Archimedes / AI infrastructure

An overheating AI data hall, now $227k a year cheaper to run.

A 1.86 MW hall in Ashburn, Virginia ran its cooling flat out and its hottest rack still hit 35.6 °C. Archimedes found why: hot exhaust was looping back into the racks. It fixed the airflow first, then designed two upgrades.

ARCHIMEDES TECHNICAL CASE STUDY

How to interpret this report

Results apply only to the stated geometry, operating conditions, numerical models, and verification record.
They are not product certification, safety approval, or a general claim outside the documented scope.
Limitations and adverse findings are retained because they are part of the engineering result.

REPORT ID
data-centre-cooling

CANONICAL SOURCE
standardphysics.com/archimedes/data-centre-cooling

$227k / year
saved by the full retrofit, 10.9% less electricity for the same computing load

79%
of the savings from the cheap air-side fix, with no new coolers, for under a quarter of the cost

1,460
designs tried by agents on 27 cloud machines in 17 hours

The ask

Use less electricity over a full year of local weather.

Keep every rack under 35 °C, and keep it there if any one cooling unit fails.

What it found

The cooling wasn't weak. The air was going to the wrong places.

Some floor tiles blew backwards and hot exhaust spilled into the rack inlets. Colder water couldn't fix that.

What it did

Contained the hot exhaust, rebalanced the tiles, then turned the water up.

Moving most of the heat to coolers next to the racks let the old units run at about a third of their fan speed and the plant cool with outside air for 4,787 hours a year.

What went wrong

Its first winner couldn't be built.

It assumed the 2008 cooling coils could handle warmer water than they can. Verification caught it, and the second search built that limit into the score.

Two ways to do it.

Cheap

Air-side fix

What changes
air barriers, floor tiles, blanking panels, water and fan settings

Savings
79% of the full retrofit's

Cost vs full retrofit
under a quarter

Most savings

Full retrofit

What changes
adds 20 in-row and 40 rear-door coolers

Savings
$227k a year

Cost vs air-side fix
about 4.5x

For engineers

The full record, unedited.

Interactive comparison `explore the measured results —`

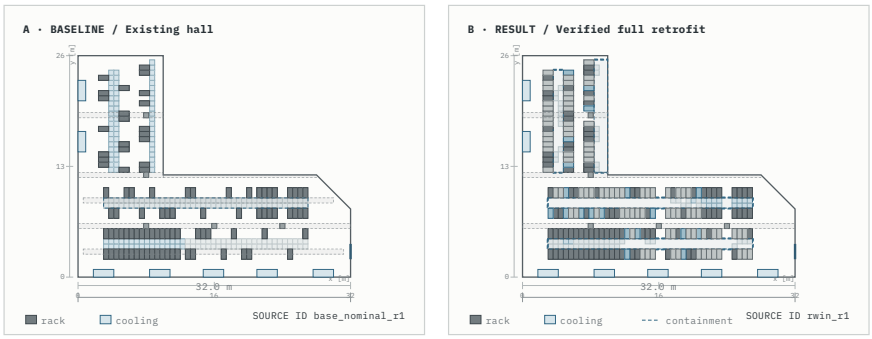
MEASURED COMPARISON

One airflow diagnosis, two buildable retrofit tiers

Select a tier to compare annual and thermal results. The plate uses the exact baseline and verified full-retrofit room records; the low-cost tier remains in the measured plot because its compact geometry export is not shown.

RECORDED GEOMETRY COMPARISON

FIXED PROJECTION · COMMON SCALE



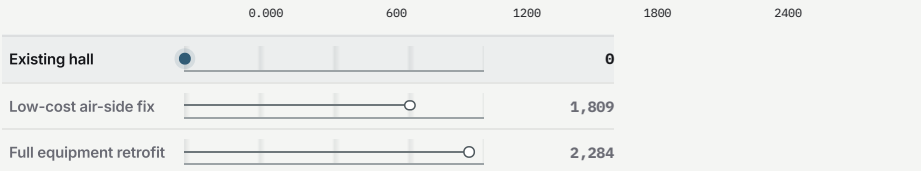
CFD room-model plan. 32.0 m hall extent. Geometry is reconstructed from the recorded campaign artifacts.

Geometry only. No inferred streamlines, pressure field, or unrecorded physical detail is shown.

A source: results/evolve/dc3-foam-7h/verify/base_nominal_r1/room.json · base_nominal_r1 · Exact recorded CFD room-model boxes and floor outline; not a BIM model.
B source: results/evolve/dc3-foam-7h/verify/rwin_r1/room.json · rwin_r1 · Exact recorded retrofit room-model boxes, containment, tiles, and cooling units.

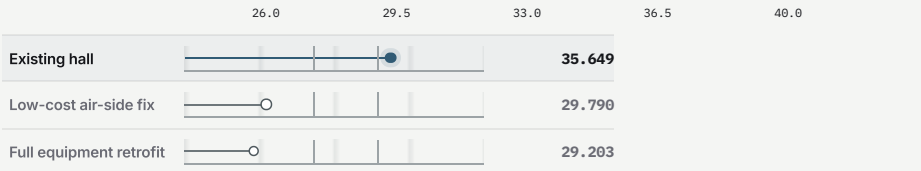
ANNUAL ELECTRICITY SAVED · MWH PER YEAR

HIGHER IS BETTER →



HOTTEST RACK INLET · °C

← LOWER IS BETTER · A1 32 · BRIEF 35



OVERCOOLED AND STILL OVERHEATING

Existing hall

Uncontained exhaust loops back into rack inlets while uneven plenum pressure reverses flow through 32 tiles on the recorded coarse mesh.

PUE 1.279, hottest inlet 35.65 °C

- 1,506 free-cooling hours
- 100% CRAH fan speed
- 39.739 °C worst across five recorded base_hold failures

EXISTING COILS RETAINED

Low-cost air-side fix

Containment, blanking panels, and demand-matched tiles stop hot-

Temperature values are the finest recorded nominal room solves. Thresholds mark the ASHRAE A1 allowable maximum and the separate brief cap.

Numerical basis: 3D buoyant RANS CFD on 4 meshes (92k to 1.1M cells) + 8,760-hour TMY3 plant model + 10 selected equipment-failure cases

air recirculation before the plant setpoints move.

PUE 1.168, 1,809 MWh per year saved

- 3,069 free-cooling hours
- 151 targeted tiles and 108 blanked positions
- 12.9 °C chilled water

BEST ANNUAL ENERGY RESULT

Full equipment retrofit

Twenty in-row coolers and forty rear-door exchangers capture heat near the rack, unloading the legacy coils enough to use 19.6 °C chilled water.

PUE 1.139, 2,284 MWh per year saved

- 4,787 free-cooling hours
- 29.2 °C hottest inlet
- 10 selected failures at or below 29.1 °C

Recorded retrofit comparison

Annual plant results and the finest recorded nominal room solves. Failure coverage is the tested set, not every plant component.

Tier	PUE	Saved	Hottest inlet	Free cooling	Chilled water	Scope
Existing hall	1.279	0 MWh/yr	35.649 C	1,506 h	7 C	100% CRAH fans
Air-side fix	1.168	1,809 MWh/yr	29.790 C	3,069 h	12.9 C	58 cost units
Full retrofit	1.139	2,284 MWh/yr	29.203 C	4,787 h	19.6 C	258 cost units

What the verification actually covered

The first warm-water winner was rejected because the installed 2008 coils could not support it.

Check	Record	Limit
Room meshes	92k, 290k, 640k, and 1.10M cells	Finest full-retrofit energy imbalance 2.681%
Nominal inlet	Full retrofit 29.203 C	Brief cap 35 C; ASHRAE A1 allowable 32 C
Selected failures	7 CRAHs and 3 in-row coolers	Hottest tested inlet 29.056 C
Not simulated	CDU, pump, dry cooler, rear-door failures	Not a complete N+1 claim

Applicability

The result is a room-and-plant retrofit study for this 1.86 MW hall. It is not a certification of an arbitrary data centre, and the failure matrix covers only the ten tested units.

References and source records

ASHRAE Thermal Guidelines for Data Processing Environments, Class A1 allowable and recommended ranges.
Recorded campaign verification summary for the Hybrid Retrofit Hall, including the four-mesh room solves and selected failure set.
Dulles TMY3 weather used by the 8,760-hour plant model.

The exact brief as given to the agents

Retrofit the 1.86 MW Hybrid AI Data Hall (96 racks across legacy rows, network racks, and a 73 kW/rack liquid-cooled AI pod; 7 perimeter CRAHs on a 0.6 m raised floor in Ashburn, VA). Minimize annual facility electricity (PUE across all 8,760 hours of Dulles TMY3 weather) while keeping every rack inlet <= 35 °C (ASHRAE A1/class limits), AI liquid supply <= 40 °C, and surviving any single cooling-unit N+1 failure.

ARCHIMEDES
17 h (7 h search + 10 h robust + 72 verification solves)

COMPUTE RECORD
1,087 first-search + 373 robust designs · 72 verification solves · ~$290 model spend

Decision log how the agents reasoned, step by step

REASONING TRACE

What changed, and why

The decisive move was sequencing. Archimedes fixed the airflow first, audited the coil physics second, then searched only the retrofit space the installed equipment could actually support.

PHASE 1 · DIAGNOSING THE PARADOX IN 3D CFD

Why 7 °C chilled water and 100% fans still left racks overheating at 35.65 °C

OBSERVED	INFERRED	CHANGED AND MEASURED
In the recorded coarse baseline solve, under-floor pressure variations caused 32 perforated tiles to flow backward while uncontained exhaust recirculated into rack inlets.	Raising chilled-water or supply-air temperature before fixing recirculation would immediately push racks past 35 °C. The air side must be sealed and balanced first so rack inlets track the supply air temperature.	Extended containment to 93.2 m and searched tile and blanking layouts that sent supply air to the loaded rows before changing plant temperatures.

PHASE 2 · FIRST SEARCH (1,087 DESIGNS) & THE COIL AUDIT

Catching the hidden 2008 CRAH coil UA bottleneck

during verification

OBSERVED	INFERRED	CHANGED AND MEASURED
The first search reached an apparent PUE of 1.1165, but post-search verification rejected its 95% liquid-fraction assumption and 23 °C chilled-water request against the installed 2008 CRAH coil model.	The room-air duty exceeded what the existing coils could transfer at that water temperature, so the warm-water result was not buildable.	Created the low-cost air-side option at 65% fans, 12.9 °C chilled water, PUE 1.1678, and 1,808.8 MWh/year saved, then embedded the coil screen in a second 10-hour search.

PHASE 3 · ROBUST SEARCH (373 DESIGNS) + 72 VERIFICATION SOLVES

Offloading the legacy coils to unlock 19.6 °C water and 4,787 free-cooling hours

OBSERVED	INFERRED	CHANGED AND MEASURED
With the 2008 CRAH coil	Twenty in-row coolers and	Unlocked 4,787 hours/year

curve enforced inside the score, raising chilled-water temperature required taking most of the room-air load off the perimeter CRAHs.	forty rear-door exchangers capture about 70% of the room-air heat near the racks. The legacy CRAHs can then operate at 30-38% fan speed with 19.6 °C usable chilled water.	of full waterside free cooling, cutting annual PUE to 1.1386 and saving 2,284.4 MWh/year while the hottest tested rack stayed at or below 29.203 °C nominal and 29.056 °C in the selected failure set.

Engineering finding
headline numbers and the mechanism

More compute without normalizing wasted cooling

This is a practical path for operators who need more rack density and less energy use without replacing an entire hall. It turns a hidden airflow problem into two costed engineering choices.

1.279 -> 1.139

annual PUE (-10.9% facility electricity): 2,284 MWh/yr saved (~$227k/yr at Virginia commercial rates) at identical 1.86 MW IT load

3D CFD on 4 meshes + 8,760 h Dulles TMY3 model

35.6 -> 29.2 °C

hottest rack inlet on the 1.1M-cell mesh, bringing an overheated hall back inside ASHRAE A1 while raising supply air from 21.7 to 27 °C

4-level mesh convergence up to 1.10M cells

<= 29.1 °C

hottest rack inlet across the 10 tested failures (7 CRAHs + 3 selected in-row coolers); CDU, pump, dry-cooler, and rear-door failures were not simulated

Selected equipment-failure CFD matrix

Why the mechanism works

Archimedes solved the airflow before changing the plant: 93.2 m of containment, demand-matched tiles, and verified blanking layouts reduced recirculation. After coil verification rejected the first warm-water winner, the robust search offloaded about 70% of room-air heat onto 20 in-row coolers and 40 rear-door exchangers, allowing 30-38% CRAH fan operation, 19.6 °C usable chilled water, and 4,787 free-cooling hours per year.

What the baseline got wrong

Why was a hall running 7 °C chilled water and 100% fan speed still overheating? The baseline CFD showed severe supply maldistribution, including 32 reversed tiles on the recorded coarse mesh, while uncontained exhaust spilled into rack inlets. The building's 2008 CRAH coils also lacked the heat-transfer area to support the first search winner's warm-water setpoint.

Full technical record
appendices, families and limits

CAMPAIGN RECORD AND LIMITATIONS

Appendix

The detailed brief, decision record, search families, solver basis, and verification checks are exposed below without tabs or collapsed panels.

Appendix A: Frozen brief and campaign scale

Retrofit the 1.86 MW Hybrid AI Data Hall (96 racks across legacy rows, network racks, and a 73 kW/rack liquid-cooled AI pod; 7 perimeter CRAHs on a 0.6 m raised floor in Ashburn, VA). Minimize annual facility electricity (PUE across all 8,760 hours of Dulles TMY3 weather) while keeping every rack inlet <= 35 °C (ASHRAE A1/class limits), AI liquid supply <= 40 °C, and surviving any single cooling-unit N+1 failure.

Search duration 17 h (7 h + 10 h robust)	**Evaluations** 1,460 designs + 72 verification solves
Compute fleet 27 cloud machines	**Solver basis** 3D buoyant RANS CFD on 4 meshes (92k to 1.1M cells) + 8,760-hour TMY3 plant model + 10 selected equipment-failure cases

Appendix B: Full decision log

01 Hour 00:00 - 02:00 · Phase 1 · Diagnosing the Paradox in 3D CFD

Why 7 °C chilled water and 100% fans still left racks overheating at 35.65 °C

OBSERVATION

In the recorded coarse baseline solve, under-floor pressure variations caused 32 perforated tiles to flow backward while uncontained exhaust recirculated into rack inlets.

REASONING

Raising chilled-water or supply-air temperature before fixing recirculation would immediately push racks past 35 °C. The air side must be sealed and balanced first so rack inlets track the supply air temperature.

ACTION AND RESULT

Extended containment to 93.2 m and searched tile and blanking layouts that sent supply air to the loaded rows before changing plant temperatures.

02 Hour 02:00 - 07:00 · Phase 2 · First Search (1,087 Designs) & The Coil Audit

Catching the hidden 2008 CRAH coil UA bottleneck during verification

OBSERVATION

The first search reached an apparent PUE of 1.1165, but post-search verification rejected its 95% liquid-fraction assumption and 23 °C chilled-water request against the installed 2008 CRAH coil model.

REASONING

The room-air duty exceeded what the existing coils could transfer at that water temperature, so the warm-water result was not buildable.

ACTION AND RESULT

Created the low-cost air-side option at 65% fans, 12.9 °C chilled water, PUE 1.1678, and 1,808.8 MWh/year saved, then embedded the coil screen in a second 10-hour search.

03 Hour 07:00 - 17:00 · Phase 3 · Robust Search (373 Designs) + 72 Verification Solves

Offloading the legacy coils to unlock 19.6 °C water and 4,787 free-cooling hours

OBSERVATION

With the 2008 CRAH coil curve enforced inside the score, raising chilled-water temperature required taking most of the room-air load off the perimeter CRAHs.

REASONING

Twenty in-row coolers and forty rear-door exchangers capture about 70% of the room-air heat near the racks. The legacy CRAHs can then operate at 30-38% fan speed with 19.6 °C usable chilled water.

ACTION AND RESULT

Unlocked 4,787 hours/year of full waterside free cooling, cutting annual PUE to 1.1386 and saving 2,284.4 MWh/year while the hottest tested rack stayed at or below 29.203 °C nominal and 29.056 °C in the selected failure set.

Appendix C: Search families

2 engineered retrofit tiers. These are distinct programs or engineering configurations, not cosmetic renders.

Full equipment retrofit: 93.2 m containment + 20 in-row coolers + 40 rear-door exchangers + 88 blanked positions (PUE 1.1386, -2,284 MWh/yr)

Low-cost air-side fix: 151 targeted tiles + 93.2 m containment + 108 blanked positions + 12.9 °C CHW (PUE 1.1678, -1,809 MWh/yr)

Unscreened warm-water search family (caught and corrected by the existing 2008 CRAH coil UA verification screen)

Appendix D: Numerical basis and verification

3D buoyant RANS CFD on 4 meshes (92k to 1.1M cells) + 8,760-hour TMY3 plant model + 10 selected equipment-failure cases

Re-solved across four systematically refined 3D meshes (92k, 290k, 640k, and 1.10M hex cells); the finest full-retrofit energy imbalance is 2.681%, inside the 3% gate.

Tested seven CRAH and three selected in-row-cooler failures, 10-25% AI pod residual-air sensitivity, and an open maintenance door. This is not a complete facility N+1 matrix.

Delivers two actionable engineering packages: the full equipment retrofit (-2,284 MWh/yr, 258 cost units) and an air-side-only rework that captures 79% of the energy savings (-1,809 MWh/yr) for under a quarter of the cost (58 units).

Appendix E: Reported outcomes and limits

`1.279 -> 1.139` annual PUE (-10.9% facility electricity): 2,284 MWh/yr saved (~$227k/yr at Virginia commercial rates) at identical 1.86 MW IT load Basis: 3D CFD on 4 meshes + 8,760 h Dulles TMY3 model.	**`35.6 -> 29.2 °C`** hottest rack inlet on the 1.1M-cell mesh, bringing an overheated hall back inside ASHRAE A1 while raising supply air from 21.7 to 27 °C Basis: 4-level mesh convergence up to 1.10M cells.
`<= 29.1 °C` hottest rack inlet across the 10 tested failures (7 CRAHs + 3 selected in-row coolers); CDU, pump, dry-cooler, and rear-door failures were not simulated Basis: Selected equipment-failure CFD matrix.	

Explicit limitations

The failure matrix covers seven CRAHs and three selected in-row units, not every CDU, pump, dry cooler, or rear-door exchanger.

ASHRAE A1 allowable maximum is 32 °C; the brief's 35 °C value is a separate hard cap.

The ~$290 figure is recorded model spend only, not total cloud or project cost.

Recorded Archimedes run: 17 h (7 h search + 10 h robust + 72 verification solves). Compute record: 1,087 first-search + 373 robust designs · 72 verification solves · ~$290 model spend.