

The Cooling Inversion

Radiative and convective heat rejection for dense compute in sunlit orbit versus on the Martian surface

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Abstract

A persistent assumption holds that space is "cold," so cooling a data center in orbit should be easy. It is not, and the reason is not temperature — it is the **absence of a convective medium**. In vacuum, the only exit for heat is thermal radiation, which is governed by the Stefan–Boltzmann fourth-power law and, in low Earth orbit (LEO), corrupted by a planet that fills most of the radiator's sky. We derive the steady-state heat balance for an orbital compute platform, show that the binding constraint is radiator area and temperature (not power), and quantify where the architecture breaks as rack density climbs from 20 kW to 100 kW and beyond. We then perform the same analysis for a radiator on the Martian surface, where a thin (≈ 6 mbar) CO_2 atmosphere restores a real — if modest — convective channel, and a cold night sky offers a clean radiative sink. The result is an **inversion**: sunlit orbit is *power-rich and cooling-poor*; the Martian surface is *power-poor and cooling-rich*. The power deficit on the surface is precisely the gap that a compact, self-extinguishing fusion plant is built to close. We state the inversion as a falsifiable engineering claim, identify the one leg that does **not** survive scrutiny (conduction into regolith — an insulator), and bound the regimes in which each conclusion holds.

1. The misconception

Two folk positions dominate discussion of space-based computing. The first: *space is naturally cold, so cooling is free*. The second: *there is no air, so cooling is nearly impossible*. Both are wrong, and the truth sits between them.

Vacuum has no temperature in the thermodynamic sense relevant to a hot object — it is a near-perfect *insulator* for conduction and convection, and a near-perfect *sink* for radiation. A spacecraft is not cooled by its surroundings; it cools **only** by radiating its own heat away faster than it absorbs heat from the Sun, the Earth, and its own electronics. The engineering question is therefore never "is cooling possible," but:

How much radiator area, temperature margin, coolant transport, and mass are required to reject a given heat load — and at what scale does that requirement stop closing?

This paper answers that for two environments that matter to off-world compute: **sunlit LEO** (today's orbital-data-center thesis) and the **Martian surface** (FUNNY's domain).

2. Fundamentals: radiative heat rejection

2.1 The Stefan–Boltzmann law

A surface at absolute temperature T with emissivity ε radiates:

$$q_{\text{emit}} = \varepsilon \sigma T^4 \quad [\text{W m}^{-2}]$$

with $\sigma = 5.670374 \times 10^{-8} \text{ W m}^{-2}\text{K}^{-4}$. The fourth-power dependence is the single most important fact in thermal design: **radiator temperature is the dominant lever**. For an ideal emitter ($\varepsilon = 1$):

T	Q_{EMIT}
20 °C (293.15 K)	419 W m ²
80 °C (353.15 K)	882 W m ²
97 °C (370.15 K)	1063 W m ²

Going from 20 °C to 80 °C **doubles** the flux; going to ~97 °C nearly triples it relative to room temperature. This is why hardware that tolerates high junction and coolant temperatures is worth far more in space than on Earth: every kelvin of allowable radiator temperature buys disproportionate area savings.

2.2 Emissivity is not unity

Real radiator coatings — optical solar reflectors (OSR), silver- or aluminized-Teflon, white paints — achieve $\varepsilon \approx 0.85\text{--}0.92$ at beginning of life, degrading toward $\varepsilon \approx 0.80$ over years of UV and atomic-oxygen exposure. Throughout this paper we adopt $\varepsilon = 0.88$ as a defensible working value. Every ideal-emitter area must therefore be scaled up by $1/\varepsilon \approx 1.14$:

T	Q_{EMIT} AT $E = 0.88$
20 °C	369 W m ²
80 °C	776 W m ²
97 °C	935 W m ²

2.3 The net-flux equation (the part folk treatments omit)

A radiator does not emit into a 3 K void unless it faces deep space. It also **absorbs** from whatever its surface sees. The correct steady-state net rejection per unit area is:

$$q_{\text{net}} = \underbrace{\varepsilon \sigma T_r^4}_{\text{emitted}} - \underbrace{\left[\varepsilon \sigma F T_{\text{env}}^4 + \alpha (F q_{\text{albedo}} + q_{\text{solar}} \cos \theta) \right]}_{\text{absorbed}}$$

where T_r is radiator temperature, T_{env} the effective temperature of the body in view, F the **view factor** to that body, α the solar absorptivity, q_{albedo} the reflected-sunlight flux, q_{solar} the direct solar

flux, and θ the solar incidence angle. By Kirchhoff's law the surface's infrared absorptivity equals its emissivity ε in the IR band; its **solar** absorptivity α is a separate property (a good radiator has high ε and low α — e.g. OSR with $\alpha \approx 0.10\text{--}0.17$, $\varepsilon \approx 0.85$).

The naïve "space is a 3 K sink" model sets the bracket to zero. In LEO that is badly wrong, as §3.2 shows.

3. The orbital case: sunlit LEO

3.1 Baseline area (the optimistic number)

Take a 20 kW computing payload; essentially all electrical power becomes heat. Ignoring the environment and treating both faces of a flat plate as ideal emitters into deep space:

$$A = \frac{Q}{2 \varepsilon \sigma T_r^4}$$

At 80 °C, $\varepsilon = 0.88$: $A = 20,000 / (2 \times 776) \approx 12.9 \text{ m}^2$ of plate. This is the headline that makes orbital cooling sound trivial — *a Starlink-class bus is roughly this size*. It is also the number that does not survive the environment.

3.2 The Earth fills the sky

The fatal omission is the **view factor to Earth**. At an altitude $h = 550 \text{ km}$ (Starlink shell), Earth's angular radius is

$$\rho = \arcsin \frac{R_\oplus}{R_\oplus + h} = \arcsin \frac{6371}{6921} \approx 67^\circ,$$

so Earth subtends a $\sim 134^\circ$ cone — most of the lower hemisphere. For a flat plate facing nadir, the view factor to Earth is

$$F_E = \sin^2 \rho \approx \sin^2(67^\circ) \approx 0.85, \quad \text{not } 0.5.$$

Earth radiates as a $\sim 255 \text{ K}$ body ($\sigma T_E^4 \approx 240 \text{ W m}^{-2}$ outgoing longwave) and reflects $\sim 30 \%$ of incident sunlight (albedo). A **nadir-facing** radiator therefore absorbs:

- Earth IR: $\varepsilon F_E \sigma T_E^4 = 0.88 \times 0.85 \times 240 \approx 180 \text{ W m}^{-2}$ — and this is IR it *cannot avoid* absorbing, because high ε means high IR absorptivity.
- Reflected sunlight (sunlit arc): $\alpha F_E a q_{\text{solar}} \approx 0.15 \times 0.85 \times 0.30 \times 1361 \approx 52 \text{ W m}^{-2}$.

Net rejection of the nadir face:

$$q_{\text{net}}^{\text{nadir}}(T_r) = 0.88 \sigma T_r^4 - 180 - 52.$$

T_R	$E \Sigma T_R^4$	$Q_{\text{NET}}^{\text{NADIR}}$
80 °C	776	$\approx 545 \text{ W m}^2$
20 °C	369	$\approx 137 \text{ W m}^2$

This is the result that reframes everything. A nadir radiator at 20 °C nets $\sim 140 \text{ W m}^{-2}$ — nearly useless. At 80 °C it nets ~ 545 . The collapse at low temperature is *the physical reason high radiator*

temperature is non-optional in orbit — not an optimization, a requirement. The popular "just add ~400 W/m² of Earth load to the budget" shortcut gets the magnitude roughly right but hides the temperature dependence and the $F_E \approx 0.85$ geometry.

3.3 Realistic orbital area

A flat plate has one face toward nadir and one toward zenith (deep space, ~3 K, full $\varepsilon\sigma T_r^4$). At 80 °C:

$$q_{\text{plate}} = \underbrace{776}_{\text{zenith}} + \underbrace{545}_{\text{nadir}} \approx 1321 \text{ W m}^{-2} \text{ of plate.}$$

For 20 kW: $A \approx 15.1 \text{ m}^2$. A favorable attitude — **dawn-dusk sun-synchronous orbit**, radiator broad-faces edge-on to the Sun and tilted off nadir so both faces see more deep space — recovers toward the 13 m² ideal; an unfavorable one (nadir-locked for downlink, broadside Sun) pushes past 20–25 m². The honest planning range for a 20 kW payload is therefore **~15–22 m²**, not the textbook ~12 m². Orientation is doing the heavy lifting, and the three demands a real bus juggles — point solar arrays at the Sun, point antennas at Earth, point radiators at the dark — fight each other.

3.4 The wall at scale

For moderate loads (≤ 20 kW) a Starlink-sized bus is in the right order of magnitude. The architecture **breaks** as rack density rises — and modern AI racks already run 100–140 kW. Two regime changes occur:

1. **Area scales linearly with load** while the bus does not. 100 kW at 80 °C needs ~75–110 m² of radiator (deployed), 5× the bus's native area → large deployable panels with their own structure, hinges, and failure modes.
2. **The problem stops being area and becomes mass + transport + reliability.** Heat must move from chips to radiators through pumped loops. Areal radiator mass runs ~5–10 kg m² for the panel alone; with manifolds, redundant pumps, deployment structure, and micrometeoroid armor the system mass is:

$$m_{\text{rad}} \approx \underbrace{\frac{Q}{q_{\text{plate}}}}_{\text{area}} \times \underbrace{8 \text{ kg m}^{-2}}_{\text{panel}} \times \underbrace{(1.4-1.7)}_{\text{loops, pumps, structure, MMOD}}$$

For 1 MW at 80 °C: ~760 m² → ~6 t panel → **~10–12 t/MW conservative** (~6–8 t/MW with aggressive lightweight panels). At hyperscale-orbit power levels (tens of MW), radiator mass alone becomes a launch-manifest line item measured in hundreds of tonnes.

3.5 Coolant transport

Single-phase water removing 100 kW across a 20 °C rise:

$$\dot{m} = \frac{Q}{c_p \Delta T} = \frac{100,000}{4186 \times 20} = 1.19 \text{ kg s}^{-1} \approx 71 \text{ L min}^{-1}.$$

Water is avoided in flight (freezing risk in cold legs); ammonia and glycol are standard. **Two-phase** loops slash mass flow because latent heat dwarfs sensible heat — ammonia's latent heat $\approx 1.37 \text{ MJ kg}^{-1}$, so full evaporation rejects 100 kW at

$$\dot{m} = \frac{100,000}{1.37 \times 10^6} \approx 0.073 \text{ kg s}^{-1},$$

~16× less flow than single-phase water. Pumping power is small relative to the heat moved but scales steeply with pressure loss: micro-channels improve heat transfer and cut coolant inventory but raise viscous losses — a mass/power/reliability trade with no free optimum.

3.6 Active refrigeration is self-defeating

One might try to reject heat at a temperature *above* the electronics by pumping it uphill with a heat pump. On a power-limited platform this is a trap: the Carnot work

$$W = Q \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{cold}}}$$

itself becomes additional heat to radiate, compounding the load. **The correct lever is hot-tolerant silicon, not colder coolant.** Raise T_r via the T^4 law (§2.1); do not spend power to lower it.

4. The surface case: Mars

The Martian surface restores two cooling channels that vacuum denies, and degrades the power supply that orbit enjoys. We take each leg in turn — adversarially, killing the one that fails.

4.1 Convection — real, modest, decisive

Mars' atmosphere is thin (~6 mbar, ~95 % CO₂) but **not** a vacuum. Measured and modeled free-convection coefficients at the surface are

$$h \approx 3.5 \text{ W m}^{-2}\text{K}^{-1} \text{ (0.5 m s}^{-1} \text{ wind)} \rightarrow \approx 9 \text{ W m}^{-2}\text{K}^{-1} \text{ (4 m s}^{-1}\text{)},$$

roughly one-third to one-half of Earth's natural convection (~5–25 W m²K⁻¹). With a fan-blown sink (~15 W m²K⁻¹) and a 60 K surface-to-air difference:

$$q_{\text{conv}} = h \Delta T \approx 15 \times 60 \approx 900 \text{ W m}^{-2},$$

with no T^4 penalty and effective at low ΔT . This is the qualitative break from orbit: a channel that simply does not exist in vacuum reappears, and it does not punish you for running cool.

4.2 Radiative night sky — a clean sink

The Martian night sky/ground effective temperature is ~150–170 K. A surface radiator at 80 °C rejects:

$$q_{\text{rad}} = \varepsilon \sigma (T_r^4 - T_{\text{sky}}^4) = 0.88 \sigma (353^4 - 165^4) \approx 738 \text{ W m}^{-2}.$$

Because $T_{\text{sky}}^4 \ll T_r^4$, the cold sink is *nearly as good as deep space* — and critically, it is **not contaminated by an Earth-IR hemisphere** the way an orbital nadir face is (compare §3.2's 545 W m⁻²). Daytime degrades this (warmer, dustier sky), but the diurnal cycle guarantees a cold-sink window every night.

4.3 Mars illumination: how much does Mars load the radiator?

Symmetric to the orbital Earth-illumination accounting of §3.2, we now ask what Mars itself throws back at a *surface* radiator — its atmosphere's thermal emission, the ground's emission, direct sunlight, and reflected sunlight. The decisive fact is **geometry**: a flat radiator laid **face-up** has its productive (sky-facing) face seeing *only the sky* across its entire upper hemisphere; the warm ground, direct Sun, and reflected sunlight all live in the **lower** hemisphere — geometrically disjoint

from the radiating view, and therefore shieldable. (All fluxes below are *absorbed* by the radiator — already multiplied by $\varepsilon = 0.88$ in the IR and $\alpha \approx 0.15$ in the solar band; ground emissivity $\varepsilon_g \approx 0.95$.)

Downwelling atmospheric (sky) IR — small, because the atmosphere barely emits. A 6 mbar CO₂ atmosphere is a weak IR emitter, so the effective sky temperature is only ~150–165 K and the up-face absorbs just **~37 W m⁻² on a clear night** ($\sigma 165^4 = 42 \text{ W m}^{-2}$ blackbody, $\times \varepsilon$). This is the *direct analogue of Earth's 180 W m⁻² in orbit (§3.2)* — and it is ~5× smaller. A global dust storm raises the effective sky temperature (nightside surface warming up to 42 K has been observed), lifting the absorbed sky term to **~50–88 W m⁻²** — roughly double, but nowhere near the orbital figure.

Ground IR — the real daytime load, and it lives in the lower hemisphere. Equatorial ground peaks at ~290–300 K at midday, emitting $\varepsilon_g \sigma 293^4 \approx 381\text{--}397 \text{ W m}^{-2}$, of which a ground-facing surface absorbs **~335–350 W m⁻²**; at night the ground falls to ~183–200 K and emits only **~53–76 W m⁻² absorbed**. Critically, *this load reaches only faces with a view factor to the ground* — for the up-face it is zero.

Direct solar and albedo — daytime, lower-hemisphere, and self-cancelling under dust. Peak insolation ~590 W m⁻² → absorbed $\alpha \cdot 590 \approx 88 \text{ W m}^{-2}$ on a sun-exposed face; surface albedo 0.16–0.27 gives a reflected term up to ~148 W m⁻², of which a ground-facing face absorbs **≤22 W m⁻²**. Both fall steeply under dust (Beer's law) — so exactly when the sky term *grows* (dust), the solar/albedo terms *shrink*; they partly cancel.

Net rejection, face-up at 80 °C (emission $\varepsilon \sigma 353^4 = 776 \text{ W m}^{-2}$):

CONDITION	UP-FACE ABSORBS	Q_{NET}
Night, clear sky	~31	≈ 745 W m⁻²
Night, global dust storm	~50–88	≈ 690–725 W m⁻²
Day, sun shielded, dusty sky	~52	≈ 724 W m⁻²
Day, sun-exposed (no shade)	~52 + 88 + 22	≈ 613 W m⁻²

Compare the orbital **nadir face: 545 W m⁻² at 80 °C (§3.2)** — and *unavoidably so*, because Earth fills $F_E \approx 0.85$ of that face's own hemisphere and cannot be shielded without also blocking the radiating view. The Mars up-face nets **~724–745 W m⁻²** with the contaminating sources pushed into a separable lower hemisphere: a **~33–37 % cleaner radiating environment, and a controllable one**. Dust erodes the night case by at most ~30–60 W m⁻² and never closes the gap.

One honesty discipline (do not overclaim). This advantage is in *environment quality and controllability*, **not** in raw flux per kilogram of radiator. An orbital flat plate radiates from *both* faces (zenith 776 + nadir 545 = 1321 W m⁻² of plate, §3.3); a face-up surface radiator's down-face sees warm ground, not deep space, so per unit of radiator *material* the orbital double-sided plate can still win on raw flux. The surface's true wins are (i) a clean, shieldable sky over a full hemisphere, (ii) the convective channel of §4.1 that orbit cannot have at all, and (iii) the ability to *trade* between radiation and convection across the diurnal cycle. The claim is "cleaner and more controllable," which is exactly true — not "more flux per kg," which is not.

4.4 Conduction into regolith — this leg fails

It is tempting to treat the ground as a heat sink. It is not. Dry Martian regolith has thermal conductivity $k \approx 0.039 \text{ W m}^{-1}\text{K}^{-1}$ (InSight) — an **insulator**. Steady conduction through a 0.1 m layer at $\Delta T = 50 \text{ K}$ delivers

$$q_{\text{cond}} = \frac{k \Delta T}{L} = \frac{0.039 \times 50}{0.1} \approx 19.5 \text{ W m}^{-2},$$

i.e. **~50 m² of contact area to reject a single kilowatt** — and the surrounding regolith, with no convective refresh, saturates and collapses the gradient over hours. Regolith is a *slow diurnal thermal buffer*, not a steady-state sink. **Any architecture that leans on ground conduction for continuous rejection is wrong, and we drop it.**

4.5 The power penalty

What the surface gives in cooling it takes in power. Peak Martian solar irradiance is ~590 W m⁻² (~44 % of Earth's), further cut by atmospheric optical depth, the day–night cycle, dust on panels, and — decisively — **global dust storms that suppress surface solar by 80–90 % for weeks to months**. Photovoltaics alone cannot guarantee continuous power to a dense compute load through a dust season. This is the gap.

5. The inversion

Placing the two environments side by side (per unit radiator/plate area, 80 °C surfaces, $\varepsilon = 0.88$):

PROPERTY	SUNLIT LEO	MARS SURFACE
Power availability	Rich — 1361 W m ⁻² , uninterrupted	Poor — 590 W m ⁻² peak, -80–90 % in dust storms, night gap
Convection channel	None (vacuum)	Real — $h \approx 3.5\text{--}9$ ($\approx 900 \text{ W m}^{-2}$ blown), no T^4 penalty
Radiative sink quality	Corrupted — Earth fills $F_E \approx 0.85$ of nadir sky; nadir net $\approx 545 \text{ W m}^{-2}$ @80 °C (≈ 137 @20 °C), fixed	Clean & controllable — up-face net ≈ 724 (day, shielded) / 745 (night) W m ⁻² @80 °C; loads confined to a separable lower hemisphere
Conduction sink	n/a	Fails — regolith $k \approx 0.039$; ~50 m²/kW; insulator
Dominant constraint	Radiator area, temperature, mass (~10–12 t/MW)	Power continuity through dust storms
Hot-silicon lever	Essential (low- T radiators near-useless)	Helpful but not existential (convection works at low ΔT)

The thesis, stated as a falsifiable claim:

In sunlit orbit you have abundant power but only one way to dump heat — radiation against a T^4 wall, with the Earth glowing in your radiator's face. On Mars you trade power for a thin but real atmosphere that lets you convect, plus a genuinely cold night sky to radiate against. The ground itself is no help — regolith is an insulator. The inversion is real; it lives in the air, not the soil.

Orbit is **power-rich, cooling-poor**. The Martian surface is **power-poor, cooling-rich**. These are not rhetorical opposites; they are quantified above, and each leg is individually checkable (and one — conduction — has already been falsified and removed).

6. Closing the loop: why this is a fusion argument

The inversion would be a curiosity if the surface power deficit were unfixable. It is exactly the deficit a compact fusion plant is built to close:

- **Solar fails on the surface when it is needed most** — through multi-month dust storms, on the dark side, at the poles. Fusion does not care about the sky.
- **A fusion plant self-extinguishes**. Unlike fission, a magnetic-confinement fusion device holds milligrams of fuel and collapses on any upset; failure mode is "it turns off," not runaway. For a crewless plant under light-lag, passive self-extinction is a genuine safety asset.
- **The surface cooling environment makes dense compute *easier* than orbit** — once the power is guaranteed. Convection plus a clean night-sky sink beats an Earth-IR-contaminated orbital radiator, at lower radiator temperature and lower mass per kW.

This is the FUNNY dependency loop in thermal terms: **fusion supplies the power the surface lacks; the surface supplies the cooling that orbit lacks; autonomous AI runs the plant under light-lag**. Orbit is solar's turf — power is free there and cooling is the wall. The surface is the regime where fusion's power advantage and the environment's cooling advantage compound.

7. Limitations and honesty notes

Per FUNNY doctrine, the boundaries of this claim:

1. **Orbital figures assume favorable-to-moderate attitude**. A real comms+compute bus may do worse than §3.3's 15–22 m²/20 kW; we do not claim the optimistic 13 m².
2. **Mars convection is environment-dependent**. h varies with wind speed, surface roughness, and forced-flow design; the ~900 W m⁻² blown figure assumes engineered airflow, not still-air free convection (which is $\sim 3.5 \times \Delta T$).
3. **Dust is a double-edged variable**. Storms suppress solar (helps the cooling argument's *contrast*, hurts the surface power story) and coat radiators (degrades ε/α — a maintenance burden, not a thermal showstopper).
4. **Conduction is excluded, not minimized**. We are not claiming a small regolith contribution; we are claiming it is negligible for steady-state rejection and should not appear in a surface thermal budget.

5. **No device-level fusion claim is made here.** This paper concerns *heat rejection environments*. The power source's feasibility is treated in the fuel-cycle and autonomy studies; FUNNY integrates existing physics and does not assert a net-gain device.
6. **This is a systems-research artifact, not a flight design.** The numbers are decision-grade order-of-magnitude with cited constants; a flight radiator requires detailed transient, MMOD, and degradation modeling.
7. **The surface cooling advantage is environmental, not per-kg (§4.3).** An orbital flat plate radiates from *both* faces ($\sim 1321 \text{ W m}^{-2}$ -of-plate); a face-up surface radiator's down-face sees warm ground. The defensible claim is a *cleaner, controllable* radiating environment plus a convective channel orbit lacks — **not** higher flux per kilogram of radiator material.

8. Conclusion

Cooling computers in space is neither free nor impossible. The real enemy is the absence of convection, not the coldness of space: heat must be deliberately transported to a radiating surface and emitted, against a fourth-power temperature law and — in LEO — against a planet that fills most of the radiator's sky. At moderate power ($\leq 20 \text{ kW}$) a Starlink-class bus is broadly in range; at 100 kW and beyond the architecture is dominated by deployable radiator area, coolant transport, and mass ($\sim 10\text{--}12 \text{ t/MW}$). The Martian surface inverts the problem: it is power-poor but cooling-rich, because a thin atmosphere restores convection and a cold night sky offers a clean radiative sink — while the ground, an insulator, offers nothing. That inversion is the thermal case for surface fusion: the power deficit the surface suffers is exactly what a self-extinguishing fusion plant exists to fix, and the cooling advantage the surface enjoys is exactly what sunlit orbit cannot have.

9. Symbols

SYMBOL	MEANING	UNITS
σ	Stefan-Boltzmann constant	$\text{W m}^{-2} \text{ K}^{-4}$
ε	IR emissivity	—
α	Solar absorptivity	—
T_r, T_E, T_{sky}	radiator / Earth / Mars-sky effective temperature	K
F, F_E	view factor (to body / to Earth)	—
$q_{\text{solar}}, q_{\text{albedo}}$	direct solar / reflected-sunlight flux	W m^{-2}
Q	heat load	W
$\dot{m}, c_p$	mass flow / specific heat	$\text{kg s}^{-1}, \text{J kg}^{-1}\text{K}^{-1}$
h	convective coefficient	$\text{W m}^{-2} \text{ K}^{-1}$
k, L	thermal conductivity / path length	$\text{W m}^{-1}\text{K}^{-1}, \text{m}$

10. Constants and sources

QUANTITY	VALUE	SOURCE
σ	$5.670374 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$	CODATA
Solar constant (TSI)	1361 W m ⁻² mean (1322–1414 over eccentricity)	IAU/PMOD; ICES-2021-425
Earth OLR (global mean)	238–240 W m ⁻²	Earth energy budget
Earth Bond albedo	~0.30	Earth energy budget
OSR / silver-Teflon	$\alpha \approx 0.08\text{--}0.17, \varepsilon \approx 0.80\text{--}0.88$	OSR literature; spacecraft thermal control
Radiator areal mass	1.6–3.9 kg m ⁻² (light deployable) → up to ~12 kg m ⁻² (heavy)	NASA SoA; arXiv 2511.06683
Mars free-convection h	~3.5 (0.5 m/s) → ~9.2 (4 m/s) W m ⁻² K ⁻¹	Martian convection lit.
Mars regolith k	0.039 W m ⁻¹ K ⁻¹ (InSight, dry)	Grott 2021
Mars peak solar	~590 W m ⁻² (clear, equatorial)	Appelbaum & Flood, NASA TM-102299
Mars ground temp (equatorial)	~290–300 K day peak; ~183–200 K night	EMM/Curiosity/Perseverance; MNRAS Lett. 2022
Mars ground emissivity ε_g	~0.95	regolith thermal IR
Mars sky effective temp	~150–165 K clear; ~200–225 K dust storm	Streeter 2020 (dust-storm warming)
Mars surface albedo	0.16 (dark) – 0.27 (bright dust)	Pleskot & Miner 1981; Mars Express
Ammonia latent heat	~1.37 MJ kg ⁻¹	NIST

References: Solar irradiance (Wikipedia) · ICES-2021-425 LEO thermal environment · Earth's Energy Budget (Science of Doom) · Spacecraft thermal control (Wikipedia) · Multifunctional Lightweight Radiators (arXiv 2511.06683) · NASA SoA Thermal Control · Convective Heat Transfer at the Martian Surface (ResearchGate) · CO₂ enclosures on Mars (Energies 2018, doi:10.3390/en11040756) · Grott 2021, InSight soil thermal conductivity (JGR) · Piqueux 2011, regolith thermal inertia (JGR).

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