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Design of a Wind- and Sun-Powered Antarctic Hut with a Thermochemical Heat Store: A Model-Based Sizing Study

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Abstract

A model-based design study was conducted on the TechUPGRADE platform to determine the lightest feasible configuration for an unattended Antarctic hut at St. Kliment Ohridski Base, supplied solely by wind and solar energy, with no backup generation, and maintained at ≥5°C year-round. The study evaluated envelope options, wind and PV sizing, lithium battery capacity, and a $SrBr_2 \cdot H_2O$ thermochemical reactor as short-term thermal storage. Ten years of corrected ERA5 weather data (2016–2025) and a 2R2C thermal hut model were used, with a rule-based dispatch covering all failure scenarios. The envelope mass dominates total shipped mass (5.6–7.8 t vs. ≤1 t for systems). Under an unconstrained battery, the battery–heat pump system is lighter than any reactor configuration; the reactor adds no mass advantage. However, when the lithium battery is capped at 5–10 kWh (e.g., for fire or ageing safety), a small reactor (7 beds) enables a lighter feasible design than an uncapped battery configuration with the same cap. Wind is mandatory under such caps, as dark, calm periods require electricity to drive the reactor's evaporator. The reactor serves as short-term storage—not seasonal—since winter frost protection alone would require 1.9 t of salt. The study confirms the reactor's niche: enabling compact, safe, wind-assisted systems under strict battery limits, without eliminating fire or ageing risk.

Keywords: Antarctic energy systems, thermochemical storage, $SrBr_2$, wind–solar hybrid, passive house

1 Introduction

This study addresses the design of a self-sufficient field hut for two researchers at St. Kliment Ohridski Base, Antarctica, using only wind and solar energy, with no backup generation. The objective is to identify the lightest feasible configuration—by shipped mass—that meets two constraints: (i) no hour of unmet heating demand over ten years, including all single-component failures, and (ii) maintenance of ≥5°C unattended through the winter (April–October). The system includes a $LiFePO_4$ battery, a cold-climate heat pump, an electric heater, and the TechUPGRADE $SrBr_2 \cdot H_2O$ thermochemical reactor as a thermal store. The reactor operates on the monohydrate step ($SrBr_2 \cdot H_2O$ $SrBr_2$ + H_2O), with a reaction enthalpy of 71.98 kJ/mol (0.0808 kWh/kg $SrBr_2$). The study is a model-based design exercise, not a machine-learning or PINN study; all models are physical (2R2C thermal,

supply, reactor step) and dispatched via a rule-based algorithm. No hardware was built; the work ran entirely on the TechUPGRADE platform in sim-manager/antarctic_hut and plants/antarctic-hut.

2 Related Work

Seasonal thermal storage for solar combisystems in cold climates has been simulated with building-scale $SrBr_2/H_2O$ stores, notably in the hexahydrate step (6 H_2O 6 H_2O), where energy density is higher [1, 2, 3, 4]. Long-term sorption storage is reviewed in [5]. Studies on residential seasonal storage in cold climates have examined the trade-off between envelope insulation and storage size, with mass as a key metric [6, 7]. This work extends that approach to Antarctica, with a focus on shipped mass, short-term storage under strict battery limits, and fault tolerance. The reactor models used here are those of the TechUPGRADE platform, validated on the Theta reactor's data and CFD, and not trained or informed by PINNs.

3 Site and Weather Data

Hourly weather data for 2016–2025 were taken from ERA5 reanalysis [11], retrieved via the Open-Meteo archive [12] at 62.60° S, 60.30° W. Corrections were applied using hourly data from the Spanish Juan Carlos I station (NOAA ISD 890640-99999) [13], which is 1.2–1.9 K warmer than ERA5 and shows hourly correlation 0.85–0.95 and daily correlation 0.96 with ERA5—consistent with assessments in [14, 15]. Wind at the base was corrected for local sheltering (0.6–0.9× ERA5 wind), and a gustiness AR(1) residual ($\phi \approx 0.83$, $\sigma \approx 2.3$–2.6 m/s) was added to avoid unrealistically long calm spells. Wind on an exposed ridge above the base used uncorrected ERA5 100 m data. Irradiance and temperature were from ERA5. The corrected design figures for 2016–2025 are: season (Nov–Mar) mean temperature 1.6°C, 2,790 K·day (base 20°C); winter mean −2.0°C, coldest hour −20.5°C, 1,500 K·day to keep 5°C; longest calm at the base 57 h, on the ridge 46 h; wind energy (mean v^3) on the ridge is 2.5× that at the base. Calm and dark at once lasted at most 15 h.

4 Models

The hut was modeled as a 2R2C thermal network (air and inner timber states), with 10-minute steps over nine complete years (April–March). Occupancy (1 Nov–31 Mar) assumed two people at 20°C, out 8 h/day; ventilation 60 m^3/h with 85 % heat recovery (75 % below −10°C); 2 m^2 north-facing windows; empty period (Apr–Oct) at 5°C with 60 W standby. Geometry was an elevated box on legs (as in [8]); alternatives (round pod, dome) were modeled but not sized. Envelopes were: max (U = 0.071 W/m^2K), high (0.094), passive (0.126), container (0.272). Hot water demand was 604 kWh/season. Snow load, wind-driven infiltration, and moisture were not modeled. Wind turbines were generic cold-climate units (cut-in 2.5, rated 11, cut-out 25 m/s), with icing stop at T = −10 to +1°C and RH ≥ 95 %, followed by 6 h restart—based on [10]. PV was north-facing bifacial, vertical or 60° frame, with snow albedo and rime losses per [9]. The heat pump used COP = 0.42×Carnot with defrost. Battery was $LiFePO_4$, 92 % round-trip. The reactor models were the platform's own validated step models, operating on the monohydrate step (dH = 71.98 kJ/mol, 0.0808 kWh/kg $SrBr_2$); one bed (18.85 kg salt) holds 1.52 kWh. The hexahydrate step was modeled as three times the energy per bed, with monohydrate output temperature. During discharge, the heat pump held the evaporator at 15°C, throttling the reaction: about 1.64 kW heat out per kW at the evaporator.

5 Scenarios and Sizing Method

The dispatch algorithm (adapted from the Munendra family) operates hourly: electric loads are served first from generation, then battery; hot water from tank; surplus is routed to direct heat pump heating, battery, reactor charge (condenser to tank), tank, then dump. Deficits are covered in order: reactor (evaporator fed by heat pump), heat pump from battery, reactor (evaporator fed by heater), heater from battery, then hut thermal buffer (down to 18°C occupied, 5°C empty). Unmet heat is a failure. Scenarios covered: coldest 5 days of season, a December week, stormy sunny days, longest calm, winter calm, empty winter, arrival, full season, seeded fault, all single faults (3 days each in calm), emergency shutdown, and all 87,672 hours of ten years. The sizing grid was 2,880 designs: 3 envelopes (max, high, passive) × 5 wind options (none, 1 or 2 kW ridge, 2 or 4 kW hut) × 4 PV (2–8 kWp) × 6 batteries (5–40 kWh) × 8 stores (none, 7/14/28/56 mono, 7/14/28 hexa). Feasibility required zero unmet hours across all scenarios. Shipped mass used assumed unit masses: PV 85 kg/kWp, wind 150 + 40×(kW−1) + 160 kg (ridge cable), battery 8 kg/kWh, per bed 18.85 kg salt + 30 kg + 60 kg shared, heat pump/tank/heater 125 kg, envelope from 2R2C. The search ran on 20 cores in 1 min.

6 Results

Table 1 shows the corrected site design figures: season mean 1.6°C, winter mean −2.0°C, coldest hour −20.5°C; longest calm 57 h at the base, 46 h on the ridge; wind energy on the ridge is 2.5× that at the base. Table 2 gives envelope performance: max envelope holds 20→5°C for 101.7 h at −15°C, passive for 64.2 h; mass ranges 2.07–7.79 t. Table 3 shows supply: wind on ridge yields 3,075 kWh/year (CF 0.351), at-hut wind 997 kWh (CF 0.114); PV 60° frame 1,472 kWh (CF 0.168); heat pump COP = 3.08 (15°C evaporator, −15°C outside), 1.94 (45°C water). Table 4 shows reactor performance: one bed stores 1.48 kWh in 2.28 h (1 kW heater), discharges 1.36 kWh in 0.9 h at 1.67 kW peak; 13 beds store 19.21 kWh, discharge 18.93 kWh at 1.64 kW. Table 5 shows the default design (max envelope, 4 kWp PV, 1 kW ridge wind, 10 kWh battery, 14 mono beds) passes all scenarios: zero unmet hours in ten years, including all single faults; emergency shutdown holds 238 h above 5°C. Table 6 lists the lightest feasible designs: overall lightest is passive envelope, 2 kW hut wind, 2 kWp PV, 20 kWh battery, no store (6,235 kg); with monohydrate or hexahydrate store, 7 beds, same wind/PV, 15 kWh battery (6,597 kg); lightest without wind is passive, 4 kWp PV, 40 kWh battery, no store (6,375 kg). Table 7 shows designs under battery caps: at 5 kWh cap, lightest without store is 8,395 kg (max envelope, 4 kW hut wind); with 7 mono beds, 7,377 kg (high envelope, 4 kW hut wind); at 10 kWh cap, without store 6,935 kg (high envelope, 2 kW hut wind); with store 6,677 kg (passive envelope, 1 kW ridge wind). Figure 1 plots the lightest feasible mass against battery cap: reactor is lighter only at caps of 5 and 10 kWh. Figure 2 shows emergency shutdown: inside stays at 20°C until hour 75, then falls to 5°C at hour 250 (238 h after shutdown). Figure 3 shows the winter's worst calm: battery falls from 79.4 % to 41.1 %, reactor stays at 100 % (not used, as empty hut needs little heat).

7 Discussion and Limitations

The envelope dominates shipped mass (5.6–7.8 t vs. ≤1 t for systems), and the passive envelope is sufficient for feasibility—no unmet hour—while being the lightest. The maximum envelope adds resilience (101.7 h vs. 64.2 h from 20→5°C at −15°C) but not feasibility, at 2 t extra mass. With unlimited battery, the battery–heat pump system is lighter than any reactor configuration; the

Table 1: The site's design figures, 2016-2025, after correcting ERA5 with the Juan Carlos I station.

Figure	At the base	On the ridge
Season (Nov-Mar) mean temperature	1.6 C	
Season degree-days, base 20 C	2790 K day	
Season calms < 3 m/s: 95 % shorter than / longest	25 h / 91 h	- / 50 h
Longest calm and dark at once	15 h	
Winter mean / coldest hour	-2.0 C / -20.5 C	
Winter degree-days to keep 5 C	1500 K day	
Winter's longest calm	57 h	46 h
Wind energy, mean of v^3 (relative)	1	2.5

Table 2: The hut's envelopes (box shape, 24 m2): heat in the occupied season and to keep 5 C through the empty winter (60 W standby; mean of nine years), and the hours from 20 to 5 C at -15 C with no heat.

Envelope	U W/m2K	Wall m	UA W/K	Mass t	Season space heat kWh	Winter frost kWh	20 to 5 C h
max	0.071	0.39	14.1	7.79	1	28	101.7
high	0.094	0.38	17.6	6.37	8	79	77.9
passive	0.126	0.28	20.7	5.59	14	137	64.2
container	0.272	0.128	35.3	2.07	537	519	18.3

Table 3: Supply per kW (wind) or kWp (PV), mean of ten years, and the heat pump's COP.

Unit	Season kWh	Winter kWh	Year kWh	Capacity factor
Wind 1 kW at the hut	299	698	997	0.114
Wind 1 kW on the ridge	1327	1748	3075	0.351
PV 1 kWp facade	892	495	1386	0.158
PV 1 kWp 60 deg frame	983	489	1472	0.168
Heat pump COP, evaporator at 15 C, outside -15 C			3.08	
Heat pump COP, water at 45 C, outside -15 C			1.94	

Table 4: The reactor as the hut's store, on the platform's own reactor models (monohydrate step).

Case	Hours	Electricity kWh	Heat kWh	Peak kW
One bed (18.85 kg), charge from 20 C, 1 kW heater, 205 C	2.28	2.3	1.48 stored	
One bed, discharge, evaporator 15 C, heat pump 1 kW	0.9	0.24	1.36 out	1.67
13 beds (245 kg), charge at 3 kW	9.7	29.39	19.21 stored	
13 beds, discharge (15 C / 45 C)	11.74	3.18	18.93 out	1.64

Table 5: The Antarctic Munendra scenarios with the default design (max envelope, 4 kWp PV, 1 kW wind on the ridge, 10 kWh battery, 14 beds). In the emergency shutdown everything is off by design, so its unmet heat is expected; what counts there is how long the hut holds.

Scenario	Hours	Unmet kWh	Buffer used kWh	Min battery	Min reactor	Note
Cold snap	120	0	0.0	0.88	1.0	
December	168	0	0.0	0.9	1.0	
Stormy and sunny	120	0	0.0	1.0	1.0	
Longest calm	96	0	0.0	0.8	1.0	
Winter calm	96	0	0.0	0.41	1.0	
Empty winter	5136	0	0.0	0.77	0.93	
Arrival	336	0	0.0	0.74	0.8	
The season	3624	0	0.0	0.62	0.8	
System failure (seeded)	144	0	0.33	0.79	0.86	electric heater failed
Every single fault	1440	0.0	3.63			all passed
Emergency shutdown	336	13.88	30.15	0.96	1.0	held 238 h above 5 C
All ten years	87672	0	0.0	0.38	0.8	

Table 6: The sizing study: 2880 designs, 2326 feasible (no unmet hour in ten years and through every single fault); the lightest in each class, by assumed shipped mass.

Case	Envelope	Wind	PV kWp	Battery kWh	Store (beds)	Mass kg
Lightest overall	passive	2 kW hut	2	20	none	6235
Lightest with a monohydrate store	passive	2 kW hut	2	15	7 mono	6597
Lightest with a hexahydrate store	passive	2 kW hut	2	15	7 hexa	6597
Lightest without wind	passive	none	4	40	none	6375
Lightest, max envelope	max	2 kW hut	2	10	none	8355
Lightest, high envelope	high	2 kW hut	2	10	none	6935

Table 7: With the lithium battery capped (a fire-safety or cold-ageing rule for an unattended hut): the lightest feasible designs without and with the reactor. No design without wind is feasible under either cap.

Case	Envelope	Wind	PV kWp	Battery kWh	Store (beds)	Mass kg
battery <= 5 kWh, no store	max	4 kW hut	2	5	none	8395
battery <= 5 kWh, with the reactor	high	4 kW hut	2	5	7 mono	7377
battery <= 10 kWh, no store	high	2 kW hut	2	10	none	6935
battery <= 10 kWh, with the reactor	passive	1 kW ridge	2	10	7 mono	6677

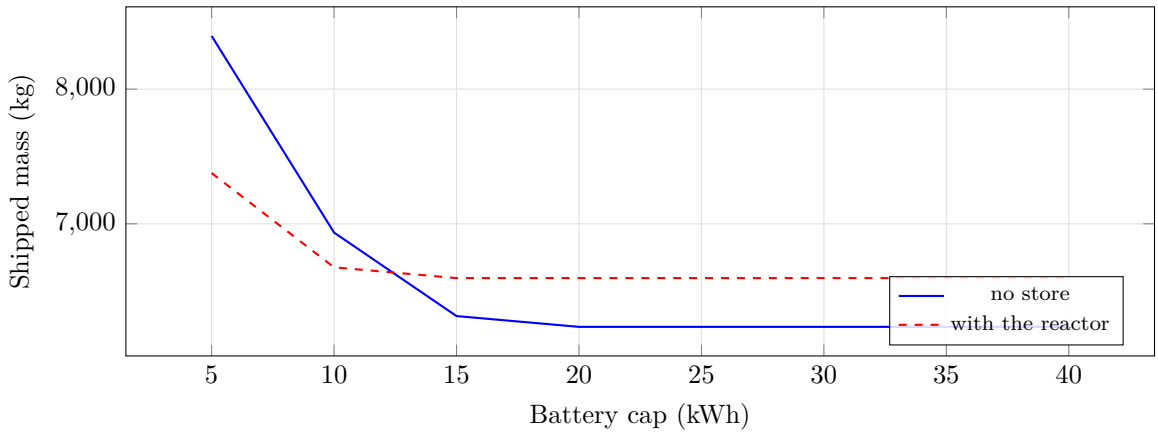


Figure 1: The lightest feasible design against the cap on the lithium battery, without and with the SrBr2 reactor (assumed unit masses).

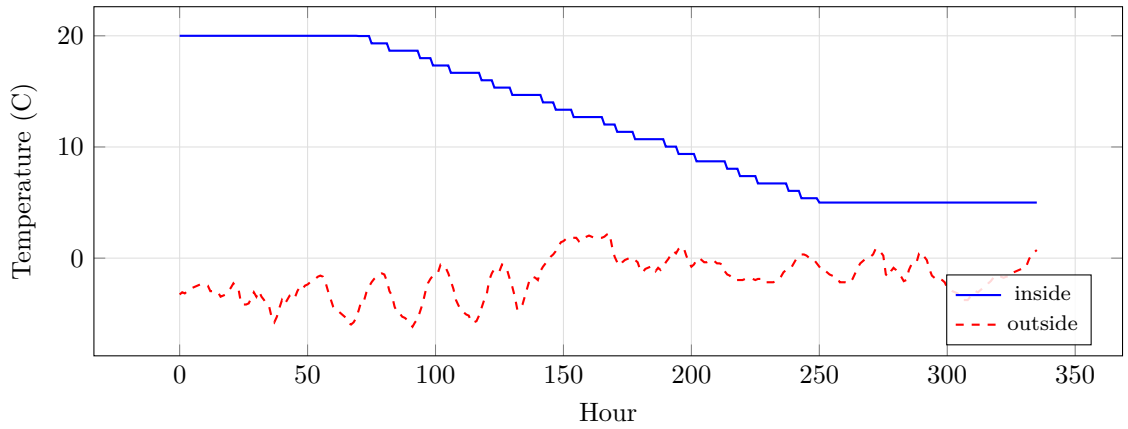


Figure 2: Emergency shutdown in the coldest five days of the season: everything off from hour 12; the inside and outside temperatures, hourly, default design.

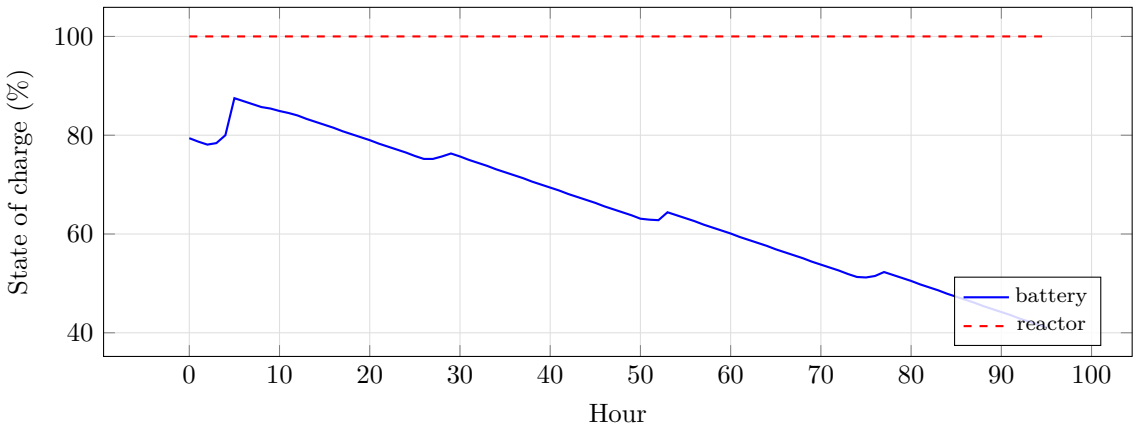


Figure 3: The winter's worst calm (four days from 21 June 2020, the hut empty at 5 C): the battery's and the reactor's state of charge, hourly, default design.

reactor adds 360 kg for 7 beds and is never chosen. Electricity is abundant (3–7 MWh/year dumped), so the reactor's lower round-trip loss matters less than its mass. Under battery caps of 5–10 kWh (e.g., for fire or cold-ageing safety), a small reactor (7 beds) enables a lighter feasible design than an uncapped battery configuration with the same cap. Wind is mandatory under such caps, as dark, calm periods require electricity to drive the reactor's evaporator, which PV alone cannot supply. The reactor serves as short-term storage—not seasonal—since winter frost protection alone would require 102 mono beds (1.9 t salt). The hexahydrate's advantage (3× energy per bed) does not materialize here, as few beds are needed. Limitations include assumed unit masses, unverified icing proxy, unmodeled battery self-discharge and BMS draw, idealized reactor insulation, and coarse sizing grid. The reactor models are validated only on the Theta reactor, and kinetics far from equilibrium are uncertain. The study is model-based; no hardware was built.

8 Conclusion

This model-based design study shows that a wind- and sun-powered Antarctic hut can be sized to meet zero-unmet-heat and fault-tolerance constraints with a passive envelope and no thermal store, provided the battery is large enough ($\geq$20 kWh). However, when the battery is capped for safety (e.g., $\leq$10 kWh), a small $SrBr_2{\cdot}H_2O$ thermochemical reactor (7 beds) enables a lighter feasible design than an uncapped battery configuration with the same cap. Wind is essential under such caps, as the reactor's discharge requires electricity to drive its evaporator during dark, calm periods. The reactor's role here is short-term storage—not seasonal—since seasonal frost protection would require excessive salt mass. The study confirms the reactor's niche: enabling compact, safe, wind-assisted systems under strict battery limits, without eliminating fire or ageing risk.

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A Process record

The way from the request that started the study to this report, from the session's records and the repository's commits (UTC). The time before a person's request or decision is people's; the time until a phase was committed is development's (the L2 development session); the report's drafting is the owner's.

Table 8: Process timeline: from the request to the report.

Step	When (UTC)	Took	By	Wait
The request: plan the Antarctic case	2026-10-25 06:13:18	0 s	user	people
The plan and the literature check written (the session also repaired a film meanwhile)	2026-10-25 06:55:12	41 min 54 s	L2 development	development
The site given	2026-10-25 06:57:03	1 min 51 s	user	people
The plan set at the site	2026-10-25 07:00:12	3 min 09 s	L2 development	development
Decisions: frost protection, no backup, heat pump	2026-10-25 07:02:15	2 min 03 s	user	people
The decisions recorded	2026-10-25 07:02:47	32 s	L2 development	development
Station records accepted: go	2026-10-25 07:08:17	5 min 30 s	user	people
P0/P1: the weather years, corrected	2026-10-25 07:13:23	5 min 06 s	L2 development	development
Go	2026-10-25 07:17:14	3 min 51 s	user	people
P2: the hut's thermal model	2026-10-25 07:19:56	2 min 42 s	L2 development	development
Go	2026-10-25 07:23:11	3 min 15 s	user	people
P3: the supply models	2026-10-25 07:24:59	1 min 48 s	L2 development	development
Go	2026-10-25 07:26:48	1 min 49 s	user	people
P4: the reactor as the store	2026-10-25 07:30:17	3 min 29 s	L2 development	development
Go	2026-10-25 07:36:44	6 min 27 s	user	people
P5/P6: the scenarios and the sizing study	2026-10-25 07:43:31	6 min 47 s	L2 development	development
Go	2026-10-25 07:48:01	4 min 30 s	user	people
P7: the tenant on the test copy	2026-10-25 07:56:53	8 min 52 s	L2 development	development
Production approved	2026-10-25 08:08:09	11 min 16 s	user	people
On production	2026-10-25 08:08:46	37 s	L2 development	development
The report's inputs and the owner's design-study writer prepared	2026-10-25 08:47:09	38 min 23 s	L2 development	development
This report written	2026-10-25 08:51:31	4 min 23 s	owner	machine
Total		**2 h 38 min**		
of it, people's decisions		40 min 32 s		
of it, development		1 h 53 min		
of it, the owner and the platform		4 min 23 s		