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TECHNICAL ARTICLE

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# The application of vernacular Australian environmental design principles in Glenn Murcutt's architecture

Mauricio Lecaro<sup>1</sup>, Benson Lau<sup>2</sup>, Lucelia Rodrigues<sup>2</sup>  and Dik Jarman<sup>2\*</sup> 

## Abstract

Glenn Murcutt is recognised as one of the most influential architects of the last few decades. His design philosophy, environmental awareness and in-depth understanding of the Australian context and vernacular architecture, have made him one of the leaders of critical regionalism worldwide. His buildings not only provide shelter, but also offer comfort with lower environmental impacts through simple, yet creative design solutions. Although Murcutt's architecture is well documented, limited evidence-based research has been undertaken to study his approach to design and how this has a direct influence on visual and thermal comfort in his buildings; this paper aims to fill this gap.

In this work, the authors have conducted a critical review of three of his most celebrated projects from the environmental design perspective, Marie-Short, Ball-Eastaway, and Marika-Alderton Houses. Even though these houses share a similar building typology, their time of design, location, climate, orientation, tectonics and environmental requirements greatly differ, offering an opportunity for comparative analysis. Through theoretical qualitative and quantitative studies, the close connection between the spatial qualities, environmental design strategies and performance of these houses were investigated in detail. The impact and implications of the reinterpreted elements of Australia's vernacular architecture including verandahs, overhangs, roofing shape, building form and layout, had on the performance and spatial delight of the houses was explored through computer aided modelling. Daylighting and thermal performances were assessed and analysed in correlation with Murcutt's environmental design strategies. Through this investigation it is clear that while cross-ventilation and shading devices were adopted in buildings to prevent excessive solar ingress during summertime, Murcutt seems to consciously favour scenic views, and a constant connection with nature over visual and thermal comfort. Although the three houses experience occasional visual and thermal discomfort, the research findings suggest that they perform well as free-running buildings for most of the time. They are found to be sensibly designed to be climatically adaptable, skilfully built and spatially delightful, whilst keeping a continuous dialogue with nature; it is achieving this unique balance that lies the significance of Murcutt's work.

**Keywords:** Critical regionalism, Spatial delight, Climate responsive buildings, Environmental comfort

## Introduction

The significance of Murcutt's work derived from the accumulation of lifelong experimentation and experiences in designing and building climate responsive buildings. During his first years in practice, Mies van der Rohe's influence on Murcutt's work was significant. The Laurie-Short house, as described by Fromonot ([7], p. 92) was a Meisian styled transparent glass and steel box,

which is a foreign architectural language, which didn't seem to respond well to the Australian context. Fromonot [7] further stated that, once Murcutt realized the importance of understanding the impacts of Australia's climate and landscape on architecture, he then analysed and reinterpreted the key elements of Australian vernacular architecture and the indigenous life to achieve design solutions that responded to the Australian contexts.

While the influence of modern architecture is irrefutable, the combination of Thoreau's life principles, of living a modest life in permanent contact with nature and Murcutt's environmental awareness and profound

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knowledge of the Australian context and vernacular architecture, shaped his work [7]. As explained by Beck and Copper [1], it is in this theoretical and physical context that Murcutt convincingly designed responsive buildings, whose elements are assembled 'responsibly to the land' while harmonizing and merging with the Australian landscape.

Considering Murcutt's extensive oeuvre, this study focused on assessing three of his most renowned projects as a research vehicle to understand the spatial delight and environmental performance of his buildings, the Ball-Eastaway house in New South Wales, the Marika-Alderton house in the Northern Territories and the Marie-Short House in Northern Coastal New South Wales were chosen for this study. These houses were selected based on their similar building typology and the distinctive site contexts, with an aim to holistically assess the relation between Murcutt's environmental design practice and its impacts on the buildings' spatial quality and comfort conditions.

The research process started with a qualitative analysis for the three houses by exploring their local climate (based on weather data from NatHERS in Richmond, NSW and Darwin, NT) orientation, spatial arrangement and materiality, aiming to understand Murcutt's architectural design principles and how they respond to the specific site contexts; then, a quantitative analysis was conducted by computer aided modelling (in Autodesk's Ecotect, Radiance and EDSL TAS), to comprehend the luminous and thermal environments of key spaces (i.e. living rooms and bedrooms).

Murcutt's understanding of the Australian climate and landscape contributes to the development of several key design principles, which he skilfully applies and readapts in each project. Among his basic design principles, building orientation (facing north) is essential, as it defines two fundamental design aspects: access to sunlight and prevailing winds. Additionally, Murcutt closely studies the site's geomorphology and views, (Fig. 1) in order to make an informed decision on the building's setting.

Once these key aspects were defined, Murcutt studied the rainfall and solar angles to design the roofing and overhangs shape and dimensions. In his buildings, he favours slim spaces with a standard height (commonly 2.10 m.) and permeable, lightweight building skins based on vernacular architecture and aboriginal traditional shelters (Fig. 2); these spaces are then complemented by the reinterpreted building elements, (i.e. verandahs, clerestory windows, glazing louvres and blinds) whose form, function and materiality are intended to act as the catalysts for Murcutt's responsive architecture.

### **Spatial delight in the Marie-Short house**

In 1975, Murcutt was commissioned to design the Marie-Short house located in farmland near the coast of

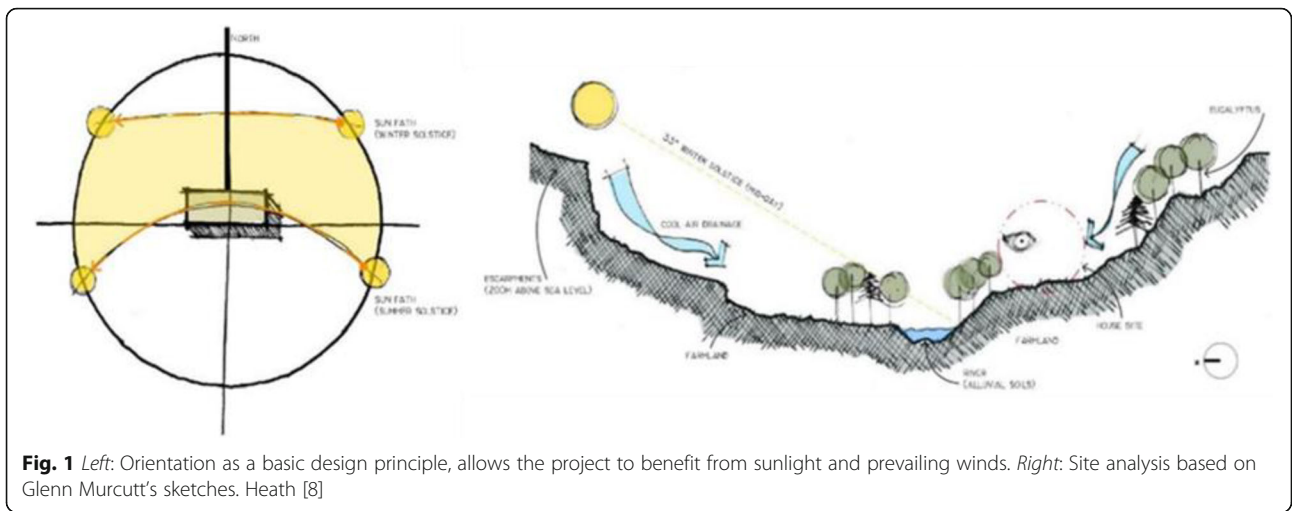
Kempsey, NSW. Considering the site's location and the locally available building materials, Murcutt opted to re-interpret the simple design of the traditional Australian woolsheds (Fig. 3) by producing a design whose form and materiality responded well to the specific site and climatic conditions.

Through building the Marie-Short House, which is a significant landmark in his career, Murcutt discovered his own architectural language.

In order to provide further evidence and evaluate the overall performance and spatial delight achieved in the Marie-Short House, performative analysis and simulations were undertaken. In order to holistically identify the effect that natural ventilation, shading devices and the reinterpreted vernacular elements had on the performance and spatial quality of the house, both luminous and thermal environments were studied through detailed computer aided modelling. In the performative analysis, Brisbane's (Queensland) weather file was used for all simulations, as the closest weather file available. Midday on 1st of January, the warmest day of the year, was selected to investigate the worst case scenario, and used to determine the influence of Murcutt's environmental design principles on the comfort conditions of the house.

Murcutt's profound understanding of the site (its landscape, views and climate conditions), led him to design a house whose main function was to provide shelter, while allowing its internal spaces to be adjusted according to their inhabitants needs. During summer, he considered the heavy rains and high temperatures, which consequently would induce significant level of humidity; Murcutt also recognised that winter was mild and solar access would be his main concern. Murcutt's in-depth knowledge of the site's climate, seemed to have led him instinctively to overlay the traditional elongated woolshed, with the lean aboriginal bark shelter on stilts, as a new, reinterpreted building typology (Fig. 4); one which once raised off the ground '...also enhances airflow and ventilation' (Beck and Copper, [1]).

As Fig. 4 above illustrates, the final design is composed by two symmetrical modular wings, (one north oriented, the other facing south) connected through a central corridor that acts as a rain gutter; both modules are staggered and raised from the ground on wooden stilts; the roof shape and overhang's responds to the solar altitude (84.8°) in summer solstice at noon, in order to prevent direct solar ingress into the interior. According to Murcutt, designing two separate wings decreased the project's scale and if relocation is needed, disassembly will be possible; in addition, he "wanted the quality of living to be close to the edge, and to enjoy the landscape views" [1]. This link between the inside and outside is maintained throughout the building, by introducing openings on both main facades with glazed louvres and



blinds, providing the inhabitants the control of the amount of daylight and fresh air entering the building.

The northern wing (facing the sun), contains the house's main living spaces (i.e. main bedroom, dining room and kitchen) whereas, the southern wing contains the secondary bedrooms and a more secluded living room. The central corridor is vital, as the pivot-hinged doors connect the main social spaces, while improving the conditions for cross ventilation. At the end of the corridor, both wings are buffered by verandahs, which act as shading devices.

When analysing the house's current layout, it shows that Murcutt positioned the main bedroom to the east, waking up the building occupants by the morning sun and exposing the space to the morning heat gains as well. However, as shown in Fig. 5, the original layout was conceived differently, as two wings with distinctive uses, (i.e. north wing contained social spaces, while the southern wing, the bedrooms) and therefore, with different spatial needs and environmental performances.

The current northern wing, was designed to receive sunlight and prevailing winds, whereas the southern wing was intended as a relaxing area thus, sheltered from direct exposure to sunlight and heat gains. After the extension,

Murcutt was seemingly conscious of the environmental implications of this alteration. When examining the luminous environment of each wing, (while overlapping the sun path diagram) as Fig. 6 illustrates, Murcutt intentionally arranged the spaces, so that the northern (and public) wing received sunlight throughout the year.

**Daylight assessment of the Marie-Short house**

In order to assess the daylighting performance of this house during summer, the house's main spaces, (i.e. living rooms and bedrooms) were analysed under an overcast sky condition, on 1st March (warmest day), with all the blinds fully opened. In this study, both the daylight factor and daylight illuminance were analysed and compared.

As shown in Fig. 7, the northern living room (NLR) achieved an average daylight factor of 5% and an illuminance level greater than 650 lux towards the exterior and lower than 150 lux near the back wall. Whilst the relatively high daylight factors (between 5% to 9%) indicate that there is no need for artificial lighting for most time of the year, and the illuminance levels exceed CIBSE's Code for Interior Lighting [5] recommendations. However, the high illuminance contrast between the exterior and the back wall, could potentially cause visual





**Fig. 3** *Left:* Traditional Australian woolshed. Murray Johnson. *Right:* Marie-Short House (1980). Richard Powers

discomfort (i.e. glare) unless the internal blinds are drawn.

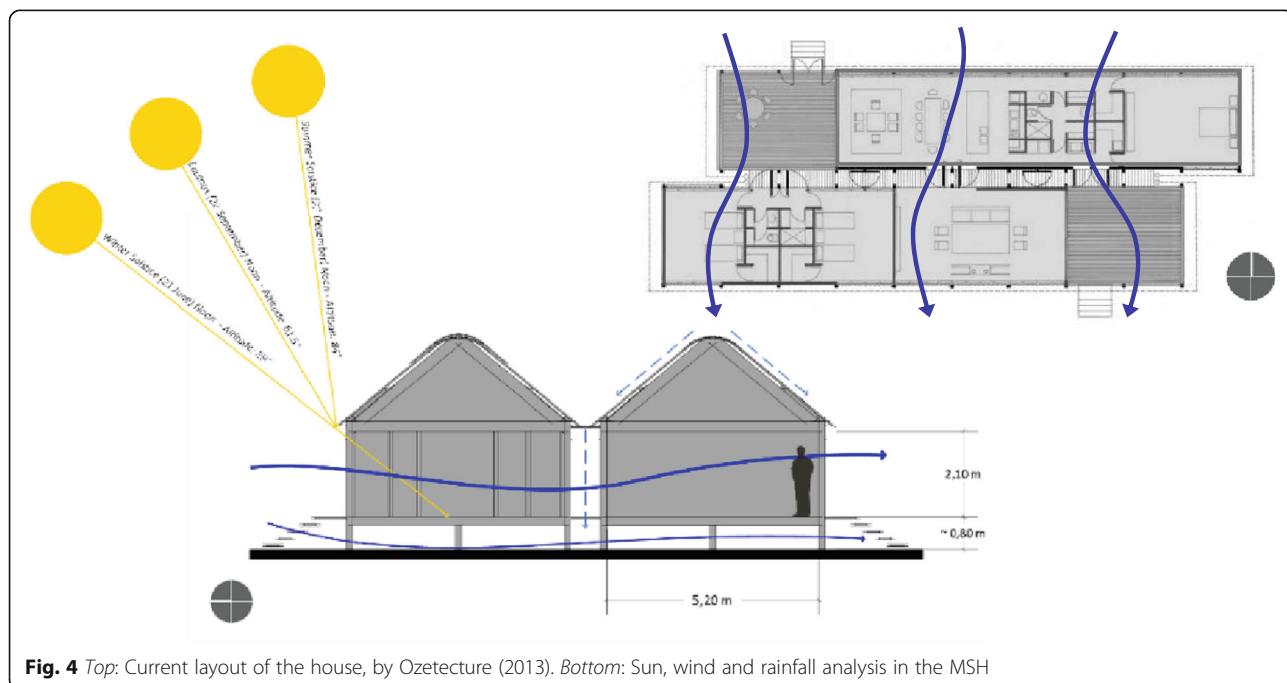
Given the difference in the orientation of the southern living room (SLR) and the North Living Room (NLR), different daylighting performance were expected. As shown in Fig. 7, surprising results were obtained for the daylight simulations, while the average daylight factor was of 9%, the illuminance levels on the interior surfaces, ranged between 250 and 750 lux. Despite daylight is more uniformly distributed when compared to NLR, (as it receives both indirect light from the exterior, and direct light from the skylight Murcutt designed for this space), the light levels indicate the potential risk of visual discomfort too.

The bedroom areas, given their use and arrangement were expected to perform differently from the living rooms previously assessed. As shown in Fig. 8, the average daylight factor for the northern bedroom (NB) was

4.5%, whereas the illuminance levels rapidly increase from 150 lux in the centre, to 750 lux towards the windows. Although artificial lighting was needed as a supplementary light source, the risk of visual discomfort might occur, but this The southern bedroom (SB), was strategically positioned by Murcutt to receive more direct sunlight (and heat gains) throughout the year a (see Fig. 8). The average daylight factor was 9% (indicating no artificial lighting is needed), while the illuminance levels ranged similarly to the NB, (i.e. between 150–750 lux) suggesting internal blinds are needed to reduce the high illuminance contrast and reduce the risk of glare.

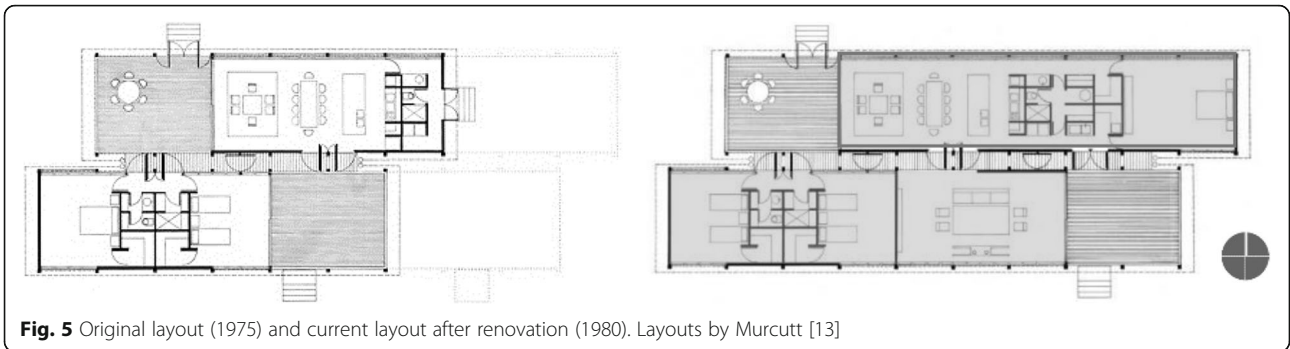
**Thermal assessment of the Marie-Short house**

To assess the thermal conditions in the selected spaces (during summer), a model of the house was built in EDSTL TAS, distributing each space as a separate thermal zone (Fig. 9), and analysing the connection between their



**Fig. 4** *Top:* Current layout of the house, by Ozetecture (2013). *Bottom:* Sun, wind and rainfall analysis in the MSH





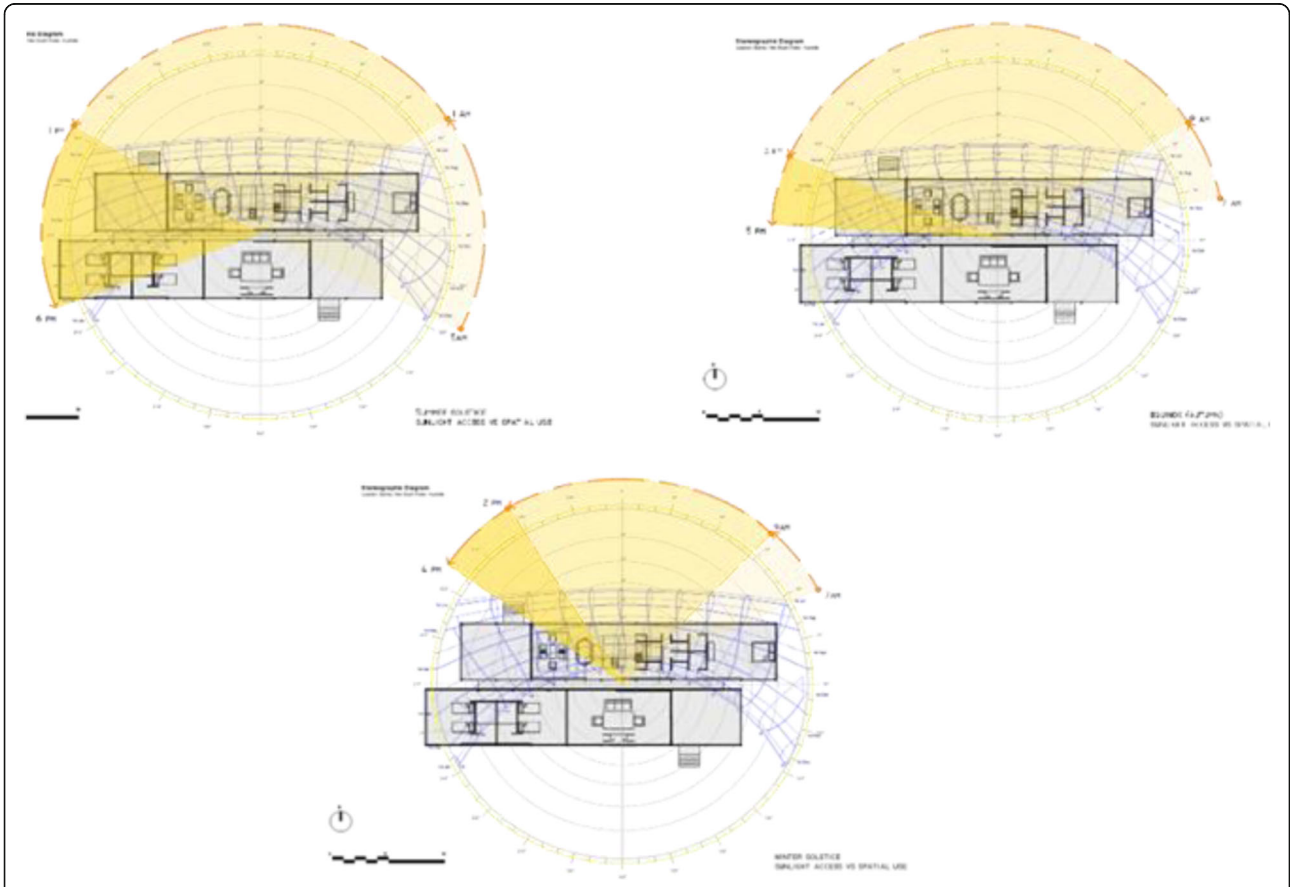
**Fig. 5** Original layout (1975) and current layout after renovation (1980). Layouts by Murcutt [13]

resultant temperatures in relation to their openings, building materials and adjacent buffer zones (i.e. verandahs). These thermal simulations were performed from day 355 until day 80, corresponding to the Australian summer time.

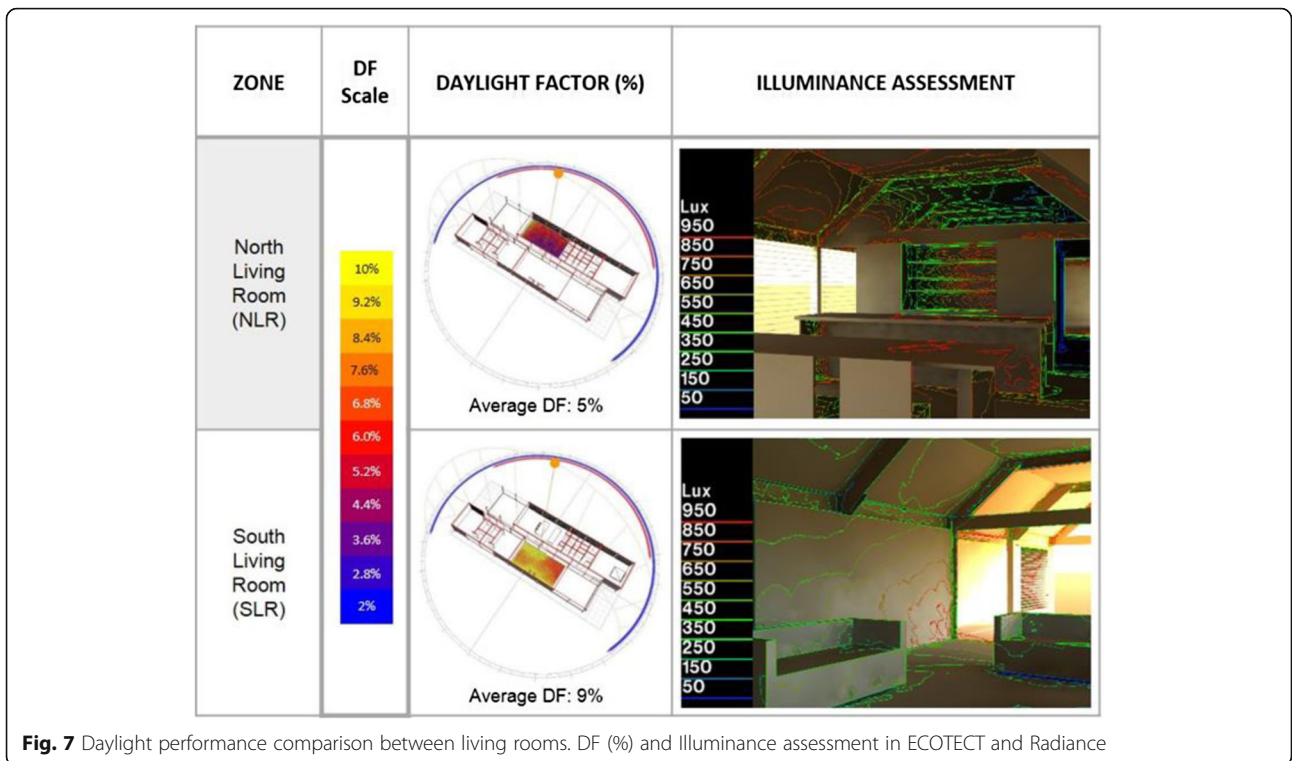
The assessment considered four possible cases (Table 1), all having a constant natural infiltration rate of 0,25 ACH and shading as designed, but varying in the levels of internal heat gains and natural ventilation rates. Case 1 was set up as a base example with no internal heat gains and

no natural ventilation, case 2 as the worst possible scenario with internal heat gains but without natural ventilation; cases 3 and 4 represented the best possible scenarios, and natural ventilation was introduced initially by having a 50% effective aperture, and then a 95% effective aperture to the openings, so that a clear understanding of the impact of natural ventilation on thermal comfort can be obtained.

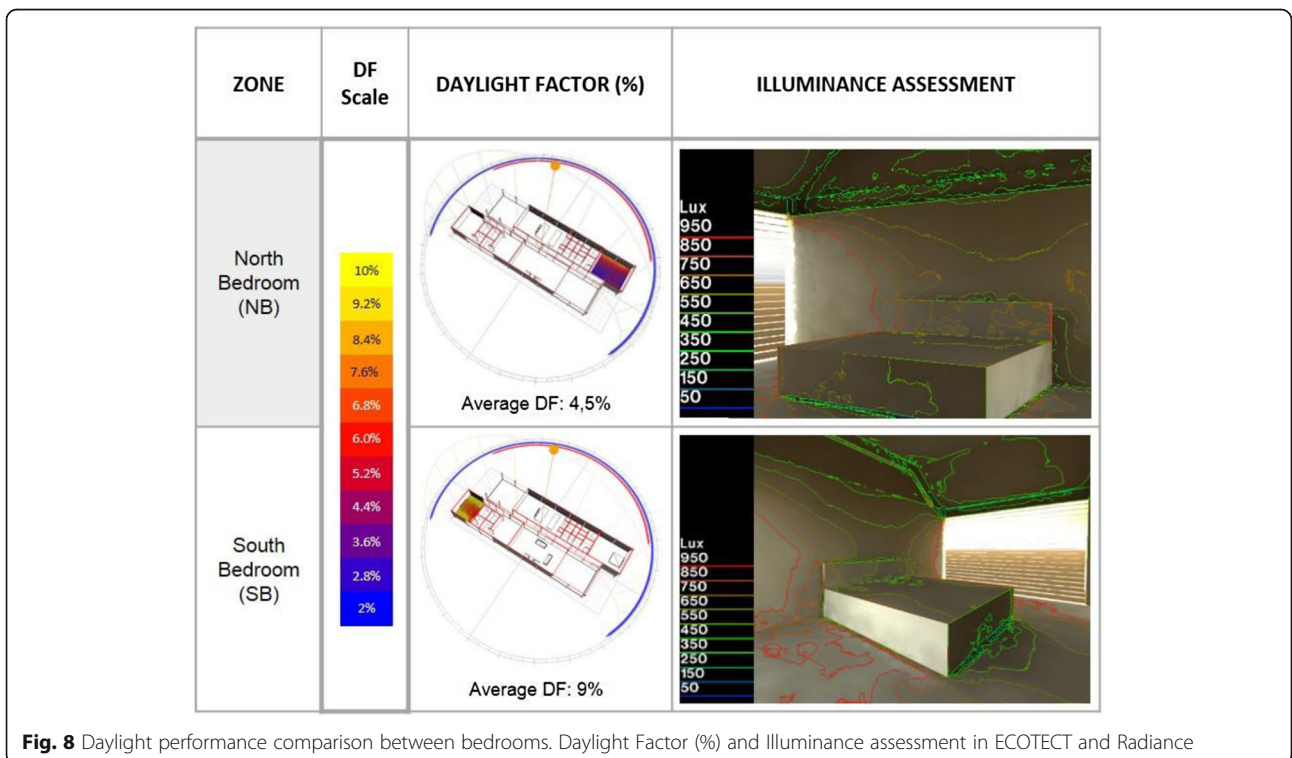
The following assumptions were considered for the simulations:



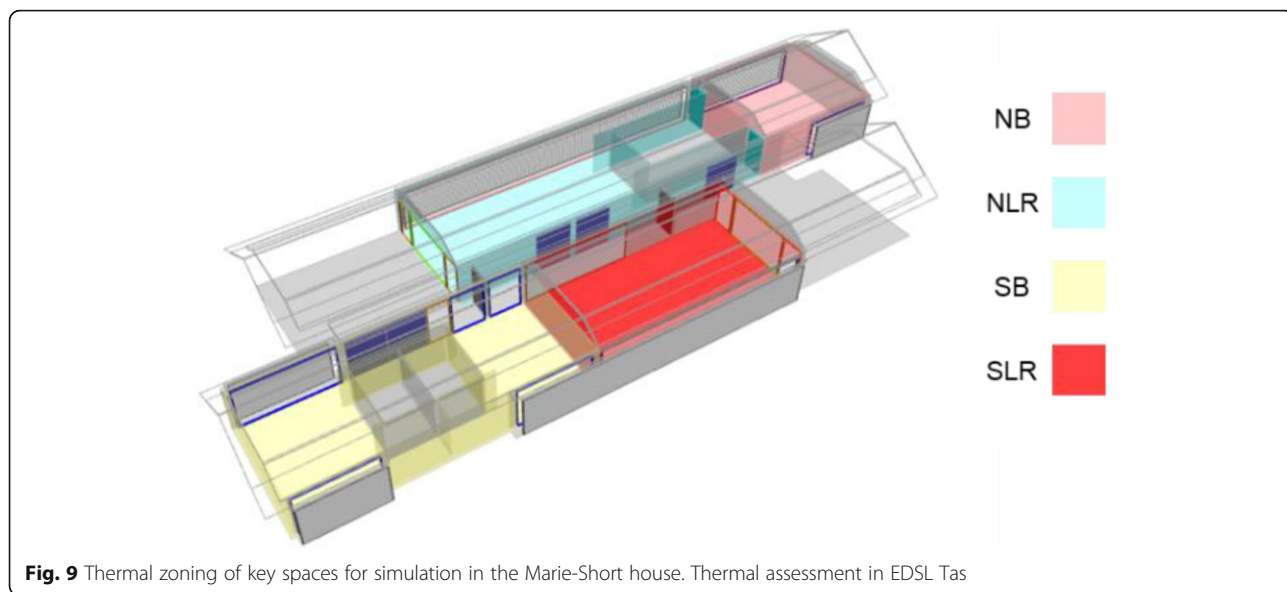
**Fig. 6** Time and spatial arrangement. Sunpath analysis during summer solstice, equinox and winter solstice



**Fig. 7** Daylight performance comparison between living rooms. DF (%) and Illuminance assessment in ECOTECT and Radiance



**Fig. 8** Daylight performance comparison between bedrooms. Daylight Factor (%) and Illuminance assessment in ECOTECT and Radiance



**Fig. 9** Thermal zoning of key spaces for simulation in the Marie-Short house. Thermal assessment in EDSL Tas

- **Weather:** Energy Plus weather data for Brisbane, Queensland.
- **Comfort range:** during summer it was assumed to be between 25 °C to 28 °C.
- **Calendar:** summer period was assumed to be from the 21st of December until the 22nd of March.
- **Internal Gains:** the following values were assumed:
  - Three people occupying the house, whose heat gains were assumed to be 120 W per person, 75 W sensible and 45 W latent.
  - The occupancy schedule was set assuming a weekly work schedule, where occupancy is highest during sleep time and falls during daytime, experiencing peaks during early morning (6-9 am), lunch (12-2 pm) and evenings (5 pm onwards).
- **Lighting:** compact low-energy florescent bulbs with a 25 W thermal load per light bulb, with a total load of 9 W/m<sup>2</sup>
- **Equipment and appliance gains:** equipment's considered were a hob, a washing machine, a dishwasher and a fridge, all with a total load of 27 W/m<sup>2</sup>.
- **Infiltration rate:** was considered to be 0.25 ACH in all zones.
- **Ventilation:** all openings have the same opening pattern during the periods when the house was

occupied and set to start opening when the temperature reached 25 °C and to be fully opened at 28 °C.

- All the cases included shading from the blinds and verandahs.

Similar to the analytical methodology adopted in the daylighting performance analysis, thermal analysis results were compared in each thermal zone with similar activities, with an aim to exam the correlations among them. The results were presented as a percentage of time when the resultant interior temperatures were ranged between 25 °C and 30 °C.

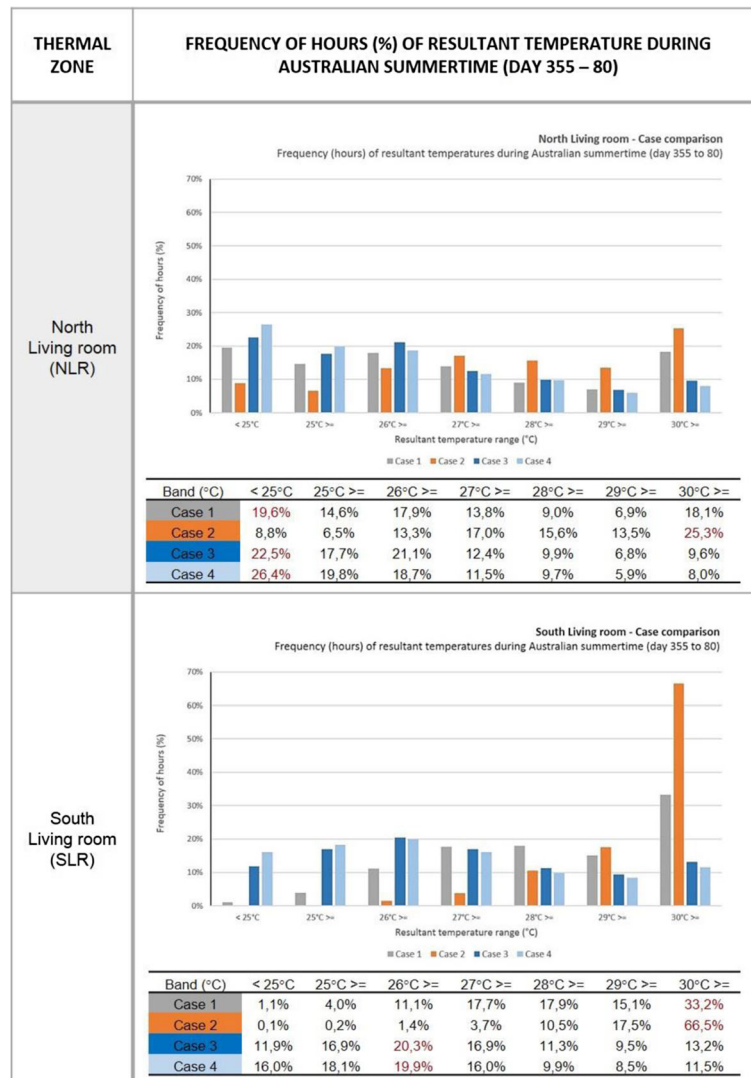
As Fig. 10 shows, both living rooms present different thermal performances. It is important to emphasize, that while both zones have a similar area, the heat gains vary greatly, as the northern living room includes the heat gains from kitchen's appliances.

- Case 1: in both zones, only 45% of the occupied hours are above the comfort range.
- Case 2: the addition of internal heat gains while the envelope remains closed, (without any ventilation) led to a significant increase in the number of hours outside the comfort range in both zones. In the NLR, over 48% of the occupied hours are outside the comfort range, while for the SLR, over 84% of the occupied hours are outside the comfort range, indicating that the building envelope and shading devices alone are not adequate to offer desirable thermal comfort in this building.
- Case 3: 50% of effective aperture in doors and windows significantly increased the number of hours within the comfort range for both zones, proving

**Table 1** Summary of thermal cases examined

	Presence (Yes/No)	Presence (Yes/No)	Presence (Yes/No)	Presence (Yes/No)
Internal heat gains	NO	YES	YES	YES
Natural ventilation	NO	NO	YES (50%)	YES (95%)
Case	1	2	3	4





**Fig. 10** Thermal performance comparison in living rooms. Thermal assessment in EDSL TAS

that natural ventilation work as intended. The simulation results also show that for over 60% of the time, the resultant temperatures are within the comfort range.

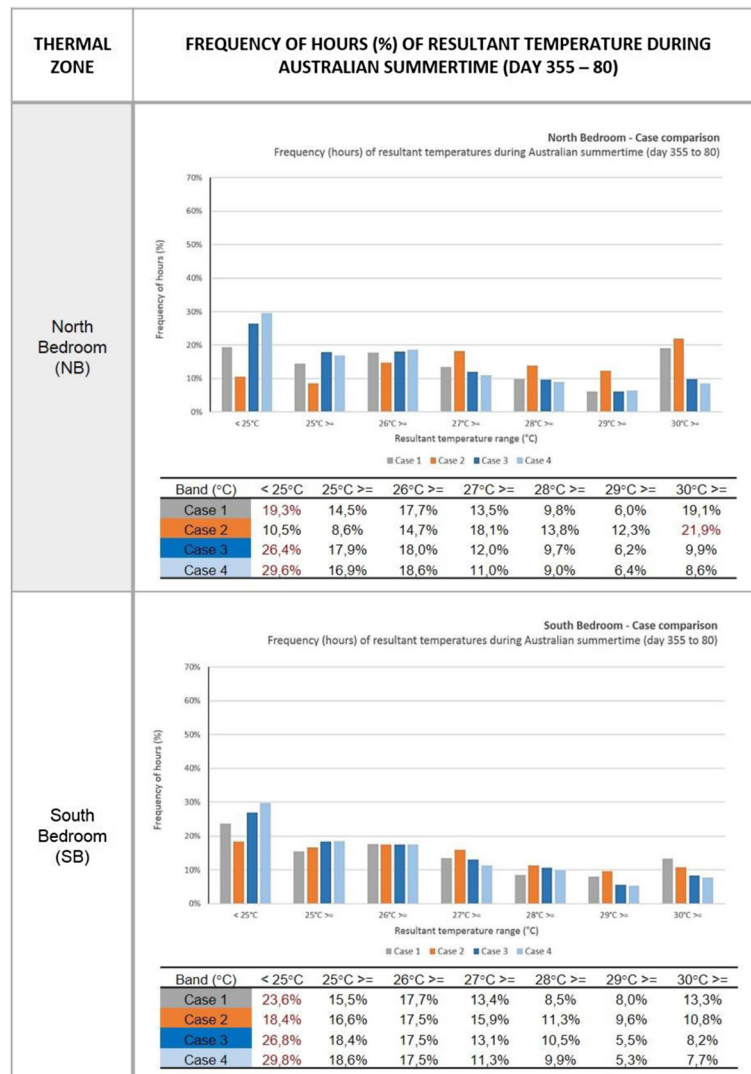
- Case 4: 95% aperture in openings did not significantly improve what was achieved in the previous case and comfort condition is achieved for over 60% of the occupied hours, indicating that a partial effective aperture of the openings (in Case 3) is sufficient to cool down the internal temperatures.

Thermal performance in both bedrooms shows a comparable trends as shown in Fig. 11.

- Case 1: in both zones, the percentage of achieving comfort levels without any ventilation present is over 65% of the hours; this is due to the shading on

the exposed facades provided by the verandahs, However 35% of the occupied hours are still outside the comfort range.

- Case 2: the results indicated that the addition of internal heat gains (while the envelope is closed), do not significantly affect the number of hours the bedrooms are within the comfort range (over 50%). The spatial arrangement of these spaces within the house is the key to attain the thermal comfort levels.
- Case 3: 50% of aperture in doors and windows increased the number of hours (above 70%) for the resultant temperatures fall within the comfort range in the bedrooms, indicating that natural ventilation improves the thermal comfort.
- Case 4: A 95% of aperture in openings, slightly increased the number (above 75%) of hours for the resultant temperatures fall within the comfort range,



**Fig. 11** Thermal performance comparison in bedrooms. Thermal assessment in EDSL TAS

showing that higher effective aperture is essential to improve the thermal comfort of these spaces.

**Spatial delight in the Ball-Eastaway house**

Completed in 1983, the Ball-Eastaway house is located at a remote bush land in Glenorie, NSW (33.6° S) and it was designed as a retreat and workspace for its artist owners. Murcutt intentionally positioned the house over a sandstone bed, and changed his distinctive preference for north orientation to exploit the site’s views and to create a more peaceful atmosphere (Fig. 12).

As suggested by Farrelly [6], this house’s configuration responds to the sandstone’s bed shape, which offered Murcutt the opportunity to lift the house off the ground on steel stilts (Fig. 12), protecting the building from wildfires while providing a less invasive building process;

the interior spaces were clearly defined between served spaces (i.e. bedrooms), positioned to the SW and serving spaces (i.e. living space) to the NE, intending to position the main spaces in contact with the exterior.

The section derived from a thoughtful site analysis, when the site’s high rainfall and surrounding trees were considered, Murcutt recognised that conventional gutters and pipes would block, therefore a vaulted, corrugated iron roof with broad gutters was his response (Fig. 13). Additionally, he favoured a light-weighted steel structure, (minimizing the use of timber) and corrugated iron exteriors, contrasting with the natural setting and the softer and warmer interior.

According to NatHERS (2014), the site experiences a seasonal climate with temperature range between 39,5 °C (January) and 0 °C (August) and a monthly mean rainfall



ranging from 122 mm (February), to 28,5 mm (July); therefore the building’s orientation and envelope are essential to cope with the site’s climatic conditions.

When the building’s orientation is analysed in relation to the sun path diagram, Murcutt’s intention of favouring the site’s views over a valuable north orientation is evident. As Fig. 13 shows, the house’s orientation exposed the public areas to partial sunlight ingress in the morning, while underexposed the private ones at the same time. According to NatHERS (2014), the optimum orientation would convey in better solar access (and heat gains) during winter, while providing a better opportunity to exploit the site’s prevailing winds during summer.

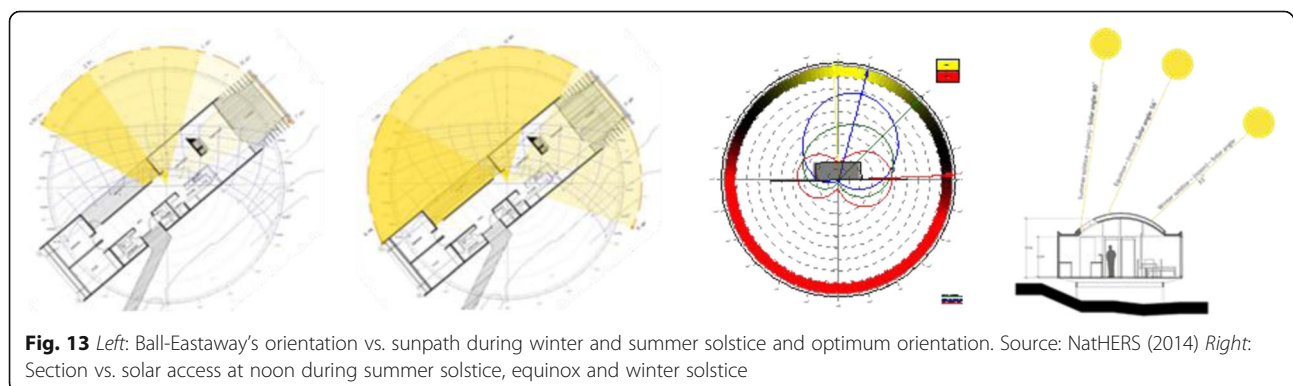
When the house’s section is overlapped with the solar angles during equinox and solstices at noon, it is clear that the roof was not intended to respond to the sun (Fig. 13), reinforcing the argument that orientation was not a priority here; nevertheless, the roof still provides shelter from the summer sun at noon and the associated heat gains, while admitting partial solar access during winter. As a free-running building, the house was designed to be cooled by natural ventilation, hence Murcutt raised it off the ground intending to improve cross-ventilation and reduce internal temperature during summertime.

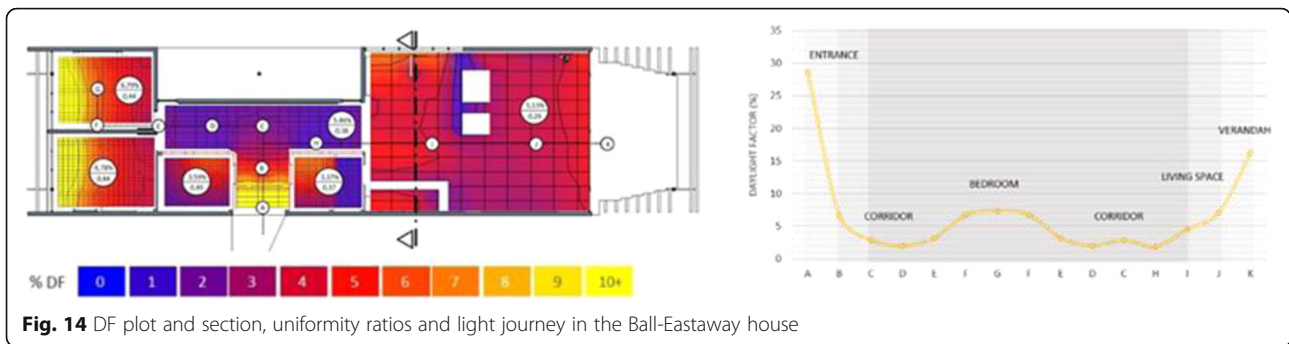
**Daylight assessment of the Ball-Eastaway house**

To assess the daylighting performance of the house’s main spaces, (i.e. living room and bedroom) and to ensure that the spaces were adequately day-lit, a target daylight factor of 2%, based on BSI [3] standard guidelines, was chosen to analyse their daylighting performance under overcast sky conditions. As shown in Fig. 14, the average daylight factor in the main spaces was above 5%, indicating that all spaces are well-day lit and no supplementary lighting from artificial sources is needed as CIBSE [4] established.

The uniformity ratios and light journey achieved (Fig. 14) in the internal spaces, showed that Murcutt designed and positioned the openings intentionally to create a dynamic, yet relaxing atmosphere. Despite the house’s orientation is not optimum, Murcutt was able to make a clear transition between the living space and the bedrooms. The most dramatic variation can be perceived in the main entrance, where the daylight factor drastically lowered providing visual adaptation to the inhabitants through the corridor.

To investigate the illuminance distribution within the house’s most occupied space (i.e. living room), daylight illuminance was assessed at noon under sunny sky (Equinox) and overcast skies conditions, to have a





**Fig. 14** DF plot and section, uniformity ratios and light journey in the Ball-Eastaway house

broader understanding of its performance. The results were compared to CIBSE [4] 300 lux recommendation.

As Fig. 15 illustrates, the high illumination levels (+680 lux average without internal blinds) present during sunny sky conditions in Equinox, indicates that while the space is well day-lit, an over-lit environment or visual fatigue might be experienced; under overcast sky conditions, the average illuminance levels significantly decreases to 280 lux, indicating adequate daylight illuminance is provided for visual perception; However, in both cases, the high illuminance levels achieved towards the opening indicate that, the use of blinds or operable shading devices is needed for improving the luminous environment.

To assess the luminous intensity, the brightness contrast ratio was used to evaluate whether the house provides visual comfort for its occupants in the living room. Although the sky conditions on site are mostly overcast, the luminance mapping was performed under both, sunny (Equinox) and overcast sky conditions, so that a more realistic luminous environment could be evaluated.

Murcutt designed the corridor as an exposition area for paintings, offering the best target for brightness contrast assessment. As Fig. 16 shows, the visual target considered does not suffer from major visual discomfort; however, as the results demonstrate, if the target is shifted towards the dining room, the luminance contrast might significantly change, implying that under these sky conditions the inhabitants may suffer from glare. If

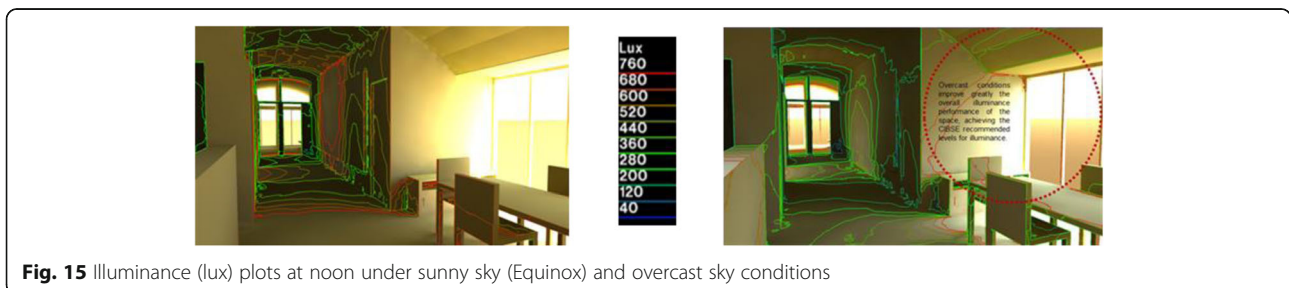
blinds or external architectural features were included, a more visually comfortable space could be provided.

### Thermal performance and spatial delight in the Ball-Eastaway house

Evaluating the thermal environment of the house was essential to have a full understanding of the building's performance and its impact on comfort, especially when Murcutt's projects are designed as free-running buildings, with operable envelopes designed to adapt to the climatic challenges. As Kallenbach [9] echoed Murcutt's words '[just as] we layer our clothing...our buildings should equally respond to their climates.'

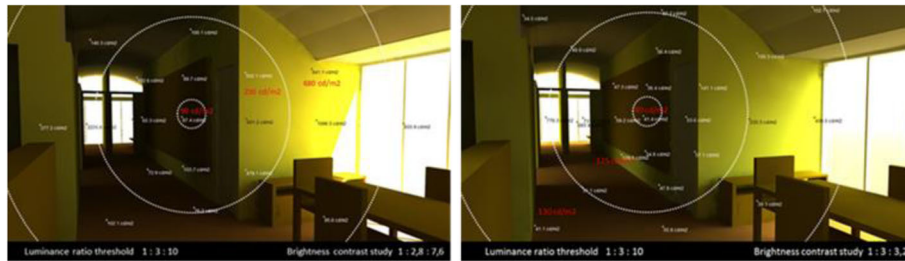
Since this house's orientation and spatial arrangement pointed to an unlikely positive thermal performance, a model of the house was built in EDSL TAS, distributing each space as a separate thermal zone (Fig. 17); simulations were performed aiming to have an overall idea of the annual thermal performance in key spaces, nevertheless, analysing winter's performance was essential and the chimney's heat transfers were considered.

The assessment considered three possible cases (Fig. 17), all having a constant natural infiltration rate of 0,50, shading as designed and varying in the levels of internal heat gains and natural ventilation rates. Case 1 was set up as a base example with no heat gains and no natural ventilation; Case 2 as summer's scenario with natural ventilation and heat gains; Case 3 represented winters' scenario and all internal heat gains were included and natural ventilation was set to occur only if the resultant temperatures



**Fig. 15** Illuminance (lux) plots at noon under sunny sky (Equinox) and overcast sky conditions





**Fig. 16** Luminance (cd/m<sup>2</sup>) assessment at noon under sunny sky (Equinox) and overcast sky conditions

surpassed the established comfortable temperature range. Aperture variation in openings was considered to recognise the influence of natural ventilation on thermal comfort.

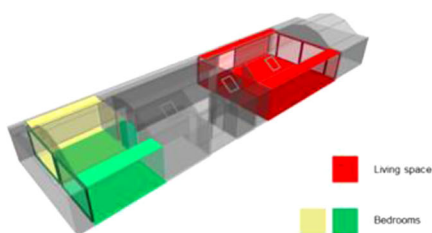
In order to define a comfort zone, monthly average temperatures were used as a base to calculate the optimal temperature for comfort (i.e.  $T_{\text{comf}}$ ) in Richmond, NSW, based on the Adaptive Model by Nicol et al.

The following assumptions were considered for the simulations:

- Weather: Energy Plus weather data for Richmond, New South Wales.
- Comfort range: winter between 19 °C to 23 °C, and 22 °C to 27 °C during summertime.
- Calendar: Annual
- Internal Gains:
  - Occupancy: two adults with heat gains assumed to be of 180 W (sensible) and 100 W (latent).
  - The occupancy schedule was set for 24 hours.
- Lighting: compact low-energy florescent bulbs with a total load of 2,5 W/m<sup>2</sup>
- Equipment gains: hob, a washing machine, a dishwasher and a fridge, all with a total load of 25 W/m<sup>2</sup>.
- Chimney sensible gains of with a total load of 40 W/m<sup>2</sup>.
- Ventilation: during occupancy periods all openings had the same opening pattern; starting to open when the temperature reached 19 °C and fully opened at 27 °C.

Thermal analysis results were compared between both thermal zones, comparing seasonal thermal performance vs. average resultant temperatures to examine the correlations. Results were shown as a percentage of time when the resultant interior temperature ranged between 19 °C to 23 °C in winter, and 22 °C to 27 °C in summer. As Fig. 18 shows, both spaces share a similar thermal performance; however, during winter, the living room’s performance improved while the bedroom’s performance becomes worse. The following conclusions were drawn from this analysis:

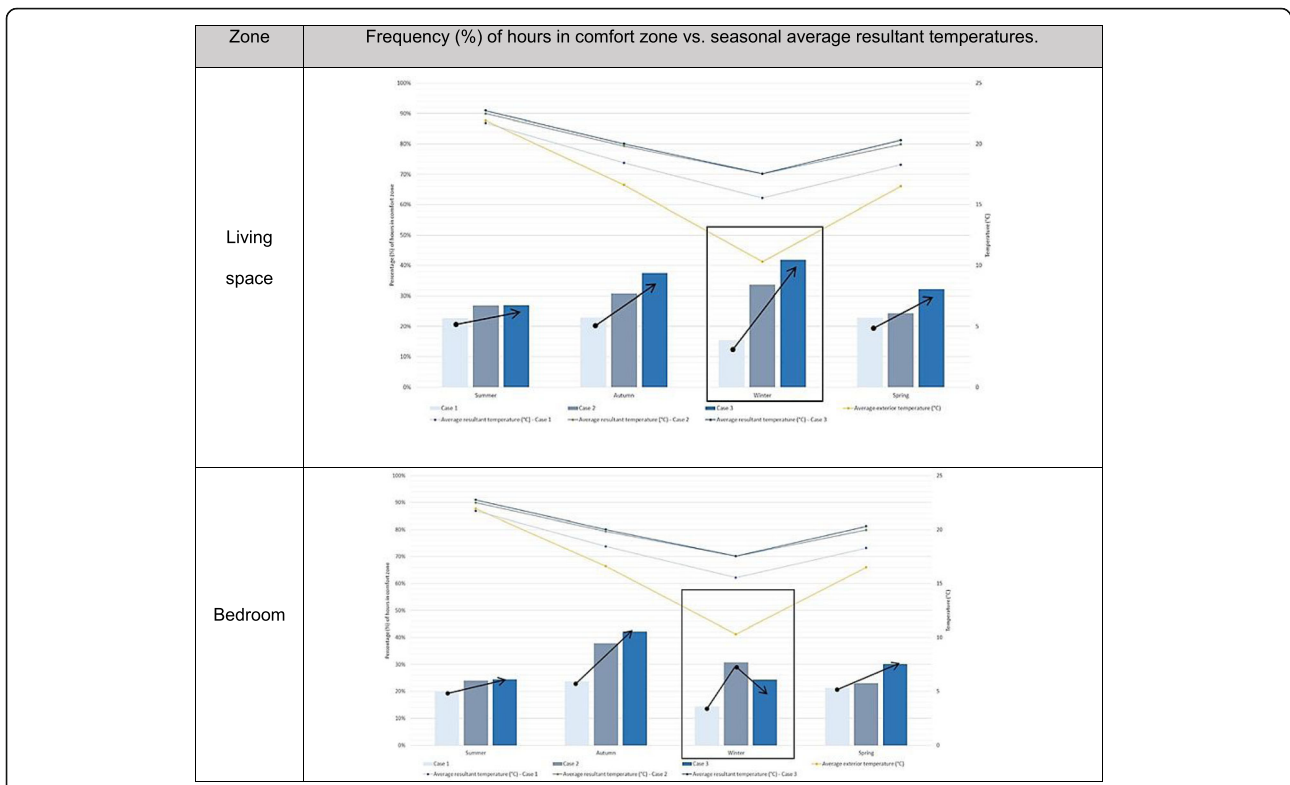
- Case 1: Annually, 20% of the occupied time in the house falls within the comfort zone, (except during winter when performance falls to 15%), inferring heat gains are essential to improve the thermal performance.
- Case 2: The thermal comfort in the internal spaces is within the comfort range for 25% of the time; despite heat gains improved the percentage of time within the comfort range, resultant temperature was 17 °C (below comfort); in summer, natural ventilation can help improve the thermal environment as the predicted resultant temperature reached 22 °C.
- Case 3: represented the best scenario during winter for the living room, while unexpectedly the worst for the bedrooms; the chimney’s heat gains seem to have a significant impact on the living room’s thermal performance, but seemingly the envelope’s airtightness is not enough, as heat gains from the



Case	Description
Case 1	Shell with 0.5 infiltration rate, no ventilation or internal heat gains considered.
Case 2	Shell with 0.5 infiltration rate + natural ventilation* (1.5 ach) with 30% aperture when resultant temperature reaches 19°C + internal heat gains.
Case 3	Shell with 0.5 infiltration rate + natural ventilation* (1.5 ach) with 90% aperture when resultant temperature reaches 19°C + internal heat gains + chimney heat gains**

\* Natural ventilation is assumed not to be needed during wintertime (May - August)  
 \*\* Chimney heat gains only considered during occupancy hours.

**Fig. 17** Left: Thermal assessment and zoning of key spaces in the Ball-Eastaway house. Thermal assessment in EDSL Tas. Right: Summary of thermal cases examined



**Fig. 18** Seasonal thermal performance of main spaces vs. average exterior and resultant temperatures

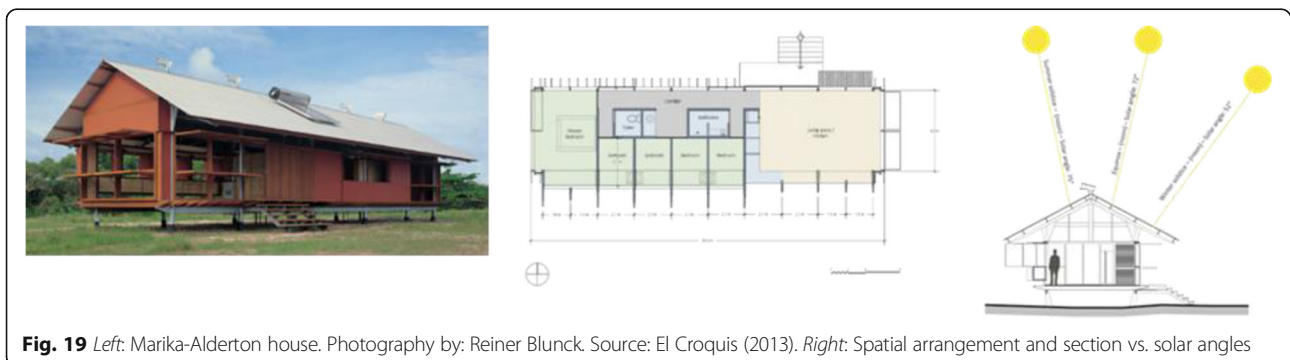
chimney seemingly do not reach the bedrooms. During summer there was no perceptible improvement, indicating that natural ventilation by itself is not enough to dissipate the internal heat gains. Annually both spaces performed thermally at an average of 30% of the occupied time.

**Spatial delight in the Marika-Alderton house**

The Marika-Alderton house is positioned by the seaside in Eastern Arnhem, NT (12.5° S) and was completed in 1994. According to Beck and Copper [1], the house was designed for an aboriginal family intending to create a dwelling that followed native traditions, while providing shelter from climate. Murcutt oriented the house facing north (Fig. 19),

while arranging the spaces responding to aboriginal tradition, with the adult’s room positioned to the West, where the sun sets, while the children’s bedrooms are located to the East, where the sun rises symbolizing new life. In this project, Murcutt converged and materialized his life learnings on Thoreau’s philosophies, with the lessons learnt from vernacular architecture and aboriginal way of life, Fromont [7].

The house’s section was conceived to fully respond to the site’s tropical climate, (i.e. harsh sunlight, high temperatures, humidity levels and occasional cyclones) while providing visual connection with the exterior; Murcutt conceived a slim, symmetrical section (Fig. 19) raised off the ground on steel pillars to improve the effect of natural



**Fig. 19** Left: Marika-Alderton house. Photography by: Reiner Blunck. Source: El Croquis (2013). Right: Spatial arrangement and section vs. solar angles

ventilation, while the roof's long overhangs protect the interior from sun and rain. An operable and permeable envelope, (composed by slatted shutters, doors, tilting plywood panels and sun breakers) ensures a constant flow of fresh air, while the sun breakers provide shading to all bedrooms from low-angled southern sun.

When the envelope and structure's materiality is observed, the pragmatic and unpretentious intentions of Murcutt is clear. By using modest building materials such as steel, timber, plywood and corrugated iron, it is possible to orchestrate a space that adapts accordingly to climate.

According to BOM [2], the site experiences constant high temperatures (18 °C to 35 °C), humidity, rainfall, solar radiation levels and occasional cyclonic winds, thus while encouraging natural ventilation, blocking undesired sunlight is required. As Fig. 20 shows, the house's orientation as designed is very close to the optimum orientation.

Murcutt merged the outside and inside, with an aim to cool down the interior through natural ventilation and shading; nevertheless, its permanent contact with the exterior makes the building dependent on exterior temperatures to achieve comfort, hence an increase in wind speed is necessary conscious of this, Murcutt included in the roof several Windworkers designed to increase air flow within the house, encouraging natural ventilation and the extraction of heat trapped in the roof (Fig. 20).

### Daylight assessment of the Marika-Alderton house

Following the methodology described in the above case study, the daylighting performance of the house's main spaces, was investigated under overcast sky conditions. As Fig. 21 shows, the average daylight factor in the main spaces ranged from 3% to 5%, indicating that most of the spaces are well-day lit and artificial lighting is required for most of the time. Additionally, the light journey graph indicates a continuous variation in daylight, ranging from a vivid atmosphere in serving spaces, to a calmer one in the bedrooms.

The daylight illuminance was assessed in the living space, at noon under sunny sky (Equinox) and overcast

skies conditions; results were compared to CIBSE [4] 300 lux recommendation.

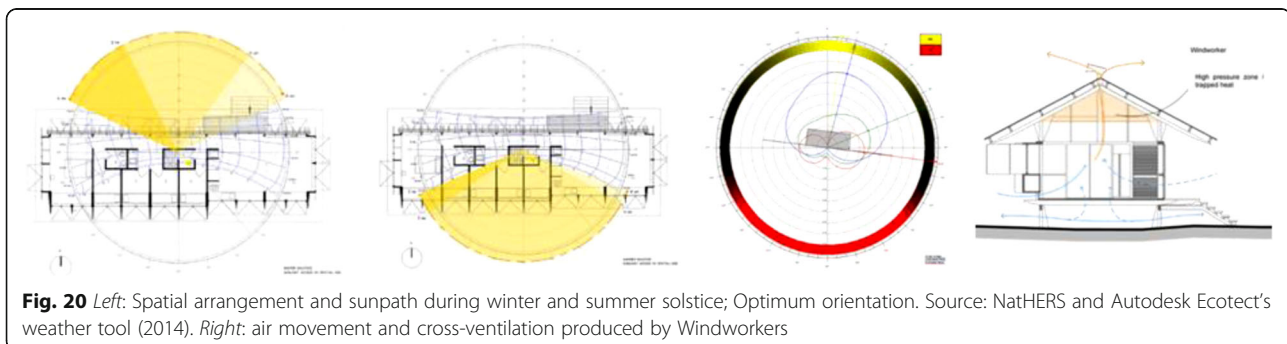
As illustrated in Fig. 22, under sunny sky conditions during Equinox, shading devices completely protect surfaces from direct sunlight, yet the high light levels (+600 lux average) indicate that even if the space is well day-lit, visual fatigue may be experienced, suggesting that if the operable openings were closed, this condition might considerably improve; however, under overcast sky conditions, the illuminance levels achieved between 250 – 300 lux in average, indicating desirable luminous environment with good level of visual acuity.

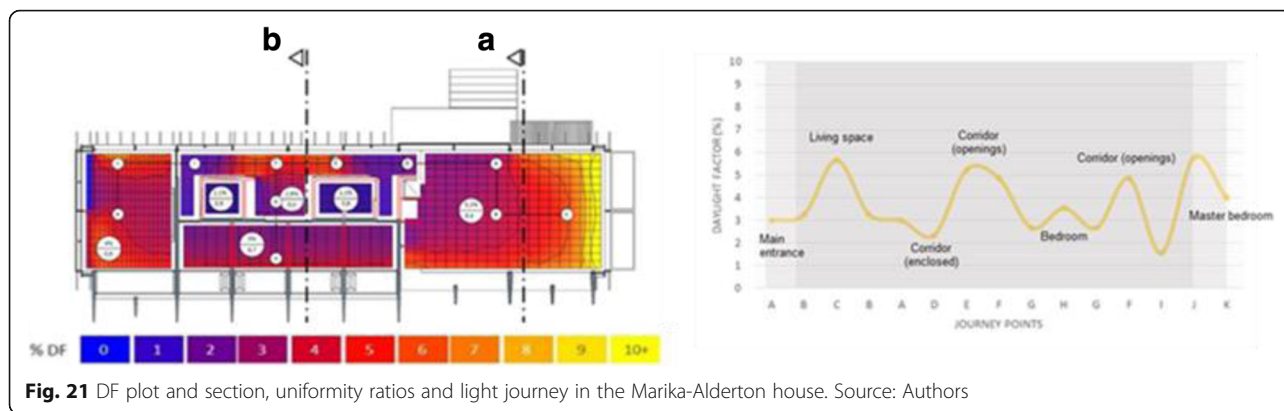
According to the results of the brightness contrast analysis (Fig. 23), the brightness contrast ratio between the visual tasks and their surroundings proved that experiencing visual discomfort is unlikely to occur. The careful selection of building materials with relatively low reflectance (i.e. mostly wood in the interior), decreased the chance of experiencing visual discomfort. Nevertheless, this study was performed considering all shutters remained opened (as worst case scenario); if they were closed, the risk of visual discomfort would be significantly reduced.

### Thermal performance and spatial delight in the Marika-Alderton house

The constant permeable nature of the house was considered, as it is dependent on the exterior thermal environment and wind to cool down the interior. Additionally, the shallow envelope (built on elements with low thermal properties), and warm air been constantly pushed into the house were taken into account.

To assess the thermal conditions, a model of the house was built in EDSL TAS (Fig. 24), distributing each space as a separate thermal zone. The simulations were performed aiming to have an overall idea of the annual performance of the main living spaces and to provide evidence on the effect that solar radiation, natural ventilation and internal heat gains had on the resultant temperatures annually. In order to have more realistic results, the Windworkers' 'Venturi' effect was simulated by adding opaque openings to the roof.





**Fig. 21** DF plot and section, uniformity ratios and light journey in the Marika-Alderton house. Source: Authors

The assessment considered three possible cases (Fig. 24), all having as constants: shading, natural ventilation (varying accordingly to each case) and infiltration rate 0,50; heat gains were the only variants. Case 1 was set as a base example with partial natural ventilation and no heat gains; case 2 represented the worse scenario, as heat gains were included; case 3 was designed as the best possible scenario, as natural ventilation was increased to have a stronger perspective on the influence natural ventilation had on thermal comfort.

Setting a comfort zone for this analysis, followed the same principles, equations and guidelines described in the above case study, based on the optimal temperature for comfort (i.e.  $T_{comf}$ ) in Darwin (NT), and based on the Adaptive Model by Nicol et al.

The following assumptions were considered for these simulations:

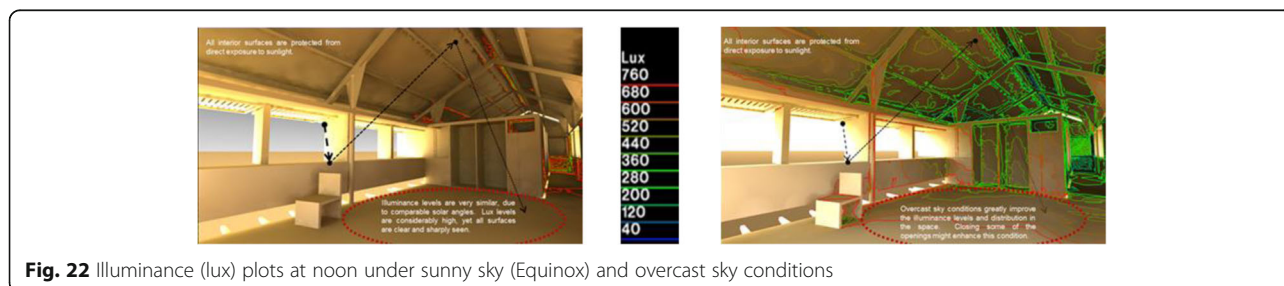
- Weather: Energy Plus weather data for Darwin, NT.
- Comfort range: assumed to be between 23 °C to 28 °C
- Calendar: Annual
- Internal Gains:
  - Occupancy: 2 adults and 4 children; heat gains assumed 450 W (sensible) and 250 W (latent).
  - The occupancy schedule was set assuming a 24 hours.
- Lighting: compact low-energy florescent bulbs with a total load of 1,5 W/m<sup>2</sup>
- Equipment gains: equipment’s considered were a hob and a fridge, with a total load of 25 W/m<sup>2</sup>.

- Ventilation: opening schedule is based on occupancy, partial natural ventilation is allowed 24 hours a day.

Thermal analysis results were compared between both zones, relating seasonal thermal performance vs. average resultant temperatures. Results are shown as a percentage of time when the resultant interior temperature ranged between 23 °C to 28 °C; yet the consequences of the house being an open space have to be considered.

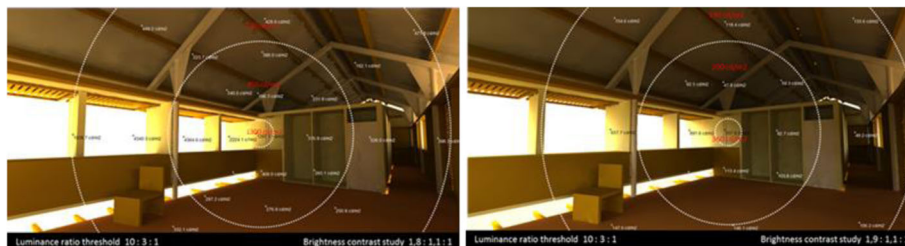
As Fig. 25 shows, both spaces shared a similar thermal performance; annually none of the spaces reached a 30% of time within the comfort range, having significantly high resultant temperatures fluctuating between 27 °C to 35 °C. The following conclusions were drawn from the analysis:

- Case 1: 20% of the occupied hours in a year are within the comfort range (without any heat gains). During winter the thermal performance fell with 16% of the occupied hours falling within the comfort zone.
- Case 2: Presented an insignificant improvement when compared to Case 1; only a 3% increase of the time within the comfort zone was experienced when natural ventilation was introduced; overheating could be experienced and extra cooling is needed.
- Case 3: The comfort range slightly increased to 25% when twice the air flow was introduced, still the building is unable to rapidly exhaust warm air trapped under the roof, leading to overheating.



**Fig. 22** Illuminance (lux) plots at noon under sunny sky (Equinox) and overcast sky conditions





**Fig. 23** Luminance (cd/m<sup>2</sup>) assessment at noon under sunny sky (Equinox) and overcast sky conditions

Overall, the thermal performance of both spaces is poor, only 30% of the occupied hours in a year are within the comfort range, demonstrating it potentially needs mechanical cooling; however, the thermal conditions could potentially be improved and moderated by the occupants' control of the building's operable envelope.

**Conclusion**

Through an in-depth analysis of each house, supported by the factual evidence gathered from qualitative and quantitative analysis, the authors have attained a holistic understanding of Murcutt's architectural achievements, the reasoning behind his design approach and building solutions. Moreover, the authors have outlined the significant impact that Murcutt's design intents have on the visual and thermal comfort of his buildings.

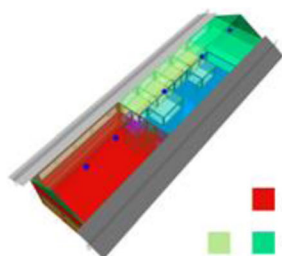
From a qualitative perspective, not only were Murcutt's design intentions revealed, but also, the intrinsic connection he proposed between the manmade space and nature were presented. Through simple forms and humble materials, Murcutt merges his buildings with nature, not implying the superiority of one over the other, but through unity, his architecture constantly reminds us the significance of nature.

Detailed site-specific climate analysis including the solar trajectory, prevailing winds, rainfall and landscape, is Murcutt's essential first step in dealing with a design challenges. When all these factors combine, nature seems to speak and guide him to define forms and spaces that are translated into climate responsive, potentially free-running vernacular inspired architecture. Once this in-

depth contextual knowledge is overlaid with his main environmental design strategies, (i.e. orientation, narrow plans with climate-responsive sections, natural ventilation, shading and light-weighted operable skins) an architecture that adapts to the local climate and site conditions is born.

When the luminous environments in the three selected buildings were analysed, they proved to be mostly well day-lit, nevertheless throughout all projects assessed, in order to improve visual comfort, shading devices (such as blinds, shutters or sun breakers) need to be constantly deployed. However, Murcutt's skilful way of handling day-light produced subtle light journeys in the houses, which offers variation in intensity depending on the spatial function and intended atmosphere, ranging from vibrant light in public spaces, to soothing light in private ones.

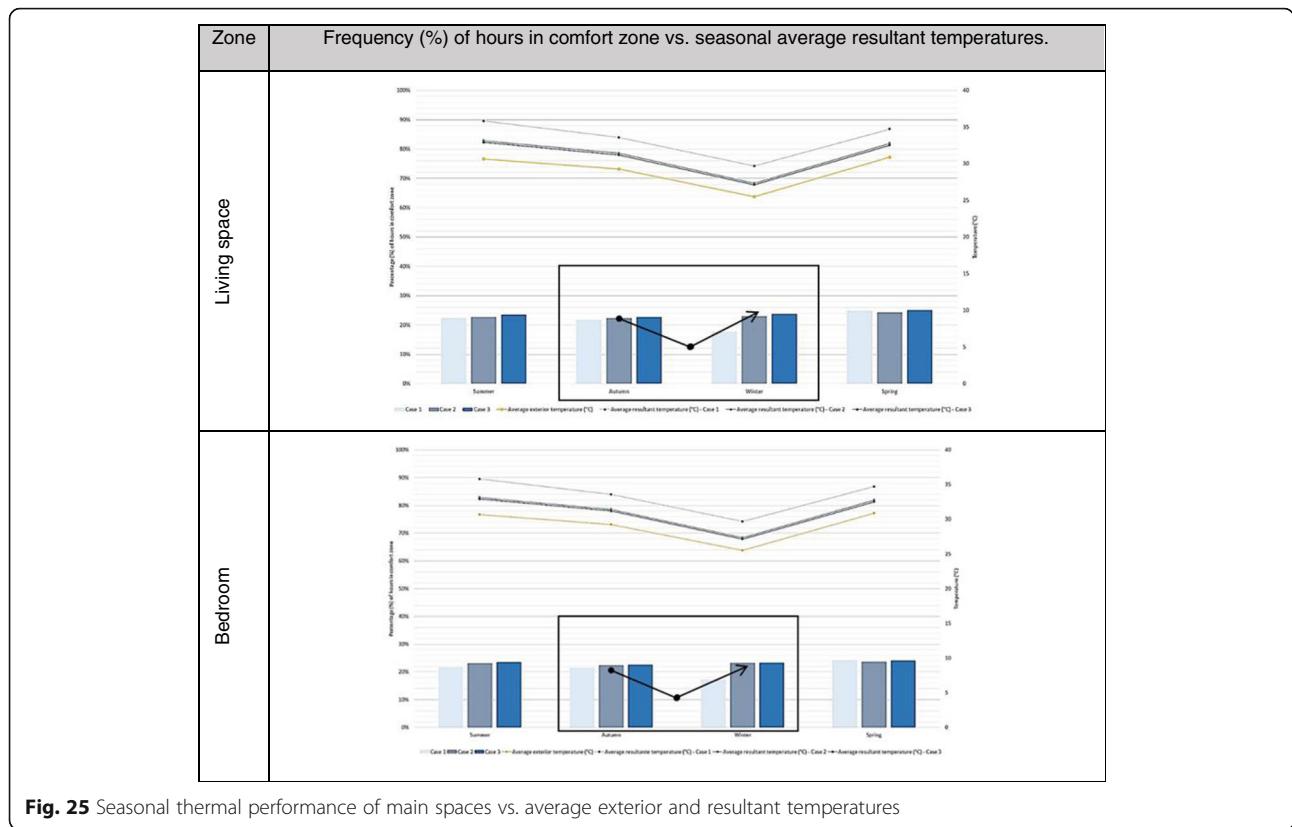
For the thermal environments in his houses, the thermal analysis revealed occasional thermal discomfort. Considering the houses' envelopes as designed, the results showed that in the Ball-Eastaway house, the thermal performance of the main spaces fell below an annual average of 30% of the occupied time within the comfort range, suggesting that improving the envelope's insulation and airtightness, combined with extra heating (for winter) could potentially improve the house's thermal comfort. In the Marika-Alderton house, which presented an annual average of 25% of the time within the comfort range, showing that even when the Windworkers was used to increase the air movement, the main spaces still experienced overheating which is caused by the fact that the building's envelope was designed to be light-weight and the roof is not



Case	Description
Case 1	Shell with 0.5 infiltration rate + 1 ach (30% natural ventilation*) NO internal heat gains considered.
Case 2	Shell with 0.5 infiltration rate + 1.5 ach (30% natural ventilation*) + internal heat gains considered.
Case 3	Shell with 0.5 infiltration rate + 2.5 ach (90% natural ventilation*) + internal heat gains considered.

\* Natural ventilation is assumed 24 hours, 365 days

**Fig. 24** Left: Thermal assessment and zoning of key spaces in the Marika-Alderton house. Thermal assessment in EDSL Tas. Right: Summary of thermal cases examined



insulated. However, occupants’ active control of the operable building envelopes might potentially help reduce certain degree of overheating in summer.

In the Marie Short house, Murcutt’s environmental design strategies, (i.e. orientation, natural ventilation, shading and designing a light weighted building, raised off the ground on stilts) created a low energy building, which constantly interacts with the outside, and offers the inhabitants the opportunity to dictate how to operate and adapt their spaces. Undoubtedly as the results demonstrated, in order to maximise thermal comfort the key living spaces are dependent on natural ventilation, as the shading alone will not significantly decrease the resultant temperatures. On the other hand, even though Murcutt provided the main facades with integrated blinds, the results have shown that if left opened, the inhabitants will experience visual discomfort, indicating that even when Murcutt wanted to have a constant connection with nature, reconsidering the opening sizes might help improve the visual comfort and spatial delight of the house.

When the Marie-Short house is fully investigated and its performance assessed, Murcutt’s design excellence and skilfulness are more significant than this building’s apparent deficiencies. The Marie-Short house has to be analysed as a free-running building, which constantly

changes and adapts to the climate and its inhabitants needs.

The spatial and environmental delight in Murcutt’s buildings lies in this delicate relationship between providing an enriching spatial experience (through a constant connection with nature), and at the same time offering desirable comfort conditions. Through his pragmatism, Murcutt designed buildings responding to the site conditions and climate. Through the balance between man and nature, Murcutt’s buildings are vivid, healthy and delightful, but more importantly, they are designed to be operable and constantly influenced by the external conditions, in order to allow the inhabitants to fully experience and control their space.

It is important to reflect that Murcutt designed these environmental conscious buildings by utilising unpretentious local materials and construction techniques. The constant connecting of his architecture with the natural environment, and his unique application of reinterpreted vernacular elements such as verandahs, overhangs and narrow spaces with permeable skins combined with Murcutt’s environmental design strategies has produced self-reliant, low energy consumption buildings.

In the case of the Marie-Short house, its cleverness at first glance is disguised as a modest woolshed. It stands lightly, quiet and unpretentious surrounded only by the Australian landscape. Through this humble design,

Murcutt transformed a seemingly artless woolshed, into a fascinating habitat, allowing its inhabitants to adjust the spaces accordingly to their needs. Just as Heath [8] described Murcutt's work as a choreography, 'designed so it can literally be tuned like an instrument to respond to seasonal cycles', the Marie-Short house performed as it was designed to, as a free-running building.

Murcutt's spatial quality transcends from mere aesthetics into workable, adaptable and pleasing spaces; through his buildings, Murcutt has revitalized (rather than imposing) the vernacular architecture principles and reapply them to create humble, yet site specific and innovative architecture.

#### Abbreviations

CIBSE: Chartered Institution of Building Services Engineers; EDSL: Environmental Design Solutions Limited; NatHERS: Nationwide House Energy Rating Scheme (Australia); NB: Northern bedroom; NLR: Northern living room; NT: Northern Territory Australia; SB: Southern bedroom; SLR: Southern living room

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#### Authors' contributions

ML did the research, software analysis and initial draft of the paper. LR and BL provided guidance, reviewed and supervised all stages of this study. DJ reviewed and edited the material to generate this technical report. All authors read and approved the final manuscript.

#### Competing interests

The authors declare that they have no competing interests.

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