TITLE:- RAPID TEMPERATURE DROP SIMULATION & AUTONOMOUS THERMAL FALLBACK RESPONSE

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Abstract:- This paper presents a Rigorous Simulation and fallback model for critical Edge-case conditions in Autonomous or System malfunctions. This scenario(04) examines the Node's Thermal Resilience falloff rate, and autonomous trigger behaviour when internal temperature beyond survivability thresholds.

Introduction:- Space based nodes in Dyson Environments operate in Volatile thermodynamics conditions, including., Eclipses, blackout, and Interstellar drifts. One of the lesser- modeled but fatal conditions in a system thermal drop – Which may arise from;

- ★ *Prolonged Shadow Trapping*
- ★ *Core Coolant failure*
- ★ *Solar Input less*
- ★ *Deep-space transition with no stellar fallback*

Physical & Mathematical Modeling:-

(i) Assumptions

↣ ★ *Initial Internal temperature (To) = 24℃*

★ *Temperature Drop rate (ΔT) = randomized 0.1 - 0.6℃ per cycle.*

★ *Fallback Threshold = -5.0℃*

★ *Total Cycles = 6000 (Each Cycle = 1 unit time)*

★ *Recovery logic = Not present in this baseline, but extensible.*

(ii) Drop Rate function

↠ *Let;*

$T(i)$ *be Initial temperature at cycle i.*

$\Delta T(i)$ *be Rate of Temperate drop (Random)*

The system evolves by;

$$T(i+1) = Ti - T\Delta i, \text{ where } \Delta T(i) \in [0.1,\ 0.6]$$

$\forall i \in [1,\ 6000]$.

Proposed Hardware Implementation:-

- ★ *Use a DHT12/DHT22 Sensor.*
- ★ *Simulate Ambient Cooling using Controlled Airflow*
- ★ *Trigger Fallback Buzzer + LED+ log top SD Card*

Deep Space orbit Conditions:- In Interplanetary or lagrange-point Environment, Spacecraft may pass through Extremely Cold Regions due to;

- ★ *Lack of Incidents Solar Radiations*
- ★ *Orbital Night Spans (Jupiter & Saturn Moon's)*
- ★ *Eclipse Alignment*
- ★ *Debris Shadow Clouds (e.g., MMOD field)*

Space ambient Temperature = ~2.7K (Cosmic Background)

Mathematical Modeling (Extended):- Let;

- ★ T_i *= Internal Temperature at Cycle i*
- ★ ΔT *= Heat Loss per Cycle*
- ★ R_C *= Radiative capacity(Based on Emissivity, Area)*

★ Q_i = Internal heat Generation (usually Zero post failure)

We Define;

$$T_{i+1} = T_i - T\Delta_i = T_i - (\epsilon * \sigma * A * (T_i^4 - T_{ext}^4) / C_{node})$$

Where.,

ϵ = Emissivity of Outer Layer

σ = Stefan- Boltzmann Constant

A = Surface Area of Node

C_{node} = Thermal capacity of Node

T_{ext} = External Space temperature (~3K)

Material Science & Design Impact:- Nodes Constructed with Carbon-based skin layer or Multi layer Insulation (MLI) show better Delay Against Rapid Drops. But a puncture/ Damaged Thermal Shell (via MMOD) accelerates Temperature Loss.

Material	Emissivity	Cooling Resistance
Carbon Fibre (Coated)	~0.85	High
Titanium Alloy	~0.55	Medium
Bare Aluminium	~0.07	Very Low

Node_ 000001 Requires MLI Shielding for ≥30 Minutes Survival Under Blackout.

Thermal Fallback AI Architecture:-

Layers	*Trigger Temperature*	*Response*
Warning	< 5℃	*Log Only*
Critical	< 0℃	*Isolate Non-essential SubSystem*
Fatal	< -5℃	*Full fallback (Node enters Hibernations)*