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INTEGRATED DETAILING AND THERMAL OPTIMIZATION IN A TENT-BASED TEXTILE STRUCTURE

THOMAS THOMMEN[*]

[*] Bieri Tenta AG, Grosswangen, Switzerland. E-mail: thomas.thommen@bieri.ch

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Summary. This paper offers a focused insight into an executed tent-based textile system at the Centro Sportivo Tenero, highlighting selected decisions and outcomes rather than providing a full project report. The goal was to achieve summer comfort without mechanical cooling on existing foundations. The method combined integrated detailing across structure and envelope with iterative verification: a 1:1 decision mock-up, geometryFEM predesign with semi-rigid joints, a full-scale portal-frame test for joint parameter calibration, a hall prototype, and in-use monitoring. Structurally, the eaves strut could be eliminated by activating moment resistance at the eaves and ridge; the semi-rigid M–φ behaviour was captured by calibrated nonlinear rotational springs. On the envelope side, a back-ventilated double-layer roof with low-emissivity inner faces was detailed and manufactured under coating-related constraints. Field measurements against a legacy army tent showed markedly lower indoor temperatures in the prototype, with differences up to about 20 K at ridge level and 15 K near the floor, and a substantial reduction of condensation risk. The approach is transferable to tent-based textile applications where comfort, speed of installation and robust detailing are critical. The paper concludes with lessons learned and priorities for further monitoring and standardisation.

1 INTRODUCTION

At the Centro Sportivo Tenero the existing tent infrastructure is being replaced by thirty-five custom units erected on the existing concrete slabs. The camping character is preserved while comfort and quality of stay are substantially raised. The project is governed by the official tender dossier[1;2;3;4;5]. The primary goal is to prevent summer overheating through an envelope-driven solution so that mechanical cooling can be avoided[1].

Clear technical guardrails define the scheme. A two-layer ventilated roof guides air at the eaves and at the ridge and reduces heat gain. Generous openings enable effective cross-ventilation. The inner face of the textile envelope is optimized for thermal performance. The structure is designed to SIA requirements for wind and snow[6]. The safety concept includes a fire detection system, textiles with the specified fire performance class, grounding and lightning protection, and emergency lighting. Operation is defined as three-season use without heating[2;3].

Planning and delivery follow an integrated approach. Execution design, detailing, structural calculations, building physics, and the development of envelope and connection details lie with the contractor under defined review and approval steps. A pilot tent is required as a quality gate before series production, supported by mock-ups and by laboratory and rain tests[4]. The award procedure and submission language are set out in the offer form[5].

This case study documents a tent-based textile system as a whole. It shows how integrated detailing across structure, envelope, fabrication, and assembly couples with a passive thermal strategy, and how in-use performance can be evidenced under real operating conditions.

Figure 1: The original Army tents served as the basis for the design.

2 EARLY DESIGN PHASE

In the early project phase, several construction principles were explored together with the architects and condensed into sketches, option studies, and quick pre-checks. The starting point was a typology inspired by army tents (Fig. 1) that was progressively developed into a project-specific solution. Detailing played a central role from the outset: it served as proof of feasibility and linked form, structure, fabrication, and assembly into a coherent system.

A first approach drew on conventional aluminium tents with standardised profiles and insert pieces (Fig. 2). The primary frame was complemented by modified eave joints to enable inclined wall fields. The outer membrane was conceived as a continuous prefabricated element pulled over the structure so that the profiles remain concealed. An inner liner was hung from tensioned wire ropes, and side openings allowed operable ventilation. Access was organised as a roll-up door with zipper closure. Exterior fabrics considered included cotton blends and PVC/PES textiles[7]. The strength of this approach lies in the availability of proven profiles and detail principles that can be purposefully advanced.

A second line of thought examined a geodesic system along the lines of Zenvision (Fig. 3). It aims at reduced material usage and high-quality steel components with duplex protection. The envelope is conceived as a two-layer system: an outer weather skin and an inner layer that moderates thermal and acoustic conditions. The underside of the outer skin receives a reflective, low-emissivity inner face to noticeably reduce heat ingress. The entrance zone serves as a sheltered storage area, keeping the interior free for sleeping, living, and play[7;8].

In parallel with form finding, the indoor climate was addressed systematically. Natural air movement, a material-based reduction of summer heat build-up, and a low-E inner surface with low emissivity form the core of the strategy. For the outer membrane, a PVC/PES fabric with a PVDF top coat was considered to ensure durable dirt resistance. These technologies are widely proven in textile construction[8].

Functional requirements were specified early and fed back into the concepts: a two-layer, ventilated roof build-up with defined airflow; a coherent ventilation concept; a separated entrance zone; windows with shutters; furnishing with camp bunk beds; a variable partitioning system for zoning; and suitable membrane materials. The sketches show that practice-tested details acted as anchors of feasibility and were not postponed, but integrated from the beginning.

As the design progressed, the architects reworked the appearance fundamentally. The familiar army-tent (Fig. 1) expression was left behind, while viable givens were taken up constructively and developed into a distinctive, identity-forming form (Fig. 4). The early emphasis on detailing shortened later iteration cycles and prepared the ground for subsequent structural, fabrication, and thermal optimisations.

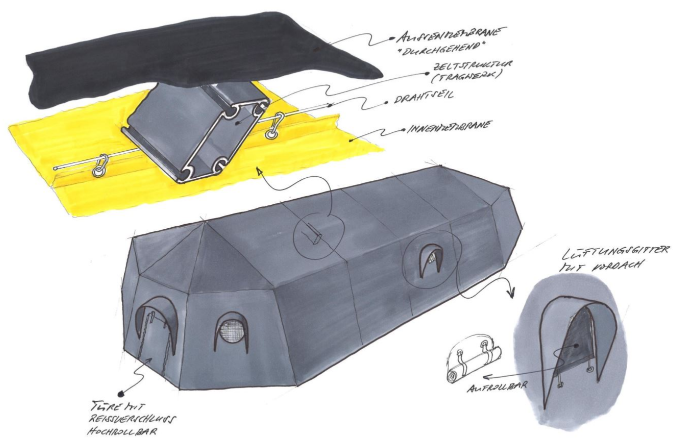


Figure 2: Concept Variant A – Conventional aluminium tent system with modified eave joints, concealed primary frame, and a continuous outer membrane.[7]

3 PROJECT AND SYSTEM OVERVIEW

The architectural design is by Baserga Mozzetti Architetti; the basic technical concept was developed by Patocchi sagl and was further engineered and delivered by Bieri Tenta AG. The starting point is a tent-based textile system that avoids summer overheating through an envelope-led strategy while preserving the camping character[1;2;3].

The primary structure consists of aluminium profiles connected by form-fitting steel inserts. This connection logic enables changes of direction and modular assembly, but introduces connection slip that affects serviceability behaviour. Actions are taken according to SIA 261[6]. The textile envelope is two-layered with defined air paths at the eaves and at the ridge; the outer skin provides weather protection (PVC/PES with PVDF top coat), while the inner visible surface is executed

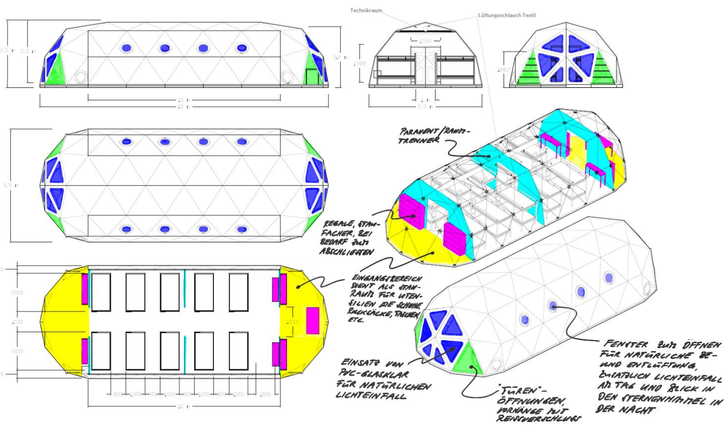


Figure 3: Concept Variant B – Geodesic tent system with a two-layer envelope and a reflective low-E inner surface.[8]

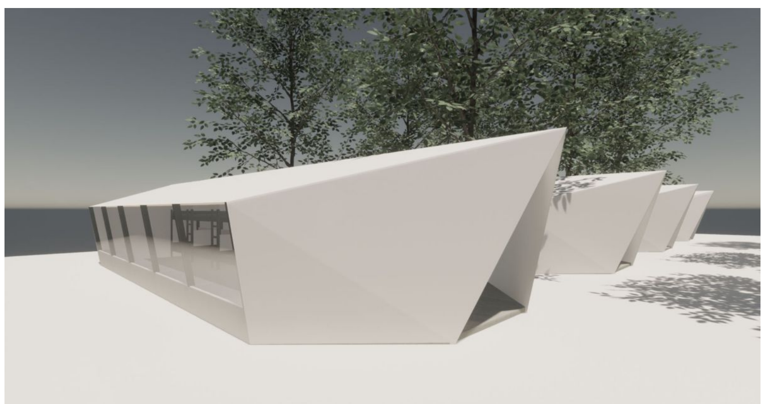


Figure 4: The architects' completely revised design.[1]

with a low-emissivity finish to reduce radiative heat gain. Generous openings enable effective cross-ventilation[3;7;8].

The system idea was developed in an early options phase and calibrated against practice-tested detail principles. Conventional aluminium frame solutions and geodesic systems were examined for feasibility, fabrication and assembly sequencing. The final decision favoured a solution that uses standard profiles while integrating project-specific details (a tensioning system with a ventilated ridge hood, perforated eaves for back-ventilation, and connection details adapted to the envelope)[7;8;1].

Note on execution readiness. The tender documents define the planning baseline and the target configuration, not a fully execution-ready solution[1;3]. At the beginning of the delivery phase, contractor-side variants were adopted, some driven by architectural wishes, others by schedule and assembly constraints. The hall mock-up served as the central decision platform; details were fixed there and aligned with proven execution standards[7;8]. As optimisation progressed, the structural system changed in its serviceability behaviour, which in turn influenced the detailing. Standard

Losberger profiles replaced bespoke aluminium sections; the eaves detail nevertheless required a custom aluminium extrusion to integrate airflow, drainage and the tensioning logic.

4 MOCK-UP AS A DECISION PLATFORM

The mock-up was built as a 1:1 detail model of a tent corner, deliberately chosen so that as many relevant connections and functions as possible meet in a single node (Fig. 5). Its purpose was to provide an early, tangible basis for discussions in the delivery phase: details could be examined on the physical model, variants assessed, and binding decisions made for the subsequent planning process. The mock-up proved particularly valuable for participants without a technical background, since drawings—even 3D models—often remain abstract; the physical model made the design logic immediately accessible.

The set-up included typical edge and corner details of the envelope and their connection to the aluminium primary structure via form-fitting steel inserts. In this configuration, it was possible to see how different requirements influence each other once they converge in a single node (e.g., tension path, clamping zones, back-ventilation areas, and water management). On this basis, detail principles were refined and aligned with practice-tested solutions; at the same time, robust inputs were derived for fabrication and assembly sequencing.

No load or deflection tests were carried out on the mock-up. Quantitative verification of structural behaviour was performed later through a separate full-scale set-up of an entire portal frame, which is discussed in a dedicated chapter.

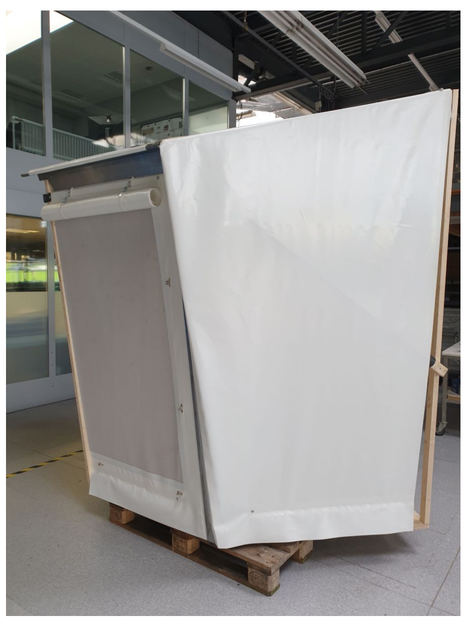


Figure 5: 1:1 detail mock-up of a tent corner as a discussion and decision platform in the early delivery phase; demonstrates how multiple connections interact within a single node.

5 STRUCTURE AND JOINT BEHAVIOR

The primary structure is a gable portal frame made of aluminium keder profiles as used in temporary tent construction (e.g., Losberger De Boer, Röder, HTS TENTIQ). The members are connected into frame joints by form-fitting steel inserts. This connection type is established in tent engineering but is not explicitly standardised as a catalogue detail in EN 1090–3, EN 1999 (Eurocode 9) or EN 13782; its behaviour is *semi-rigid* with an initial assembly clearance and is commonly described by the joint's moment–rotation relationship (M–φ). Comparable studies on related joint typologies qualitatively confirm semi-rigid behaviour and parameter sensitivities; however, these works were consulted *post factum* as contextual literature and were *not* the basis of the original design and verification[9;10].

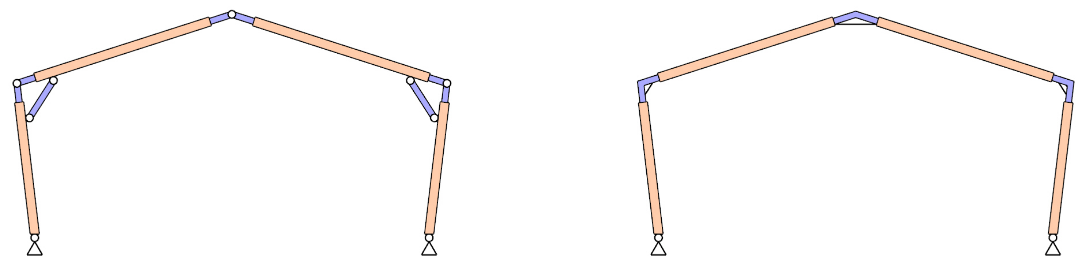
In the first scheme, the eaves joint was braced by a strut so that the insert could be idealised as *pinned*. During the mock-up discussions it became clear that this strut should be omitted for operational and safety reasons. The eaves joint was therefore designed to act *moment-resisting* in order to ensure a globally stable and serviceable frame. To further exploit the semi-rigid effect and stabilise the system response, the *ridge joint* was likewise modelled and detailed as *semi-rigid*; *only the base joints* remain pinned.

Figure 6 summarises the development of the portal-frame scheme. In the initial layout (Fig. a), an eaves strut provided global stability and the insert at the eaves could be idealised as pinned. In the optimised layout (Fig. b), the strut is removed and moment resistance is activated at the eaves and the ridge (bases remain pinned), exploiting the semi-rigid M–φ behaviour of the joints. This shift eliminates a member in the occupied zone and concentrates stiffness where it is structurally effective; the numerical model reflects this via nonlinear rotational springs with an initial slip branch.

The constructive challenge lies in the required fit-up tolerance: the steel insert must slide into the aluminium profile; fabrication and coating tolerances inevitably introduce clearance. In addition, bolted connections require hole clearance, producing a slip-dominated initial branch of the M–φ curve during load take-up. Slip can be reduced by targeted bolt patterns and counts; at the same time, bearing stresses and support forces in the aluminium must be verified. In the resistance check the welds of the steel insert did *not* govern, yet they are execution- and fatigue-sensitive and thus received particular attention in geometry, heat-affected zone, and quality control. Functional constraints also arise from integrated building services: cable runs (power, emergency lighting, fire alarm) pass inside the profiles and must traverse the insert without impairing its structural function.

A staged approach was adopted to consolidate the detail. First, a geometric verification in 3D CAD (fit, tolerance chains, clash checks) and a FEM-based predesign with contact- or spring-based assumptions for the M–φ behaviour of both eaves *and* ridge joints were carried out. The resulting parameters were then calibrated in a separate full-scale set-up of a complete portal frame, providing realistic joint properties for execution design. Based on these findings, the insert was refined: an additional rib forms a defined contact face to the aluminium profile and limits effective clearance. The rib is dimensioned with minimal installation play and can be fine-adjusted on site if required; internal cable routing remains ensured.

This approach enabled the omission of the eaves strut, the activation of both eaves *and* ridge



(a) Initial scheme with eaves bracing (b) Optimised scheme without bracing

Figure 6: Evolution of the portal-frame scheme: (a) braced eaves with pinned insert; (b) braceless frame with semi-rigid eaves and ridge, pinned bases.

joints as moment-resisting connections, and a robust, serviceable frame response with pinned bases. The calibrated joint properties form the basis for subsequent detail decisions at eaves and ridge and for the systematic evaluation of in-service deflections.

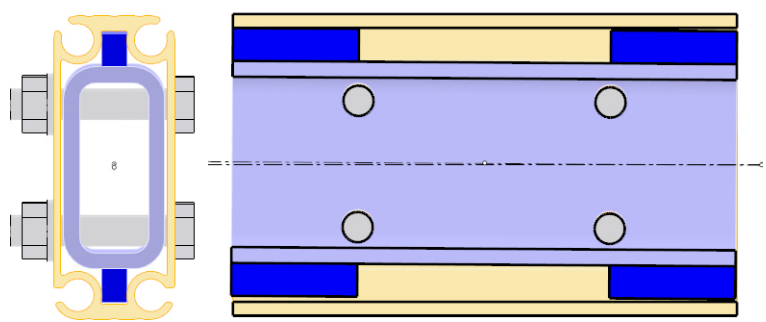


Figure 7: CAD cross-section of the aluminium keder profile with steel insert: rotational clearance (φ) within the profile, effective contact faces, and the rib acting as a stop; basis for initial-slip and M–φ assumptions.

6 FULL-SCALE TESTING

A full-scale, single-bay portal frame was first assembled from the production aluminium keder profiles with the steel insert joints and pinned bases. The frame was subjected to incremental cyclic loading and unloading blocks. Global response was recorded as vertical crown deflection w and horizontal spread Δb of the frame, complemented by member deflections of the aluminium rafters. Load scenarios followed the execution design, with cycles at characteristic (service) and design levels in line with SIA 261 [6].

To expose the influence of joint slip, tests were performed with bolts tightened to the installation torque and, for comparison, with intentionally slackened bolts. In addition, alternative insert variants were trialled. The results showed a pronounced initial slip branch followed by a stiffer

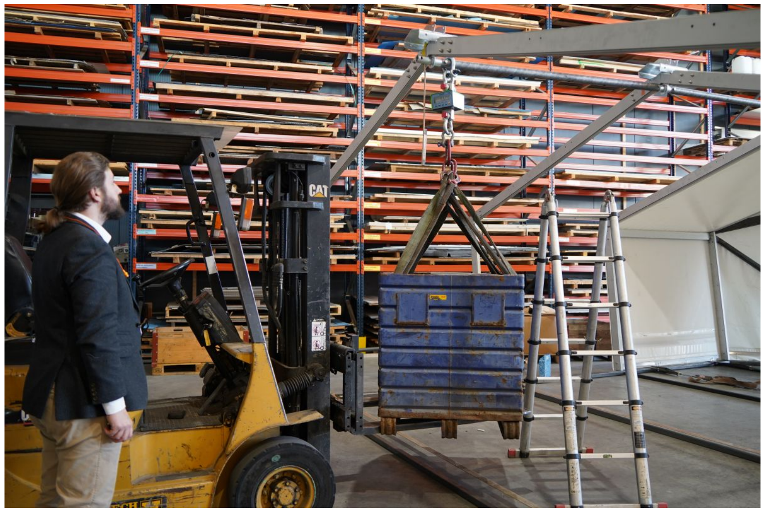


Figure 8: Full-scale portal frame test

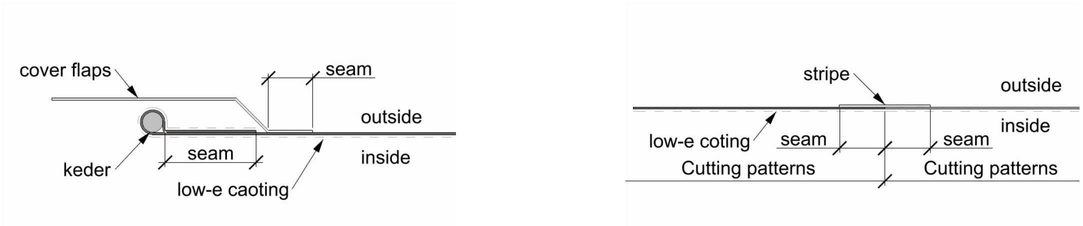
response—consistent with the target semi-rigid joint behaviour—and confirmed the functional viability of the tent-frame system without the eaves strut. The measured load–deflection histories were used to calibrate the nonlinear rotational springs of the eaves and ridge joints (initial slip rotation φ_0, initial tangent stiffness $S_{j,\mathrm{ini}}$, and post-slip stiffness), supplying realistic parameters for the execution analysis.

In a second phase, the envelope–structure interaction and assembly effects were checked by erecting a complete tent in a hall and applying localised loads to selected bays and nodes. This verified the numerical predictions under installation-realistic boundary conditions and sequences. The agreement between measured and predicted deflections was close, giving confidence that the calibrated semi-rigid model predicts serviceability performance with high fidelity despite the system's inherent nonlinearity.

Overall, the staged testing programme—portal frame first, full tent thereafter—provided the parameter identification and validation needed to remove the eaves bracing, activate moment resistance at the eaves and ridge, and set robust acceptance criteria for on-site performance.

7 TEXTILE ENVELOPE AND INTEGRATED THERMAL STRATEGY

From the early design phase, PVC/PES tent membranes with a low-emissivity inner face and a two-layer, back-ventilated roof were defined as the core of the passive climate strategy and have now been implemented in execution. The roof couples two effects that act against summer overheating. First, the low-emissivity surfaces reduce heating of the roof skin so that the membrane itself does not act as a radiator and radiant gains into the interior are diminished. Second, ventilation of the interstitial cavity between outer and inner layers enables continuous removal of heat. To maximise reflection, the low-emissivity faces of both layers are oriented towards the cavity. Free ventilation areas, allowable reductions due to purlins/rafters, and supply/exhaust openings follow the rules for ventilated roofs (SIA 232:2000, 2.2.8.2)[11]. The configuration is effective in summer by limiting heat build-up and in winter by reflecting long-wave radiation within the roof build-up,



(a) Keder detail

(b) Butt-type seam detail

Figure 9: Fabrication details

thereby moderating heat losses.

Fabrication and detail adaptations

The chosen materials require adaptations to the usual fabrication details of tent roof panels with aluminium keder profiles. In principle, three primary details govern the panels: joining of cut pieces into a full sheet, the keder edge to connect to the aluminium profile, and the hem pocket for the tension tube. Because the low-emissivity (coated) face is not weldable, we trialled several options, including mechanical removal of the coating; abrasion proved uneconomic and process-insecure. Consequently, we replaced the typical overlap weld by a butt-type weld with a single-sided cover strip (one-sided splice, welded), preserving the coated face.

For the profile connection, we deliberately avoided separate glide keder tapes—whose exposed PES substrate would be UV-critical in permanent service—and instead formed the keder directly by hemming the panel edge and inserting a keder cord. This hemmed build-up places the silver, reflective face to the exterior; since the aluminium profiles are intended to remain invisible from outside, cover flaps are provided and welded to the neighbouring panel during installation, concealing both the profiles and the silver keder zone.

The hem pocket for the tension tube is executed in the usual manner by turning the panel edge; due to the coating, the hem is formed to the outside. In the built condition this reflective strip is not visible at the ridge because it is fully covered by the ridge hood and ventilation grille. All edge and connection details are arranged so that airflow in the cavity remains continuous and the thermal function is not interrupted by clamping, seams, or cover strips.

8 INSTALLATION PROCESS

As part of the full-scale trials, the installation workflows were systematically exercised. This made it possible to fix an efficient sequence, decide which assemblies should be prefabricated in the workshop, and organise site logistics—material laydown, access routes, and auxiliary equipment—accordingly. On this basis, a lean, repeatable installation plan was prepared and schedules with other trades were coordinated in a controlled manner.

A prototype was erected in the first stage. It allowed prepared assumptions and detail points to be re-verified and fine-tuned; the prototype also served as the platform for the thermal measurements presented later. The resulting adjustments were fed directly into the installation documenta-

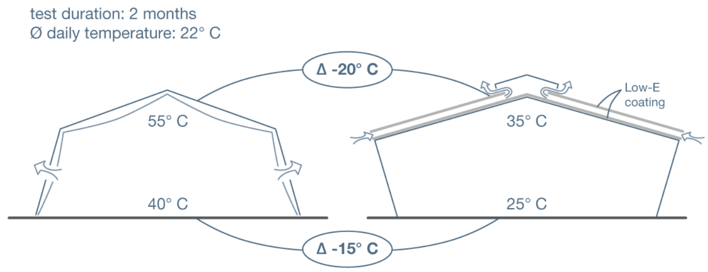


Figure 10: Comparison of indoor temperatures: legacy army tent (left) vs. prototype (right). Ridge $\approx 55°\mathrm{C}$ vs. $35°\mathrm{C}$ ($\Delta \approx 20\,\mathrm{K}$); floor $\approx 40°\mathrm{C}$ vs. $23°\mathrm{C}$ ($\Delta \approx 15\,\mathrm{K}$). The sketch illustrates reduced heat build-up and a flatter vertical gradient in the prototype.

tion and pre-fabrication.

Subsequently, the roll-out of the remaining 34 tents proceeded. The upfront work translated into a swift, well-coordinated process: defined pre-assembly steps, clear on-site sequences, and short interface times between trades ensured a robust, on-schedule installation.

9 FIELD MEASUREMENTS

The field campaign compares a legacy army tent (reference) with the new prototype. The monitored variables comprise indoor air temperature at two heights (ridge/floor), relative humidity at both levels, surface temperatures of envelope and structure, and the CO_2 concentration. The monitoring window extends from 20 May to 18 July 2022; due to commissioning and data transmission, the logged series largely cover 21 May to 16 July[12].

Daytime records consistently show markedly lower indoor temperatures in the prototype than in the reference tent; differences exceeding 15 K occurred repeatedly. At night the temperatures converge, reflecting the reduced role of solar gains and the influence of occupancy and ventilation use. The vertical temperature gradient in the prototype remained small at night; in isolated cases the lower sensor read slightly higher than the upper one, attributable to the ventilated two-layer roof and the proximity of the lower probe to the inner liner. The risk of condensation was significantly reduced in the prototype: within the observation window about 30 h of potential condensation conditions were identified, compared with roughly 250 h in the legacy tent. CO_2 values remained mostly within an acceptable range; prominent peaks correlate plausibly with occupancy and the chosen ventilation regime[12].

Overall, the measurements support the effectiveness of the combined strategy—back-ventilated two-layer roof with low-emissivity inner faces—by reducing solar heat build-up during the day, damping surface temperature swings, and stabilising the thermo-hygrometric behaviour under real operating conditions.

10 DISCUSSION

Scope and positioning. This contribution deliberately provides a focused look at an executed case: it traces how integrated detailing—structure, envelope, fabrication and assembly—was used to meet thermal and operational targets, without claiming to exhaustively document the entire project.

Transferability. Three elements generalise well: (i) modelling semi-rigid joints via calibrated M–φ springs to replace bracing where feasible; (ii) a back-ventilated double-layer roof with low-emissivity inner faces sized by ventilated-roof rules (SIA 232) for passive moderation of indoor climate[11]; and (iii) a decision mock-up to converge details and installation sequences early. The keder-based connection strategy and the custom eaves extrusion provide a template for combining airflow, drainage and tensioning in one functional node.

Limitations. Results reflect local boundary conditions (late spring to mid-summer, 20 May–18 July 2022), occupancy patterns and user ventilation behaviour. Monitoring emphasised thermal/hygrometric response; long-term durability of the reflective inner faces and PVDF top coat, as well as wind-driven rain under extreme events, require continued observation. The semi-rigid joint parameters are system-specific; while the calibration workflow is transferable, the numerical values are not. Standards (EN 1090-3, EN 1999, EN 13782) do not catalogue this insert-type joint; future standardisation could benefit from aggregated datasets and repeatable test protocols.

Outlook. Priorities include winter monitoring to quantify heating demand reductions, multi-season datasets, probabilistic serviceability checks with measured joint scatter, and a compact detail catalogue (eaves/ridge/keder/MEP) to aid replication at scale.

11 CONCLUSIONS

An envelope-led strategy coupled with integrated detailing delivered a tent-based system that achieves summer comfort without mechanical cooling while preserving the camping character. Structurally, activating semi-rigid behaviour at the eaves and ridge allowed removal of the eaves strut and produced a robust, serviceable portal-frame response with pinned bases. The joint behaviour was captured by calibrated M–φ springs derived from a full-scale portal test, enabling reliable deflection predictions.

On the envelope side, a back-ventilated double-layer roof with low-emissivity inner faces was detailed and fabricated under non-weldable coating constraints, maintaining continuous airflow and clean interfaces with the structure. Field measurements against a legacy tent evidenced markedly lower indoor temperatures and reduced condensation risk under real operation[12].

The workflow—decision mock-up, targeted testing, and in-use monitoring—proved effective for converging details, installation planning and performance verification. While numerical parameters are system-specific, the method is broadly applicable and points to practical standards for semi-rigid joint characterisation and ventilated textile roofs. Further work will extend monitoring across seasons and formalise detail catalogues for replication and guidance.

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