



WHITEPAPER 14

Fanless Panel PC Thermal Design

Avoiding Throttling, Hotspots and Premature Component Failure

Engineering conductive heat paths for sustained industrial computing



A practical guide to heat spreaders, enclosure conduction, processor power limits, display heat, ambient derating and validation under worst-case workloads.



Created by Crystal Display Systems Limited

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Executive summary

Fanless operation removes a high-wear component but transfers the entire thermal burden to conduction, natural convection and firmware control. Small interface errors or installation changes can therefore create throttling, SSD stress or premature component ageing.

A robust design starts with measured concurrent power, includes backlight and solar heat, and qualifies the full chassis path, orientation and mounting environment over production tolerances.

Core recommendation

Design a complete conductive path and validate sustained workload at worst installation. Use firmware limits as a controlled guardrail, not as hidden compensation for insufficient enclosure capacity.

How to use this whitepaper

- Use the requirement table to convert fanless thermal performance expectations into measurable pass/fail criteria.
- Use the comparison matrix to shortlist architectures without allowing one headline specification to dominate.
- Apply the weighted scorecard using the actual operating environment, duty cycle and commercial lifecycle.
- Validate the preferred approach in the final mechanical, optical, electrical and software implementation.

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Key decision principles

- Design from sustained worst-case heat and maximum ambient, not processor nominal TDP alone.
- Create low-resistance paths from every critical source to a known sink and verify contact pressure/flatness.
- Include display and solar heat in the same enclosure model as the compute system.
- Use firmware power limits and throttling as controlled protection, not as a substitute for thermal capacity.
- Validate multiple production units in the final mounting orientation and sealed configuration.

1. Define sustained heat and installation before selecting a thermal architecture

A useful fanless requirement states concurrent workload, maximum ambient, enclosure sealing, orientation, mounting surface, solar load, allowable external temperature, sustained performance and component-life targets. These values define the required thermal resistance.

Requirement domain	Questions to resolve
Heat sources	CPU/GPU/NPU, VRM, memory, storage, display backlight, radios, interface converters and power-input losses under concurrent load.
Thermal environment	Ambient range, solar load, enclosure sealing, orientation, mounting surface, airflow, altitude and nearby equipment.
Performance requirement	Sustained clocks, frame rate, AI throughput, storage/network activity, boot peaks and acceptable throttling.
Heat path	Die/package, thermal interface, spreader, heat pipe/vapour chamber, chassis, external fins, mounting panel and surrounding air.
Reliability limits	Processor junction, SSD controller/NAND, electrolytic capacitors, display polariser/backlight, touch adhesive and external touch temperatures.
Production control	Flatness, interface-pad thickness, torque, paste coverage, heat-pipe orientation, sensor calibration and thermal-material change control.

A practical weighting model

Assign each criterion a weight from 1 (low importance) to 5 (critical). Score each candidate from 1 (poor fit) to 5 (strong fit), then multiply score by weight. The arithmetic does not replace engineering judgement, but it exposes where the heat-transfer architecture depends on assumptions, incomplete test evidence or optimistic supplier data.

Do not average away a fatal constraint

A candidate that fails a non-negotiable requirement for fanless thermal performance should be removed before weighted scoring. Typical fatal constraints include unsafe operation, an unachievable environmental limit, incompatible interfaces, unacceptable field reliability or no credible supply route.

Recommended process

- Set pass/fail gates for the mandatory fanless thermal performance requirements before comparing desirable features.
- Agree criterion weights with electronics, mechanical, software, product, service and procurement stakeholders.
- Score only from controlled data, supplier evidence or representative testing; mark unknowns explicitly.
- Run sensitivity checks by changing the highest weights and identifying whether the preferred architecture changes.
- Document assumptions, test conditions and revision status so the decision can be revisited after a component or firmware change.

2. Heat-transfer architectures for fanless panel PCs

2.1 Direct chassis conduction

A machined or cast heat spreader couples the processor and other hot components directly to the metal rear enclosure. The chassis distributes heat to external surfaces and natural convection. Interface flatness and contact pressure dominate performance.

- Strengths: few moving parts, simple construction and good reliability when the heat path is short.
- Limitations: local hot spots, enclosure touch-temperature limits and sensitivity to pad/paste thickness and mechanical tolerance.
- Best fit: low- to moderate-power fanless panel PCs with metal enclosures.

2.2 Heat-pipe-assisted spreading

Heat pipes move heat from a compact processor area to a larger chassis region. They reduce local temperature rise but have orientation, bend, flattening and contact constraints. The final chassis still needs enough surface area to reject heat.

- Strengths: effective transport over distance and improved use of available enclosure area.
- Limitations: mechanical integration, orientation sensitivity for some designs and additional interfaces.
- Best fit: systems where the CPU is not adjacent to the optimal external heat sink.

Interface stack control

Specify thermal-pad/paste thickness, compressed state, flatness and screw torque. A high-performance heat pipe cannot compensate for an uncontrolled contact resistance at either end.

2.3 Vapour chamber or large-area spreader

A vapour chamber spreads heat in two dimensions and can reduce hotspot density under high-power processors. It requires a flat, mechanically supported integration and may add cost and thickness.

- Strengths: excellent planar spreading and lower peak surface temperature.
- Limitations: cost, mechanical sensitivity, integration height and limited benefit if external convection remains the bottleneck.
- Best fit: thin or high-performance fanless systems with concentrated heat.

2.4 External cold plate or mounting-panel coupling

The panel PC can conduct heat into a cabinet wall, machine frame or dedicated cold plate. This can significantly improve capacity, but performance becomes installation dependent and must be specified to the customer.

2.5 Distributed low-power compute

Selecting lower-power processors, separating accelerators or moving compute into a remote box can reduce front-panel heat density. It changes software, cabling, latency and enclosure architecture but may be the most robust fanless solution.

3. Comparative decision matrix

Criterion	Direct chassis	Heat pipe	Vapour chamber	Cold plate / split
Low-power simplicity	Excellent	Strong	Moderate	Moderate
Hotspot spreading	Moderate	Strong	Excellent	Excellent
Remote heat transport	Limited	Excellent	Strong	Excellent
Orientation tolerance	Excellent	Moderate	Excellent	Excellent
Mechanical tolerance	Moderate	Moderate	Limited	Moderate
External surface control	Moderate	Strong	Excellent	Excellent
Integration thickness	Excellent	Moderate	Moderate	Moderate
Relative cost	Excellent	Moderate	Limited	Limited
Serviceability	Strong	Moderate	Moderate	Strong
High-power scalability	Limited	Strong	Excellent	Excellent

Indicative only. Actual performance depends on the complete system architecture, supplier implementation, environmental conditions and validation method.

Example weighted scorecard

Criterion	Weight	Direct chassis	Heat pipe	Vapour chamber
35 W sustained compute	5	2	4	5
Thin enclosure	4	5	3	4
CPU hotspot limit	5	3	4	5
Orientation variation	3	5	3	5
Production tolerance	4	3	3	2
Cost	3	5	3	2
External touch temperature	4	3	4	5
Weighted total		99	98	115

For this thin 35 W panel PC, the vapour chamber leads because hotspot and surface-temperature control dominate. A heat pipe provides a lower-cost alternative if orientation and contact interfaces are tightly controlled; direct conduction lacks sufficient hotspot margin.

Reading the result

- Direct conduction is appropriate only when the chassis area and interface resistance support sustained, not burst, power.
- Heat-pipe performance must be qualified in every allowed orientation and after vibration/thermal cycling.
- A vapour chamber does not solve an undersized external convection path; total enclosure-to-ambient resistance still governs steady state.

4. Engineering trade-offs that change the answer

4.1 TDP is not the complete heat load

Processor package power can exceed nominal values transiently, while memory, SSD, VRM, radios and the display add heat. Measure representative concurrent workloads.

4.2 Natural convection depends on orientation and installation

A bench test with free vertical fins can overstate performance inside a cabinet or against an insulating wall. Define installation conditions and mounting clearance.

4.3 Interface resistance can dominate

Soft pads accommodate tolerance but add thickness; paste needs flatness and controlled coverage. Verify compressed bond line and pump-out over cycling.

4.4 Display heat couples into compute and touch

High-brightness backlights warm the same front assembly. Solar load can raise the LCD and internal air while the CPU is also at peak load.

4.5 Throttling can protect hardware but break the task

Set sustained workload acceptance and monitor actual clocks or throughput. A system that stays below T_j max by halving performance may still fail.

4.6 Storage devices and capacitors have lower thermal margins

SSD controllers, NAND retention/endurance and electrolytic life can become limiting before the CPU. Map and derate all critical components.

5. Application-led recommendations

Low-power factory HMI

Direct chassis conduction is usually adequate. Focus on thermal-pad control, vertical orientation and display heat.

Vision/AI panel PC

Use heat pipes or vapour chambers and test CPU, GPU/NPU, camera I/O and storage simultaneously at hot ambient.

Outdoor high-brightness HMI

Combine solar-load modelling, backlight derating and compute power limits. A split architecture may reduce front-panel thermal density.

Sealed washdown panel PC

Natural convection area is constrained by smooth cleanable surfaces. Use conductive mounting and conservative component limits.

Cabinet-mounted control panel

If the cabinet wall is part of the heat sink, specify material, flatness, thermal interface and maximum internal cabinet temperature.

6. Qualification and sourcing checklist

	Area	Verification action
☐	Power characterisation	Measure rail and package power for boot, steady HMI, storage/network, graphics and AI worst cases.
☐	Thermal mapping	Instrument processor, VRM, memory, SSD, backlight, internal air, touch surface and external hot spots.
☐	Orientation / installation	Test all allowed orientations, cabinet clearances, wall coupling and sealed states.
☐	Performance	Log clocks, throttling, frame rate, AI throughput and storage/network behaviour through steady state.
☐	Interfaces	Verify pad/paste thickness, contact pattern, flatness, torque and heat-pipe/vapour-chamber attachment.
☐	Environment	Run hot/cold, solar load, altitude, vibration and thermal cycling as applicable.
☐	Faults	Test blocked external surfaces, sensor faults and conservative firmware power-limit behaviour.
☐	Production	Define inspection of interface materials, torque, sensor calibration and thermal audit sampling.

Questions to ask a display partner

- What measured concurrent workload defines the sustained thermal design point?
- Which temperatures and performance limits are guaranteed at maximum ambient and installation constraint?
- How are thermal-interface thickness, flatness, pressure and torque controlled?

- Does heat-pipe or vapour-chamber performance depend on orientation?
- What backlight and solar heat are included in the model and test?
- Which firmware power limits, sensors and fault responses are part of the released configuration?

Minimum evidence pack for design approval

- Power/workload profile and sustained performance acceptance criteria.
- Thermal model and instrumented steady-state maps for all critical components.
- Controlled mechanical heat-path drawings and interface-material specifications.
- Hot-ambient, orientation, installation, solar and vibration/cycle test results.
- Firmware thermal-control/power-limit configuration and recovery evidence.
- Production torque/contact inspection, golden units and change-control plan.

7. Beyond conventional metal heat spreaders

Fanless systems are adopting more advanced spreaders, telemetry and workload control. These methods should improve measured steady-state margin without creating opaque performance behaviour.

Loop heat pipes and advanced two-phase devices

These can move larger heat loads over distance but require orientation, containment, vibration and life evidence.

Graphite and anisotropic spreaders

Thin graphite can spread heat effectively in-plane. Electrical isolation, edge damage and through-thickness limitations need control.

Predictive workload shaping

Software can schedule AI, storage or display loads to avoid simultaneous peaks. Hard performance and safety limits must remain deterministic.

Liquid or cabinet cold plates

Industrial installations can provide excellent capacity, but connectors, leaks, corrosion, service and installation responsibility become system requirements.

Thermal digital twins

Correlated models can assess variants and mounting conditions quickly. They remain valid only with controlled geometry/material properties and measurement correlation.

Adoption gate

A new thermal technique should enter production only when it reduces measured critical temperatures or preserves sustained performance across installation variants, with controlled interfaces and fault behaviour.

8. Working with Crystal Display Systems

Crystal Display Systems Limited supports fanless panel PC programmes with processor selection, metalwork and heat-path design, high-brightness display integration, sealed enclosures, custom I/O and complete thermal qualification.

Relevant CDS resources

Resource	Purpose
<u>Industrial Panel PC Solutions</u>	Integrated industrial HMI and panel PC solutions with customisation options.
<u>Industrial Panel PC Range</u>	Current panel PC platforms, processors, I/O and rugged configurations.
<u>Bespoke All-In-One Panel PCs</u>	Examples of fully customised, IP-rated and application-specific systems.
<u>Industrial Boxed PCs and Panel PCs</u>	Industrial computing platforms, customisation and long-life support.
<u>Industrial Automation Displays</u>	Display, monitor and computing solutions for automation and machine HMI.
<u>CDS Knowledge Centre</u>	Display guides and technical training documents.
<u>Request a Quote</u>	Submit project requirements for technical and commercial review.
<u>Contact CDS</u>	Contact details and enquiry routes.

Contact Crystal Display Systems Limited

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Conclusion

Fanless panel PC reliability depends on a continuous, controlled path from each heat source to ambient. Processor TDP alone is insufficient; display, storage, power and installation loads must be included. The correct architecture preserves sustained application performance and component life at worst ambient, orientation and mounting conditions without relying on uncontrolled throttling.

Final engineering rules

- Define concurrent sustained workload and installation conditions before selecting the processor.
- Model and measure every major heat source, including display and solar load.
- Control thermal interface flatness, thickness, pressure and torque in production.
- Log performance and throttling as well as temperature during qualification.
- Derate components and power limits from whole-life reliability, not only maximum ratings.

Disclaimer

This whitepaper provides general engineering guidance and does not replace application-specific design review, supplier specifications, regulatory assessment or formal product qualification. Performance depends on the exact components, implementation, environment and usage profile.