Thermal Performance of a Movable Modular Shelter for Extreme Cold Conditions: A Study in Collins Bay, Antarctica.

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Abstract: This paper summarizes the results of a pilot study on the performance of a movable modular shelter in extreme cold conditions. The shelter was designed by a mixed team of Architects and Engineers and will be used by researchers carrying out field work in the Antarctic Peninsula. Preliminary results confirm its viability, ease of use, and satisfactory thermal comfort performance. Considerations are made on contextual factors, such as comfort expectations, local climate characteristics, and design construction issues.

Keywords: Thermal Comfort, Extreme Cold Climates, Bioclimatic Design, Modular Shelter.

Introduction

The Design of the shelter was developed throughout 2018 by the Polar Lodge project team - a mixed team of Architects and Engineers from the Higher Technical Institute (University of Lisbon), Heriot-Watt University (UK) and the University of Bahrain (Kingdom of Bahrain).

Figure 1. The Polar Lodge shelter, February 2019, Collins Bay, Antarctica.

The objective of the Polar Lodge Project was to design and build a sustainable, low-impact, optimized, modular lodge, to facilitate scientific studies in the Antarctic. This lodge presents a new environmental and sustainable approach to creating resilient structures for the extreme cold, combining ancient tent design with leading edge modern technologies and materials. The major drivers for the design include that the structure should be: modular; easy to transport and fast to assemble by a small team; resistant to high winds; have minimum impact on the ecosystem; and be comfortable.

An innovative yurt-like tent was produced by July 2018, using an innovative bio-composite structure and experimental lightweight envelope and structure, designed to withstand extreme high winds, and extreme heat and cold.

This new Module follows on from a 2016 experimental prototype that collapsed in 200km/h winds in the Antarctic (Guedes, 2016): its structure, form, and building materials were overall upgraded, under the supervision of Prof. Sue Roaf (Heriot-Watt University), in order to respond to the severe conditions found in Antarctica.

1. Local Climate

Antarctica is the coldest continent on Earth, with minimal recorded temperatures ranging from −93.2 °C to −98 °C (Vizcarra, 2018). The continent has an EF Köppen classification of ice-cap climate, with very cold, and generally extremely dry weather (it is technically a desert, averaging 166 mm of precipitation per year). Temperatures in inland Antarctica rarely rise to 0°C even in summer.

With exception of a few seaside areas, snow rarely melts, and, after being compressed, forms the glaciers. The continent is rarely penetrated by weather fronts, due to the effect of of the katabatic winds. Cold air sweeps down from the central plateau toward the ocean, particularly in spring and autumn.

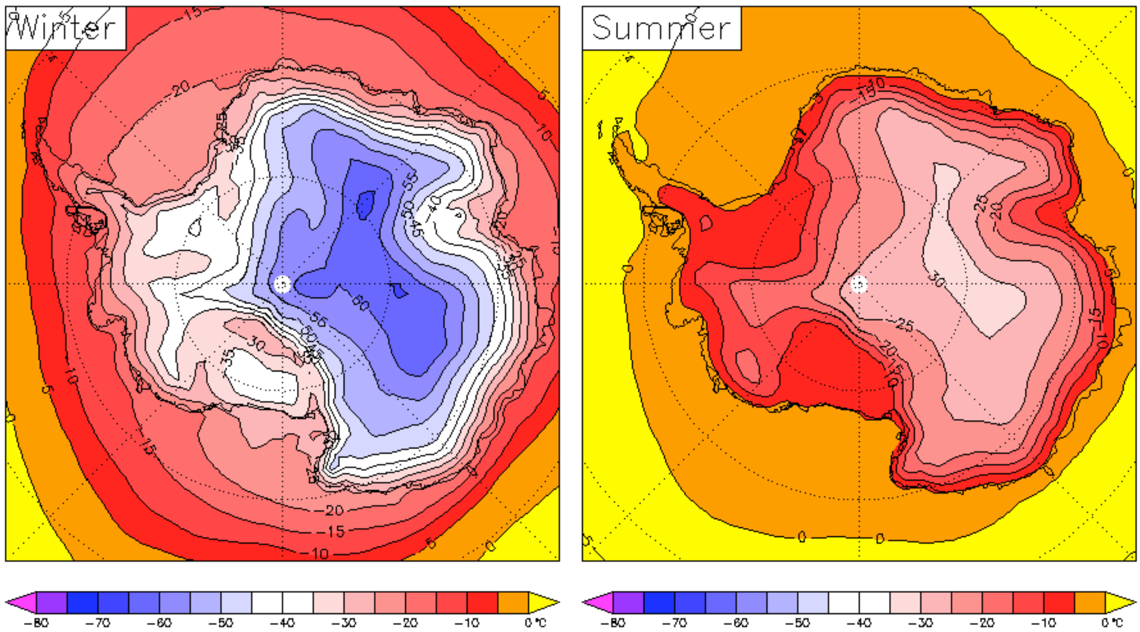

Figure 2. Surface Temperature charts for Winter and Summer (source: European Centre for Medium-Range Weather Forecasts, 2018)

Antarctica also holds the record of the strongest winds: winds can easily reach gale force, between 100 and 200 km/h, and in places where the wind flows through narrow valleys, it can attain a speed of 90 m/s (325 km/h). There are on average 11.6 days per month when the wind exceeds 100 km/h (Bromwich, 1989).

2. Thermal Comfort Expectations

Most of the research projects carried out in Antarctica involve a significant degree of fieldwork. Scientists are primarily lodged in existing station' buildings, or in research ships, and from there they proceed to take samples and measurements in the field – sometimes requiring several days of camping in remote locations outside the stations, in severe weather conditions.

A brief survey was carried out by Guedes et al. in January 2016 in the Antarctic peninsula, in both station buildings and camping sites, in order to assess the performance of station buildings and tents, and the users' expectations. Eight stations were monitored, and two camping sites, involving 43 respondents.

Overall, conditions in the base buildings or research ships are quite similar to what can be found in a standard home in Chile, i.e. inside temperature is controlled, varying between 18ºC and 26ºC. Common areas (laboratories, living rooms, study rooms) tend to be tightly controlled, whereas in sleeping rooms some differences were noted, resulting from individual preferences, i.e. some occupants opened the windows for a while to reduce perceived overheating[1].

Figure 3. Working room at the Chilean Escudero station (left), dining room at the Spanish' Gabriel de Castilla station (right)

Figure 4. Typical tents for field work' research in the Antarctic peninsula.

The feedback obtained from field campers was revealing: the large majority, even newcomers to Antarctica, perceived life in the camping site as being normal and acceptable for that predetermined period of time: the harshest hours were at night, when

[1] This "energy inefficient" behaviour was generally not frowned upon by the stations' managers – we guessed that the importance of individual adaptive control and wellbeing was a priority over energy efficiency…

temperatures get very cold – but one would be protected with sleeping bags (with an insulating capability withstanding -40ºC), and by the tent. However, the large majority stated that they would welcome an “upgrade” in terms of internal comfort (thermal and ergonomic), especially if the field work would take several days, and, most of all, their main fear and concern was the strong wind: every year campers have to be rescued as tents fly (sometimes several kilometres) when a sudden storm occurs (as experienced by the authors in 2016, when tens of campers had to be rescued from their sites by the Chilean Navy after a sudden storm with wind gusts over 200km/h).

In summary, the lesson taken from past experience is that besides the obvious need for resistance to gale-strong winds, the new Lodge design should improve internal comfort as much as possible (the sense of security and feeling of “homely”, and thermal insulation and stability) – in tune with the field researchers’ expectations.

3. Design Considerations

The focus of the new Lodge design was the structural optimization for resisting strong winds - which will be referred in other papers (Guedes et al. 2019; Pinelo Silva et al 2019; Roaf et al 2019) – and the improvement of comfort performance. For the latter purpose, a survey was carried out in the UK in early 2018 by Prof. Sue Roaf, in order to identify the best suitable envelope materials, in terms of durability, weather endurance, and thermal insulation capabilities.

The final decision felt upon two innovative materials for the skins: 1) a space blanket type multi-layer double skin from ORVEC of Hull, and 2) re-used Dyneema racing yacht sails for the outer coat from *Northsails* in Palma de Mallorca, Spain.

The optimised timber structure was made by *Yurtmaker* in Telford, and the tent cloths were manufactured by the master tent makers at *Sheerspeed* in Honiton. Insulated flooring was made of re-cycled plastic bottles by *Weaver Green* in Salcombe.

Figure 5. Transport of the (whole) Lodge in a Zodiac, heading from Escudero to Collins bay.

The portability and ease of assembly’ objectives were accomplished: The whole Lodge fitted in a single Zodiac boat, and was transported from Escudero to a remote location in Collins Bay, within Collins glacier. It was then mounted in approximately 2 hours.

Figure 6. Left: First two layers of ORVEC put over the structure. Right: the external (third) layer of DYNEEMA.

4. Results: Discussion and Further Work

Five HOBO data loggers were placed inside the Lodge during one week, to measure Air Temperature (ºC), Relative Humidity (RH%) and Lighting levels (Lux). Instantaneous measurements were also carried out, obtaining Globe Temperature, Air Temperature, and Relative Humidity.

FLIR and SEEK thermal cameras were also used to register the performance of the Lodge, particularly during night time – when temperature drops significantly. An Anemometer was also used for wind speed measurements.

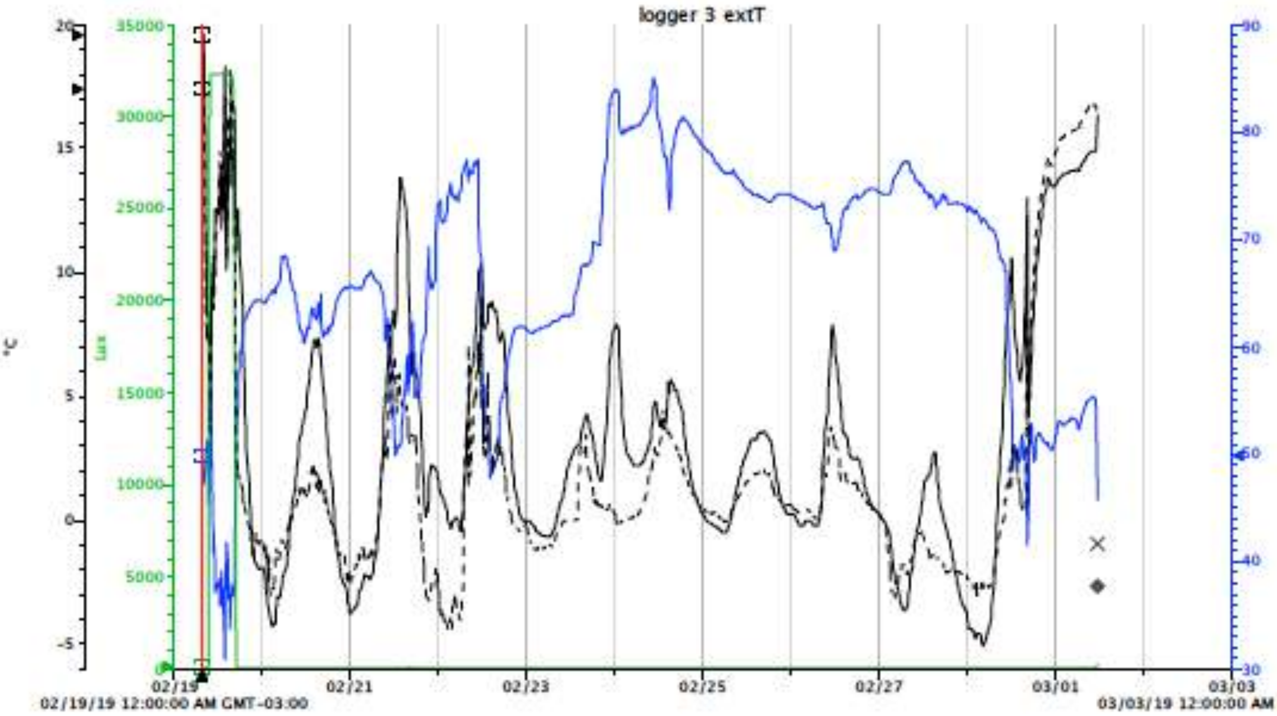

Figure 7. Monitoring of the lodge with a HOBO data logger: Internal Temperature (black line), External Temperature (black dashed line), and Relative Humidity (blue line).

The results showed that, when unoccupied, during the daytime the internal temperature was generally about 5ºC above external temperature: the black surface of the

Lodge starts absorbing solar radiation in the morning, and the heat remains trapped inside until night time.

The lodge was occupied by two people on the night of the 22nd and on the night of the 24th. On the night of the 22nd no heat sources were used: the body heat was enough to keep the internal temperature of the Lodge up to 5ºC higher that the external temperature. On the night of the 24th a small gas heater was used during three hours (9pm to 00am), and the temperature of the lodge remain well above external temperature throughout the night. The two occupants reported to have had a very comfortable night sleep in both the 22nd and the 24th.

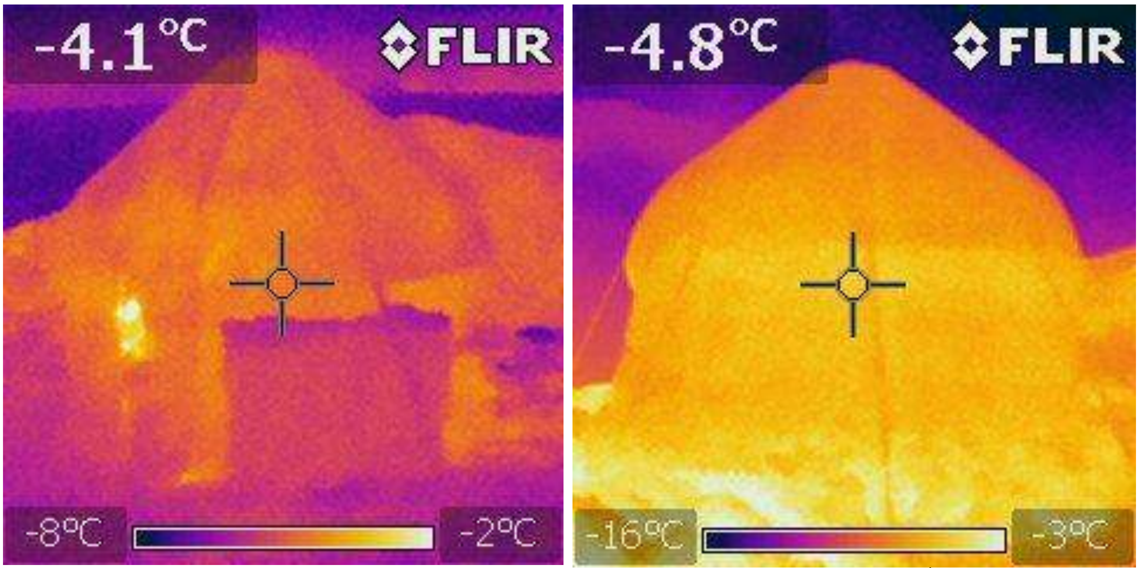

Figure 8. FLIR thermal photographs of the Lodge at night, viewed from outside on the 24th, showing no thermal bridges, and a very good insulating behaviour. Only a small spot revealed heat getting out: the door we had to open to come outside to get the shots (left picture).

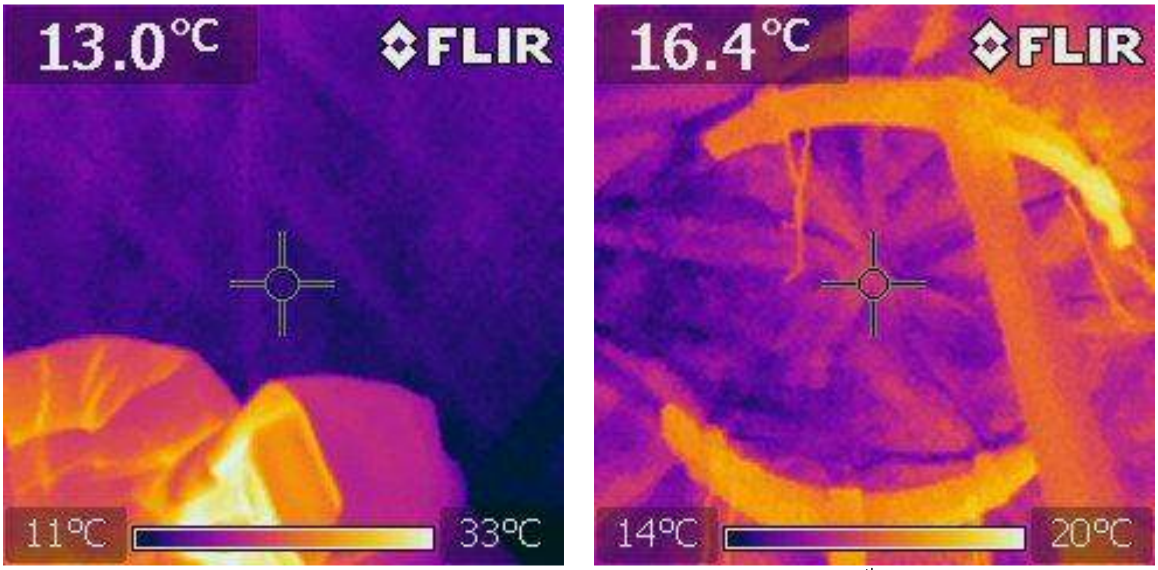

Figure 9. FLIR thermal photographs of the Lodge at night, on its interior, on the 24th. The internal temperature recorded by the FLIR cameras was 12ºC at body level on average – quite higher than the temperature recorded by the HOBO data logger, as the latter was placed at ground level.

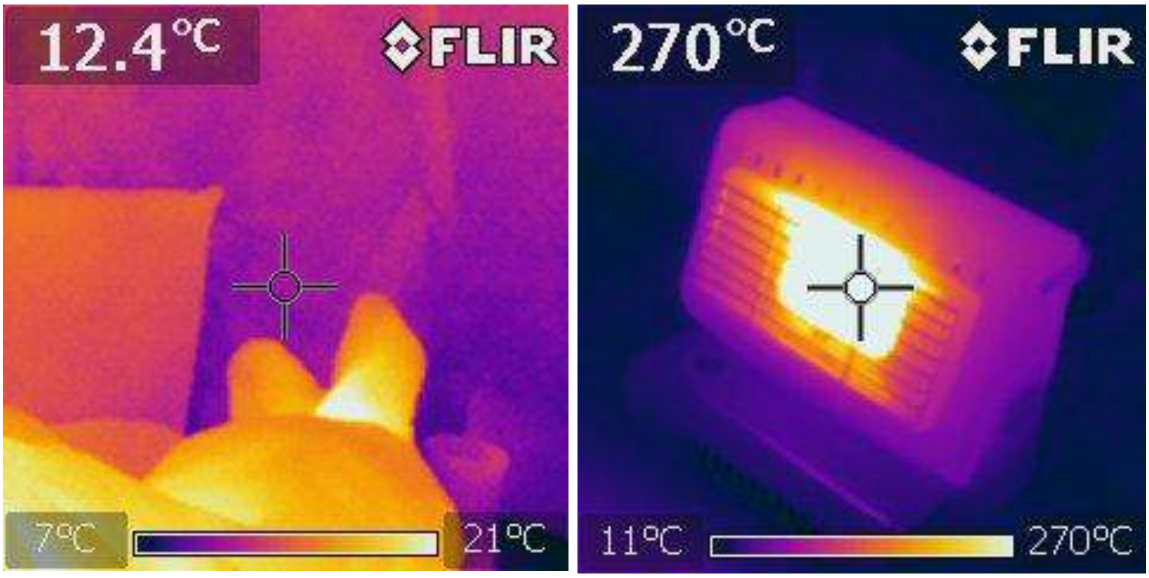

Figure 10. FLIR thermal photographs of the Lodge at night, on its interior, on the 24th. On the right the small gas heater used on the 24th, on the left a shot at body level, showing a very acceptable temperature of 12.4ºC, which remained stable throughout the night, even after the gas heater was shut at midnight.

In terms of RH%, it increased to values reaching 90% during the sleepover nights – but neither of the occupants felt any excessive humidity, which could perhaps be explained by the nature of the internal envelope materials.

A CO_2 monitor from Gas Sensing in Cumbernauld and a Carbon Monoxide monitor from Honeywell UK were also used, and limit values were surpassed on the night of the 24th due to the gas heater. A Flue will be implemented next year to avoid these situations.

Due to cost considerations and the short time available to manufacture the Lodge, it was decided that the present prototype would not have the zenital window, typical of the Yurt – as its implementation would considerably increase costs and manufacture time, and reduce the resilience of the envelope at its most stressed location. Its insertion on the Lodge is foreseen for the coming Antarctic campaign of 2019/2020. Solar lighting graciously was provided by Velux, and truly compensated this shortcoming.

The lodge will be used until the end of Summer (late March) and again from November 2019 till March 2020. Feedback from users, including questionnaires, will be collected during these periods, and posted online (at extremelodge.com). This will allow a more thorough assessment of the Lodge, leading to its optimisation.

Further issues concerning the performance of the materials, structure and overall comfort will also be assessed in the next campaign.

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