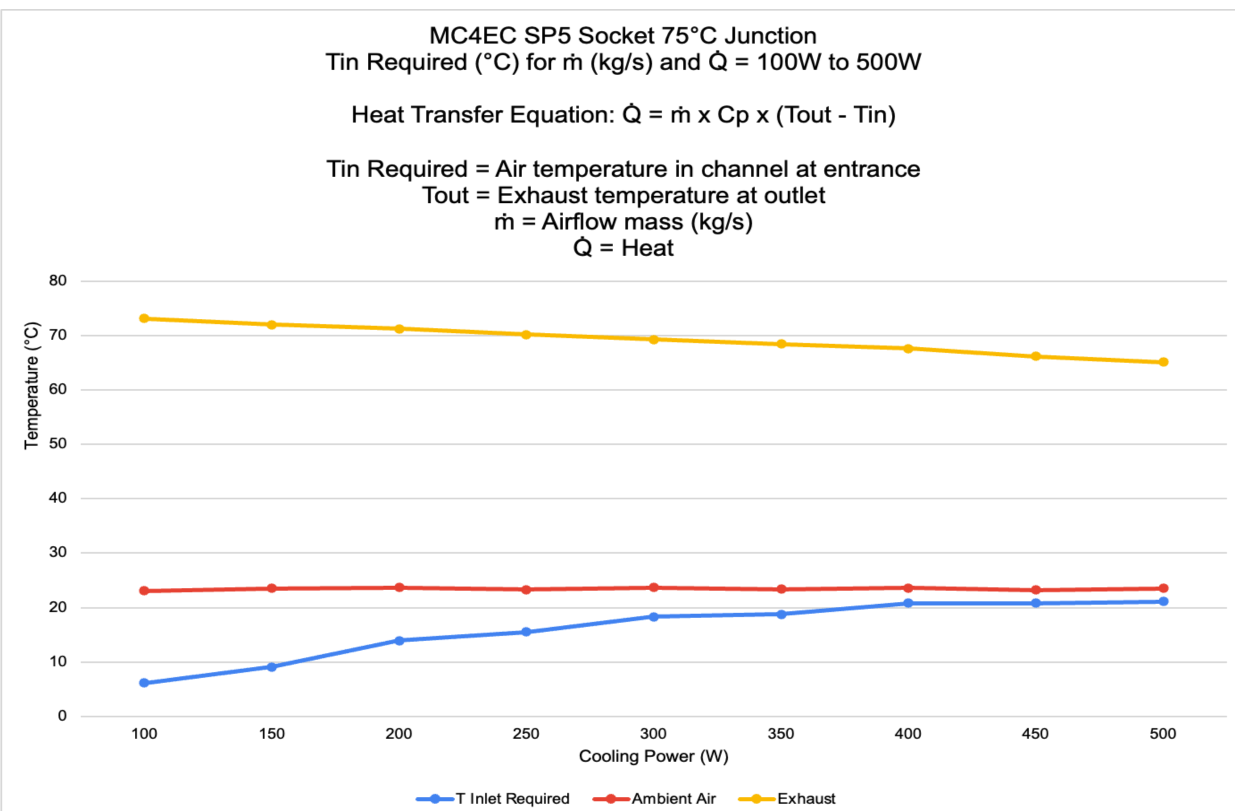
$T_{\text{Inlet Required}}$ is the calculation based on a series of measurements that indicate to engineers and OEMs the required inlet temperature to the heat exchanger in order for cooling to be successful at the set airflow and defined power level. Based on the graph above, it is apparent that all of the $T_{\text{Inlet Required}}$ calculations reflect sub ambient temperatures. The calculation of $T_{\text{Inlet Required}}$ answers the question:" How does such a small airflow cool the power densities that FP claims it to cool?"

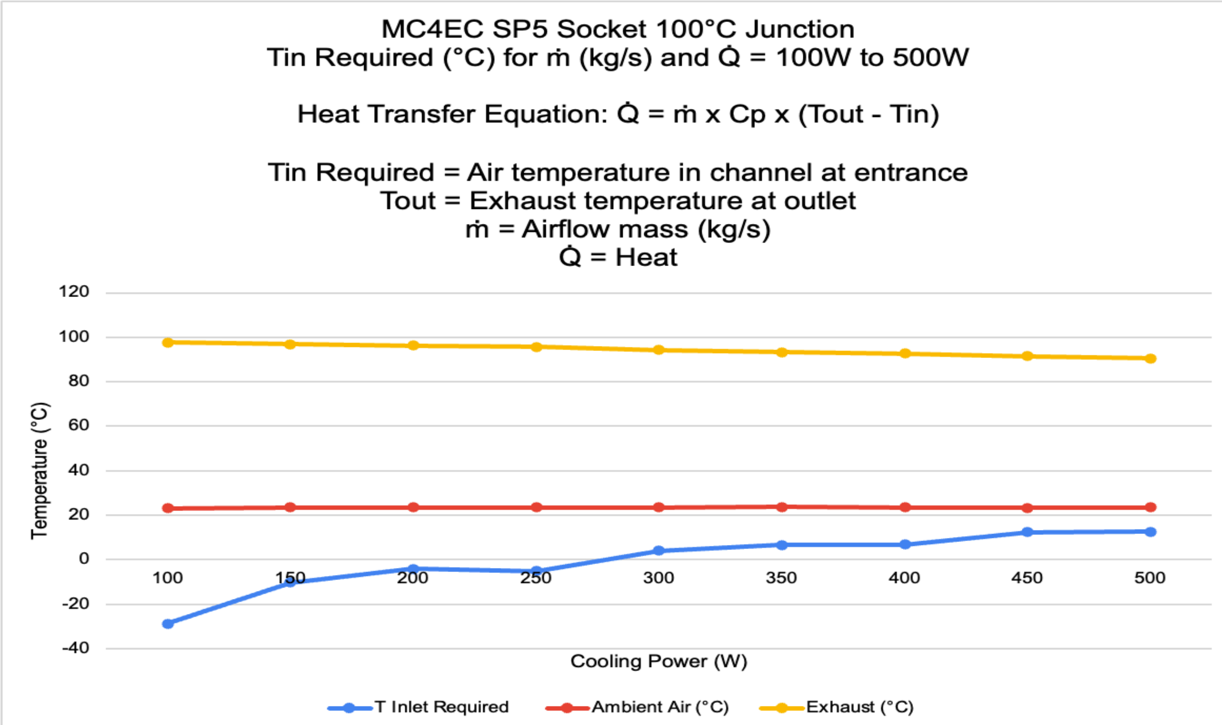
As an integral part of the "Heat Transfer Equation" **$T_{\text{Inlet Required}}$** provides empirical evidence that as ambient air enters the JouleForce™ microchannel geometry its temperature decreases below ambient. Sub ambient temperature air can have a greater temperature rise than air molecules at ambient temperature. As a result, more energy may be transferred from the surface than would be possible with ambient temperature air.

The motive force (Pa) for airflow through the microchannel geometry is provided by a fan or pump. Extracted heat energy, from the heat source, provides the power needed to "refrigerate" the air below ambient temperature as it enters the JouleForce™ microchannel geometry.

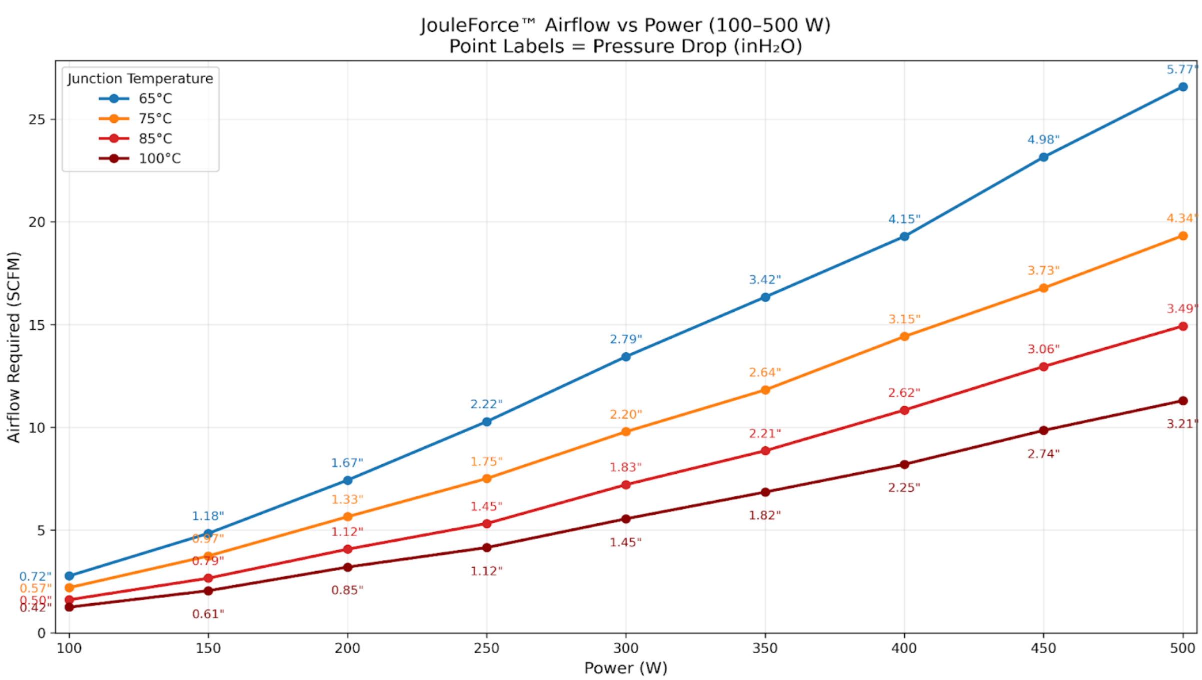
Additional $T_{Inlet\ Required}$ graphs below to show other junction temperatures.

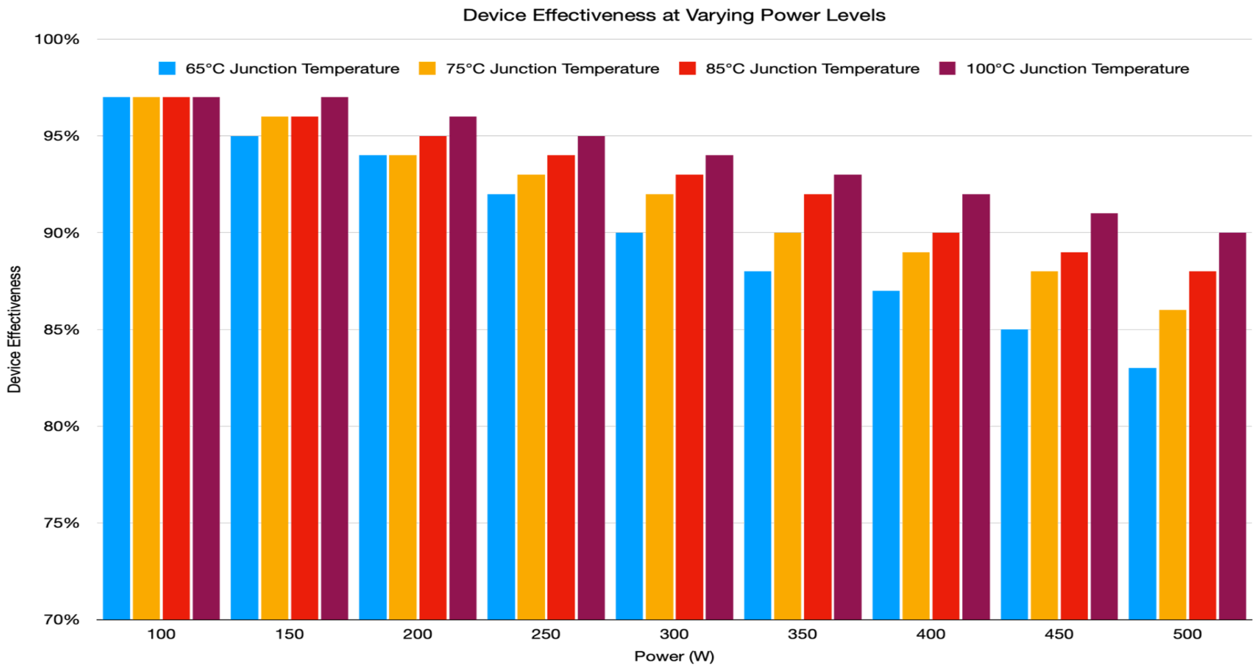




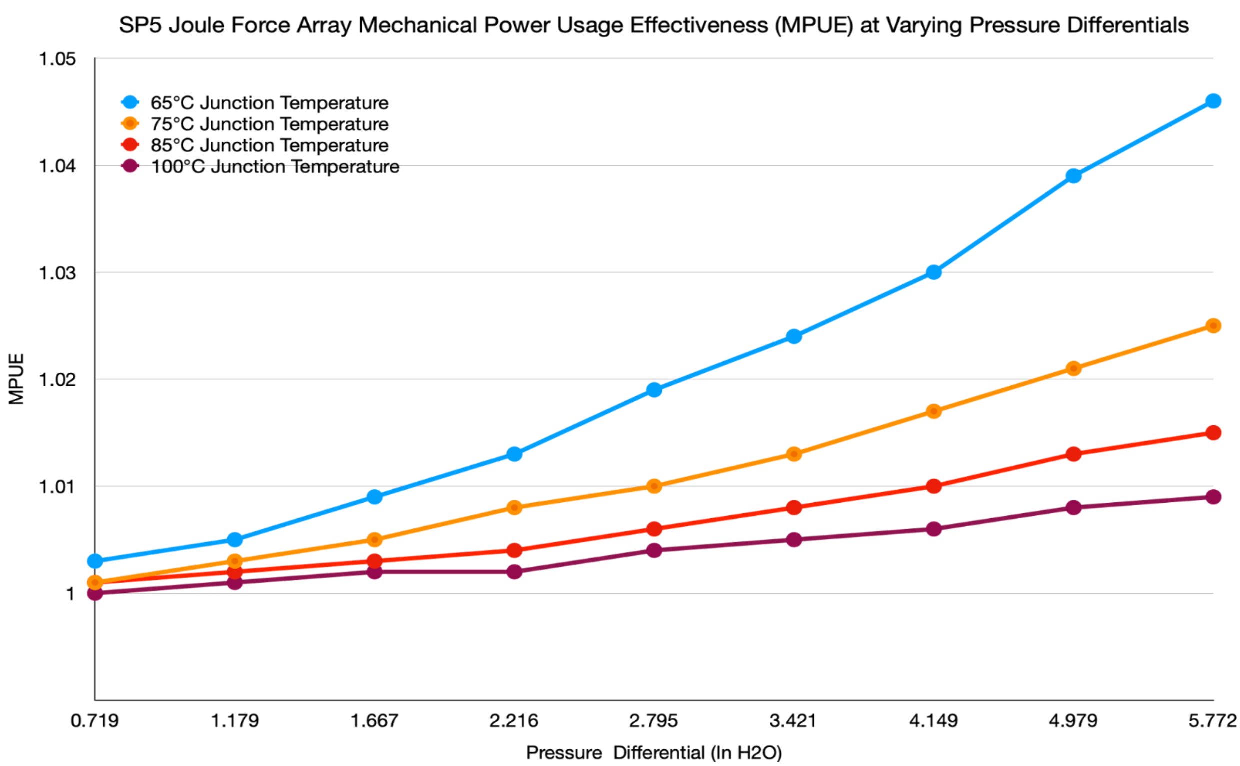


Below is a graph of the airflow required and pressure differential at the various junction temperatures demonstrated above. It is important to note that the pressure differentials shown are local to the JouleForce™ microchannels. The architectural framework creates a container of the pressure differential within the ducting and does not affect the white space or any other portion of the data center.





Due to the MC4EC's impressive effectiveness, (exhaust temperature / junction temperature) even operation at high pressure pressure differentials, with the low airflow volume results in remarkably low MPUE for the entire system. Below is a graph of the MPUE at the pressure differentials of the various temperature junctions, this MPUE was calculated with air resistance in the duct in mind by calculating with a 70% efficient fan.



Design Process

Customer requirements that influence MC4EC array design include:

- Ambient temperature at the point of use
- Target heat removal per microchannel (up to 2 W per microchannel)
- Airflow required to achieve the target heat removal at the specified ambient temperature
- Resulting pressure differential across the array

Once a target per microchannel heat removal rate is selected (for example, 1W per microchannel), the system operating point can be defined in terms of required pressure differential and airflow. For a given hardware configuration and operating condition, one would treat the required pressure differential as a fixed design point and use the resulting airflow per unit heat load (SCFM per watt) as a first order scaling parameter. Under this constant delta P assumption, total airflow scales approximately linearly with total heat load. For example, if testing or modeling shows 0.03 SCFM per watt at the selected pressure differential, then a 1 MW heat load would require approximately $0.03 \times 1{,}000{,}000 = 30{,}000$ SCFM. This provides a first order basis for ducting and blower sizing at megawatt scale. Final requirements will vary with socket and array geometry, operating conditions, and integration details

Design Flexibility

In practice, a given GPU, CPU or electronics cooling target can be met by a range of viable MC4EC JouleForce™ array configurations. Increasing the number of MC4EC microchannels distributes the total heat load across more elements, reducing watts per microchannel and, for the same heat load, lowers the required airflow and associated pressure differential.

Conclusion

JouleForce cooling represents a new frontier in cooling technology that exceeds present day electronic cooling in effectiveness, simplicity and cost. The contents of this document provide a glimpse of a new electronics cooling framework that can extend the limits of what is possible for cooling data centers. Guidelines and methods are presented on how to design and test JouleForce systems as well as empirical evidence of the power and efficacy of the technology.