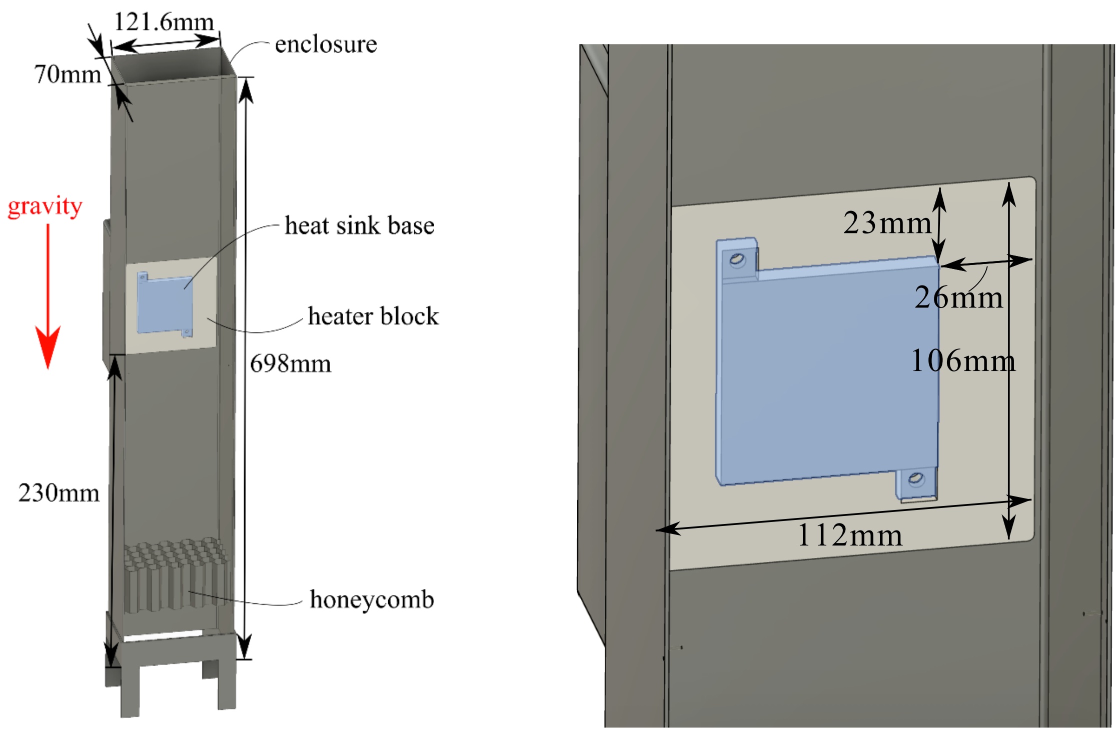
ASME K-16/IEEE EPS Heat Sink Design Competition
– Guidance Document 2023 –

This guidance document provides the details for the 2023 ASME K16 / IEEE EPS Heat Sink Design Competition. The participating student teams will design, analyse, and optimise an additively manufactured heat sink to cool a constant power module subject to natural convection in a vertical enclosure. The teams that are evaluated as having the most effective designs exploiting the design freedom allowed by additive manufacturing, will have the opportunity to have their designs printed at GE and experimentally tested at the University of Southern Denmark. The finalists will be invited to present their work at the 2023 ITherm conference.

Natural Convection Heat Sink in a Vertical Enclosure:

The design conditions are as specified by the experimental setup shown in Figure 1 for natural convection. The setup consists of a vertical rectangular enclosure with an inner area of 121.6 mm by 70mm. The enclosure is 698 mm tall, and the heater block assembly is located 230 mm from the bottom of the enclosure. Near the bottom of the enclosure, which is open, a 50 mm tall block of honeycomb (7mm hole diameter) is located 60 mm into the enclosure. The heat sink is attached in the tan highlighted heater block zone approximately 230 mm from the bottom of the chamber. The heater block and heat sink design constraints are detailed on the following pages. The placement of the heat sink baseplate within the chamber is detailed in the left panel of Figure 1. Note that the top of the enclosure is open.



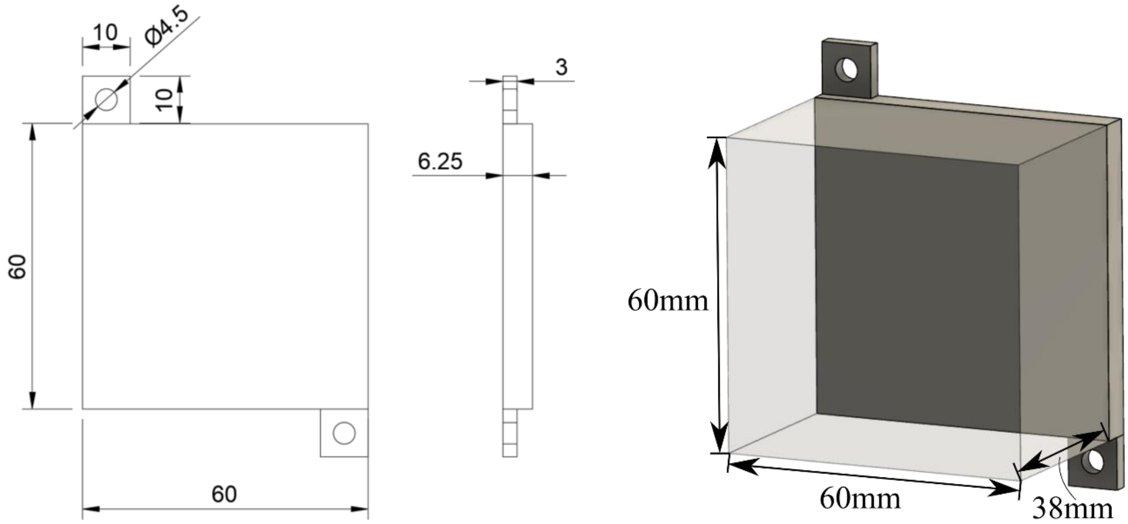
(a) (b)

Figure 1: (a) Schematic of the experimental test fixture including dimensions of the experimental setup with the fixed heat sink baseplate highlighted in light blue. **(b)** Schematic illustrating the placement of the heat sink baseplate within the test fixture.

ASME K-16/IEEE EPS Heat Sink Design Competition
– Guidance Document 2023 –

Design Constraints:

Figure 2a shows the dimensions for the fixed heat sink baseplate, which consists of a block of 60mm by 60 mm and 6.25 mm in thickness with two 3mm thick tabs of 10mm by 10mm with 4.5mm diameter holes. Each heat sink design must include this baseplate. Above the baseplate, each team can design their own heat sink. Figure 2b shows the design domain for the heat sink design competition, which is a 38 mm tall block with the same formfactor as the square portion of the baseplate, 60 mm by 60 mm.



(a) (b)

Figure 2: Dimensions of (a) the fixed baseplate and (b) the design domain for the heat sink.

Heater Block Configuration:

Figure 3 (on the following page) details the heater block assembly and heat sink mounting plate. The assembly consists of a housing, mounting bracket, and heater block. The aluminium heater block is mounted to a bracket fabricated from polyoxymethylene (POM) with a cut-out for the heat sink baseplate. The heat sink is mounted such that the top of the baseplate will sit flush with the surrounding POM surface and the inner wall of the vertical enclosure. The heat sink will be attached using the thermal interface material documented in Table 1. After the heater block assembly is mounted inside the housing, the housing is stuffed with insulating mineral wool and sealed with a backplate as illustrated in Figure 3d.

The heater block itself consists of an aluminium plate of dimensions 110 mm by 100 mm and 15mm in thickness. Four cylindrical resistance heaters (6.5 mm diameter and 55.5 mm long) are placed inside holes drilled into the aluminium block. The base of the heat sink is aligned on top of the four cylindrical heaters as shown in Figure 3b and c. The designs will be evaluated at a total power input of 18W. A K-type thermocouple is mounted in the centre of the heater block, shown by the red dot in Figure 3c.

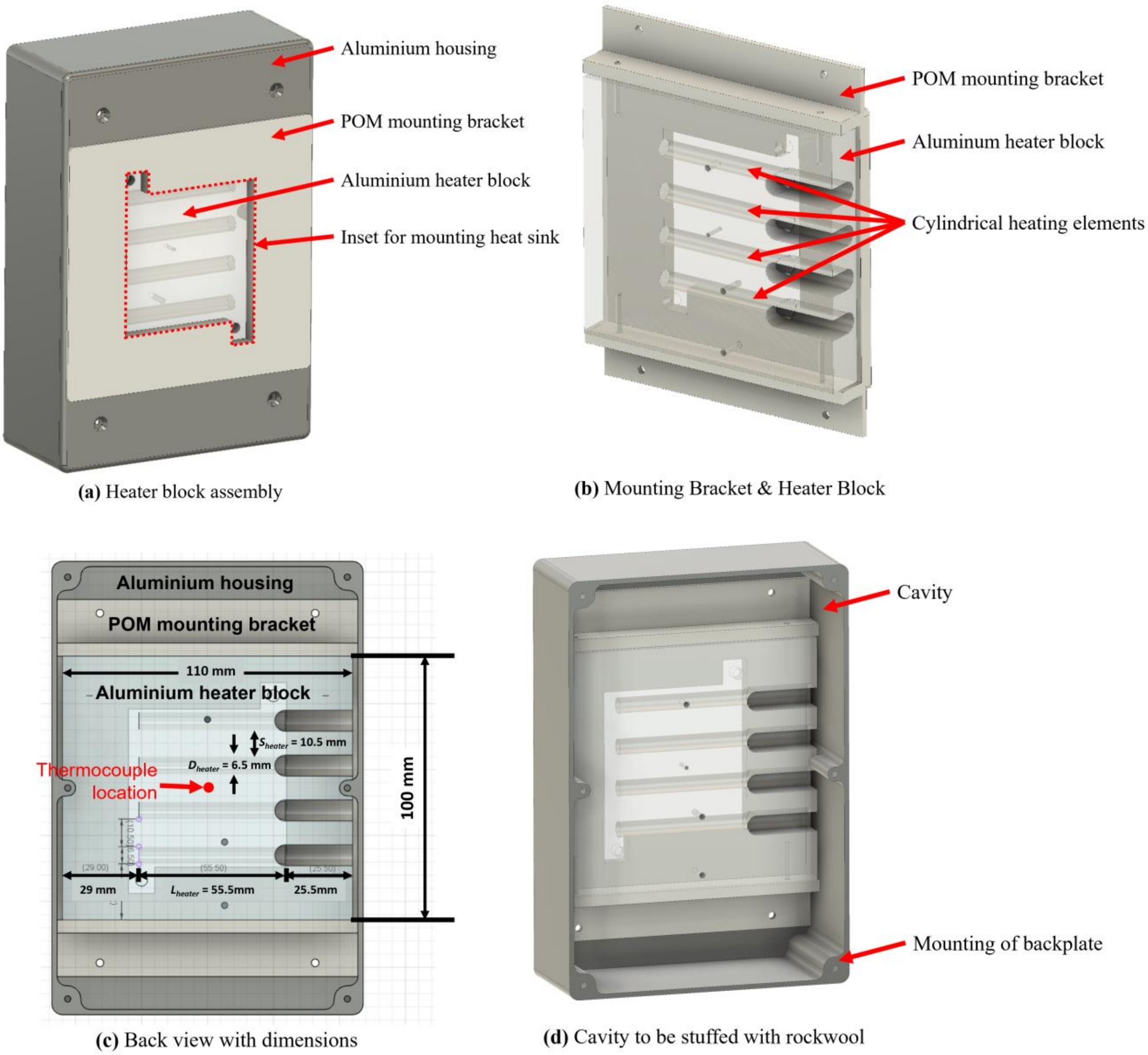


Figure 3: (a) Overview of the heater block assembly including the aluminium enclosure, POM mounting bracket, and aluminium heater block. The inset/cut-out for mounting the heat sink is outlined with a dashed red line. **(b)** Detail of the POM mounting bracket and aluminium heater block illustrating the placement of the 4 heaters. **(c)** Back view of the heater block assembly with dimensions of the cylindrical heaters (diameter D_{heater}, length L_{heater}, and spacing S_{heater}) and their placement. The temperature measurement location is at the centre of the heat sink base area is in indicated with a red dot. **(d)** Back view of the heater block assembly illustrating the cavity to be stuffed with insulating mineral wool and the mounting points for the backplate.

ASME K-16/IEEE EPS Heat Sink Design Competition
– Guidance Document 2023 –

Experimental setup details:

Assume a quiescent ambient environment with air at $T_{amb} = 20^{O}$C. Details of the experimental components are listed in Table 1 and in the CAD Models.

Component	**Type**	**Operating condition**
Vertical enclosure	Armfield HT19	Natural convection
Data acquisition and control box	Armfield HT10XC	Connected to laptop via USB
Heating block	Armfield HT19 Generic aluminium	Estimated thermal conductivity of 170 W/(m·K). Single K-type thermocouple mounted in hole using glue.
Heaters (x4)	Cylindrical resistance heaters, 24 V up to 50 W (each)	Total power set to 18 W
Thermal interface material	RS Pro 794-3973	Graphite, 10 W/(m·K), 0.16 mm thickness
Insulating mineral wool	Generic Rockwool	Thermal conductivity of approximately 0.035 W/(m·K)

Table 1: Details of the experimental setup.

CAD models:

CAD models of the heater block assembly, heat sink baseplate, and vertical enclosure can be found at: https://github.com/sdu-multiphysics/heatsinkdesigncompetition

Additive Manufacturing Details:

The heat sinks will be additively manufactured in aluminium A357. Heat-treated conventionally manufactured A357 has a thermal conductivity of 170 W/(m·K), but it is expected that the effective thermal conductivity of the printed material will be approximately 110 W/(m·K). It can be assumed that the surface roughness is 35 microns. Other manufacturing constraints including minimum feature sizes and tolerances will be posted to the competition website and the GitHub folder.

Furthermore, semi-finalists will be invited to a teleconference with GE Additive to ensure their designs meet manufacturing constraints. It is anticipated that some modifications to designs will be needed during the period of approximately January 21st – February 4th 2023.

ASME K-16/IEEE EPS Heat Sink Design Competition
– Guidance Document 2023 –

Design Objectives and Scoring:

Key Competition Dates:

- White Paper & Design Model: Due Jan 6, 2023
- Semifinalist Design Revisions: Approx. Jan 21 – Feb 4, 2023
- Printing & Testing: Approx. Feb 5 – April 30, 2023
- Finalist Announcements: Approx. April 30, 2023
- Finalist Presentations at ITherm 2023: May 30 – June 2, 2023

Pre-register your team at https://forms.gle/gpv56mHtKTLgZRA27 for updated information throughout the design period.

The competition consists of 3 phases:

1) **Design & White Paper:** During the first phase of the competition, student teams design and analyse their heat sinks, summarizing the process and results in a white paper. The white papers are evaluated by a panel of experts and the designs are further evaluated by standardised simulations run by the competition organisers after submission. A template for the white paper is available at https://github.com/sdu-multiphysics/heatsinkdesigncompetition.
2) **Revisions, Fabrication, & Experimental Evaluation:** The top designs from the white paper phase will be fabricated by GE and tested at SDU. It is anticipated that teams may need to make some modifications to designs during the period of Jan 21 – Feb 4, 2023 to meet manufacturing constraints. The top experimentally performing designs among these semi-finalists will be invited to present as finalists at *ITherm 2023*.
3) **Final Presentation:** After the designs are evaluated experimentally, the invited finalist teams will need to prepare a presentation for *ITherm 2023* describing their design and analysis process, the experimental results compared to the models, etc. Finalists will be notified approximately on April 30, 2023 and have approximately 1 month to prepare for the final competition. One member of the team will present at the conference, and a panel of experts will judge the presentations.

<u>Phase 1: Design & White Paper</u>

The objectives for **the white paper** are provided in the list below:

(a) Highest Figure of Merit (FOM) for the vertical enclosure under natural convection as evaluated by standardised simulations run by the competition organisers. See details of the FOM on the following page.
(b) Demonstrate effective use of thermal analysis and modelling
(c) Effective use of additive manufacturing in the design. See details of this metric on the page 6.
(d) Well written, formatted, and clear white paper

The assigned scoring metrics for the white paper are shown in Table 2:

Metric	**Assigned point value**
Predicted FOM*	25
Analysis and modelling	25
Effective use of AM	35
Writing style and formatting	15

Table 2: Scoring metrics for the white paper (* = as simulated by organisers).

Phase 2-3: Experimental Evaluation & Presentation Competition

The design objectives for **the final competition** are provided in the list below:

(a) Highest Experimentally determined FOM
(b) Effective use of additive manufacturing
(c) Presentation skills

Overall scoring will be assessed according to the scoring metrics in Table 3:

Metric	**Assigned point value**
Experimental FOM	40
Effective use of AM	35
Presentation Quality	15

Table 3: Scoring metrics for the final competition.

Note that designs which fail to adhere to the additive manufacturing requirements as laid out by GE may be penalised or disqualified from the competition.

Figure of Merit (FOM) and Other Metrics to Report:

Designs will be ranked based on a cost-based figure of merit (FOM). This should be calculated according to the following definition:

$$FOM = \frac{1}{\$_{hs}(T_{heater} - T_{amb})}$$

where T_{heater} is the temperature in the centre of the heater block, T_{amb} is the ambient temperature, and $\$_{hs}$ is the heat sink cost determined by:

$$\$_{hs} = \$_{powder} m_{hs}$$

with $\$_{powder} = 60$ USD/kg is the cost of the heat sink material and m_{hs} is the mass of the heat sink in kilograms (including the fixed baseplate).

Although not required in the calculation of the FoM, please also report the maximum temperature in your heat sink and the rate of heat transfer through the heat sink, and report these values in the table in the white paper template. Please note: Teams should state and justify assumptions in their models as part of the design analysis section of the white paper. If the heater block is assumed to be well insulated from the housing, then $q_{heat\ sink} = q_{input} = 18$ W. But if the heat lost by conduction through the support structure and to the environment is part of the modeling approach, please report the rate of heat transferred through the heat sink extracted from the model.

ASME K-16/IEEE EPS Heat Sink Design Competition
– Guidance Document 2023 –

Effective Use of Additive Manufacturing:

A subjective assessment will be made of the overall design aesthetics and use of the incredible design freedom provided by additive manufacturing compared to conventional manufacturing. Creativity is rewarded in this category along with the formation of structures that would otherwise not be possible to manufacture as illustrated in Figure 5.

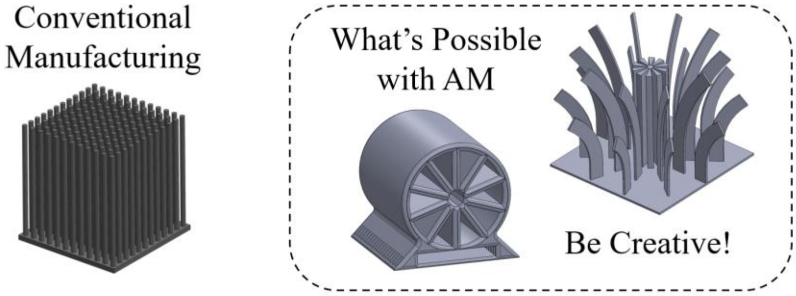
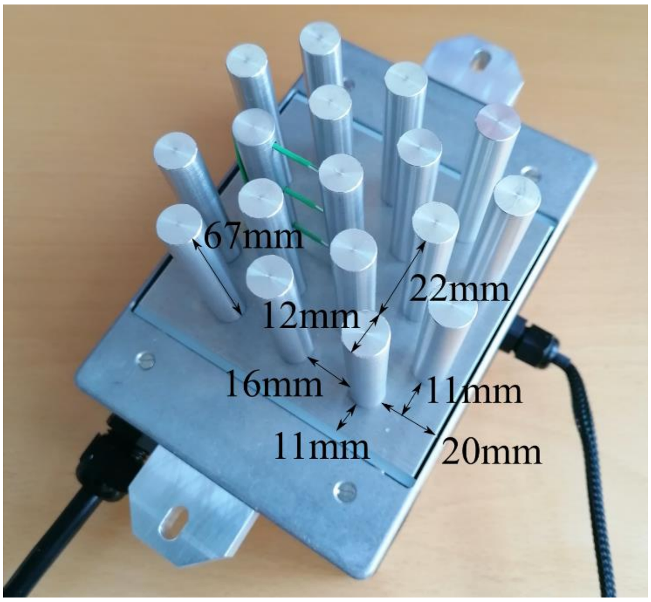


Figure 5: Illustration of conventional versus additive manufacturing design freedom.

Reference Experimental Data:

Reference experimental data will given for a flat plate and a pin fin heat sink to help teams calibrate their models. The heater block assembly is the same except that the full footprint of the heater block may be used, as shown in Figure 6.



(a) **(b)**

Figure 6: Experimental modules for (a) flat plate and (b) pin fin heat sink.

The experimental data for the reference heat sinks will be sent to participating teams as soon as possible.