Passive House vs. Passive Design: Sociotechnical Issues in a Practice-based Design Research Project for a Low-energy House

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Figure 1. Prototyping of SIP walling system for the LP13 project

145x68mm (150 x 150 DPI)

Figure 2. Suburban volume housing near Sydney

118x57mm (150 x 150 DPI)

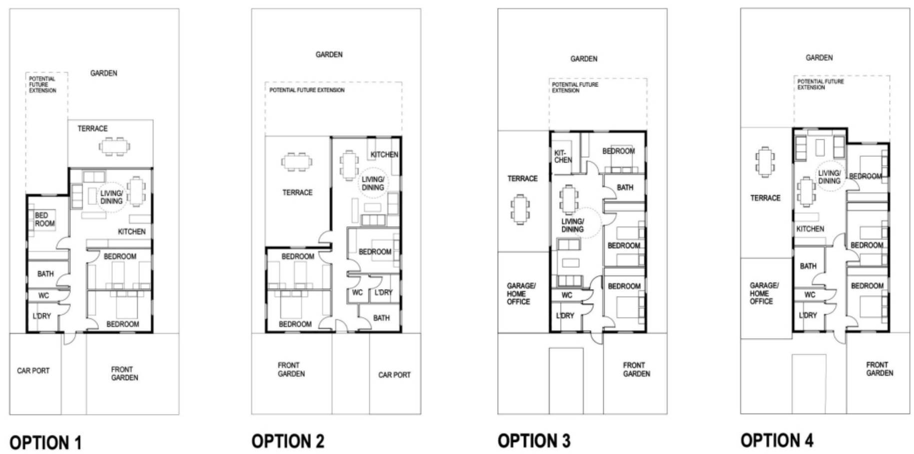

Figure 3. Initial floor plan design studies

297x209mm (300 x 300 DPI)

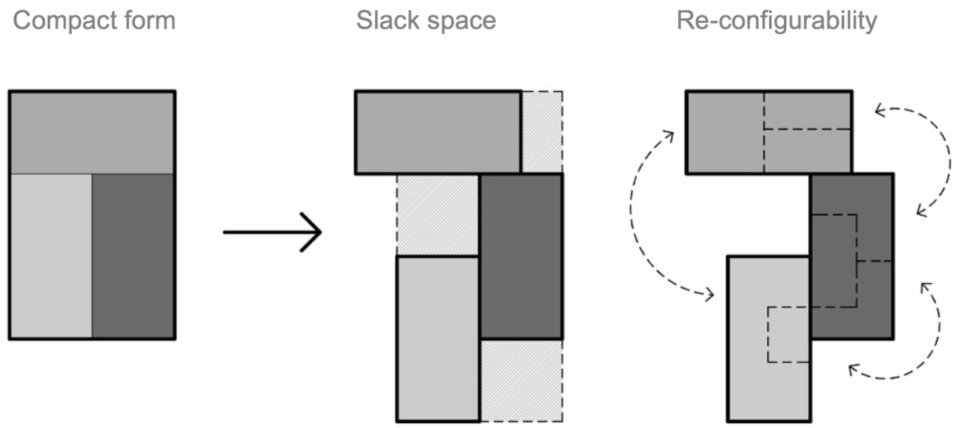

Figure 4. Design strategy diagrams

342x170mm (144 x 144 DPI)

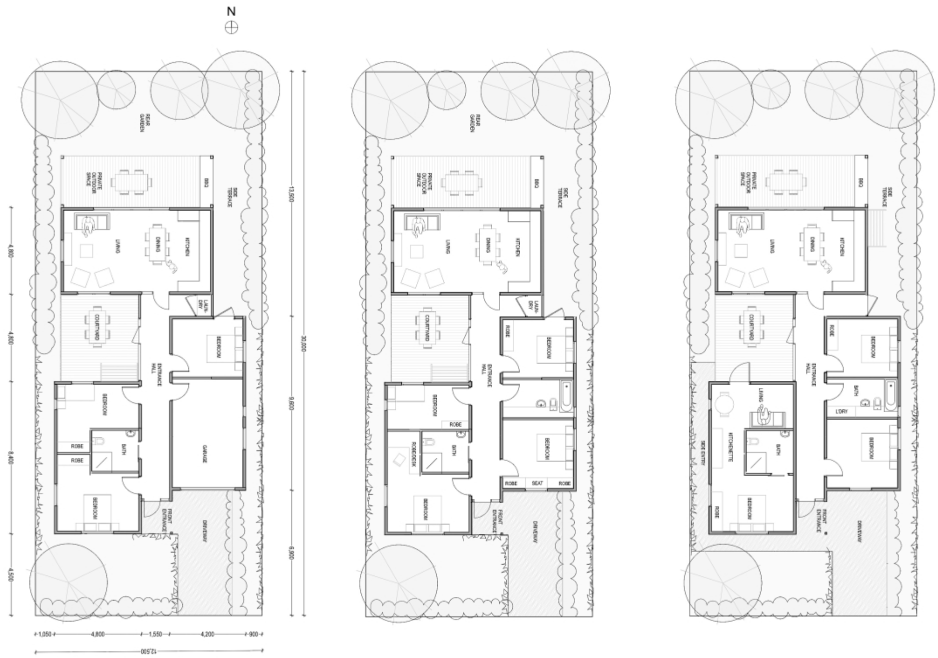

Figure 5. Three floor plan configurations (3 bed house with garage; 4 bed house; or 2 bed house and studio)

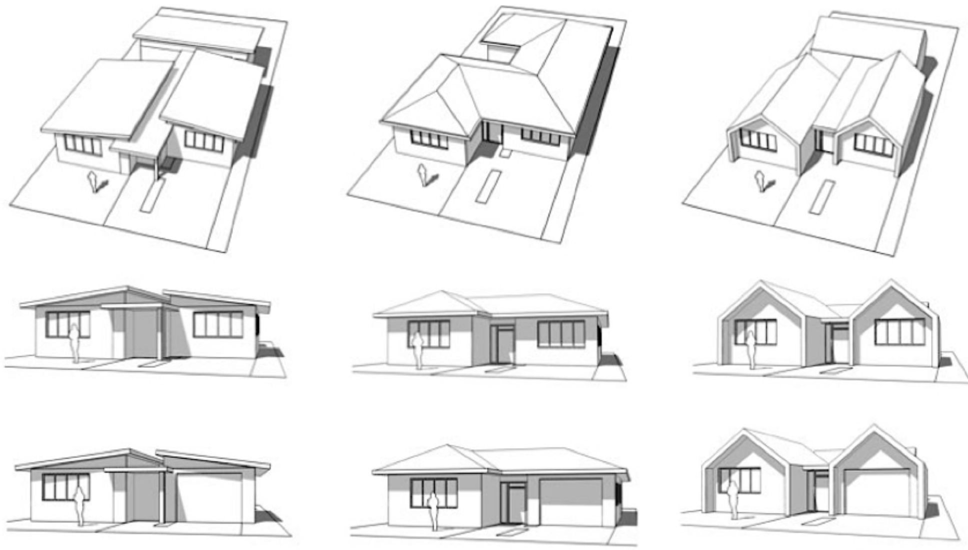

Figure 6. External envelope with a skillion, hip and gable roof option

146x81mm (150 x 150 DPI)

Figure 7. House in Adelaide Hills under construction with industry partner's SIP wall system

119x73mm (150 x 150 DPI)

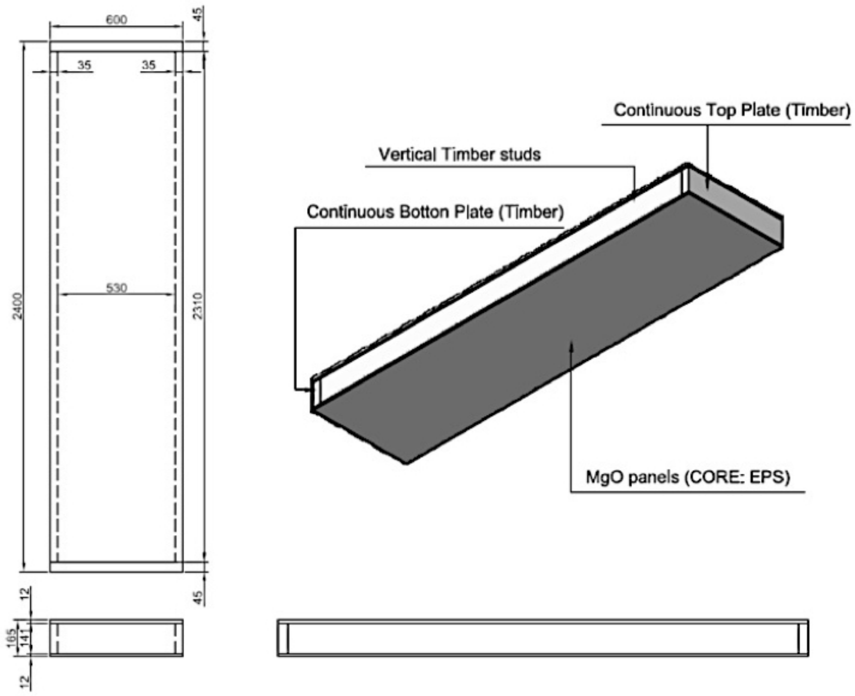

Figure 8. SIP wall panel by industry partner with timber splines

140x100mm (150 x 150 DPI)

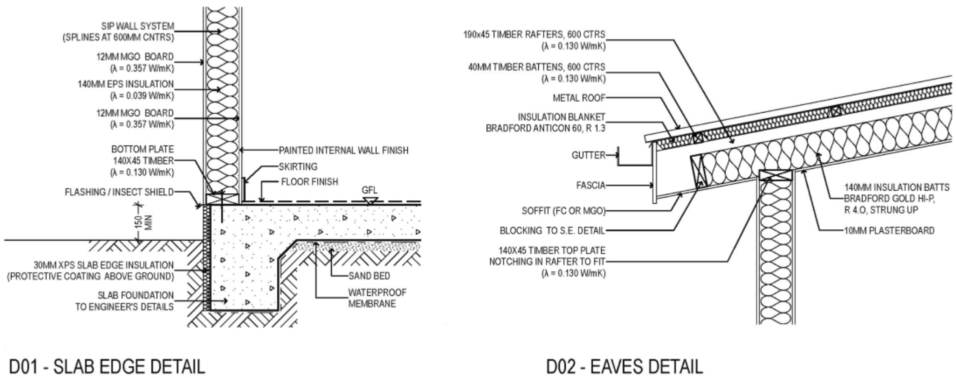

Figure 9. Key details for external envelope

279x116mm (300 x 300 DPI)

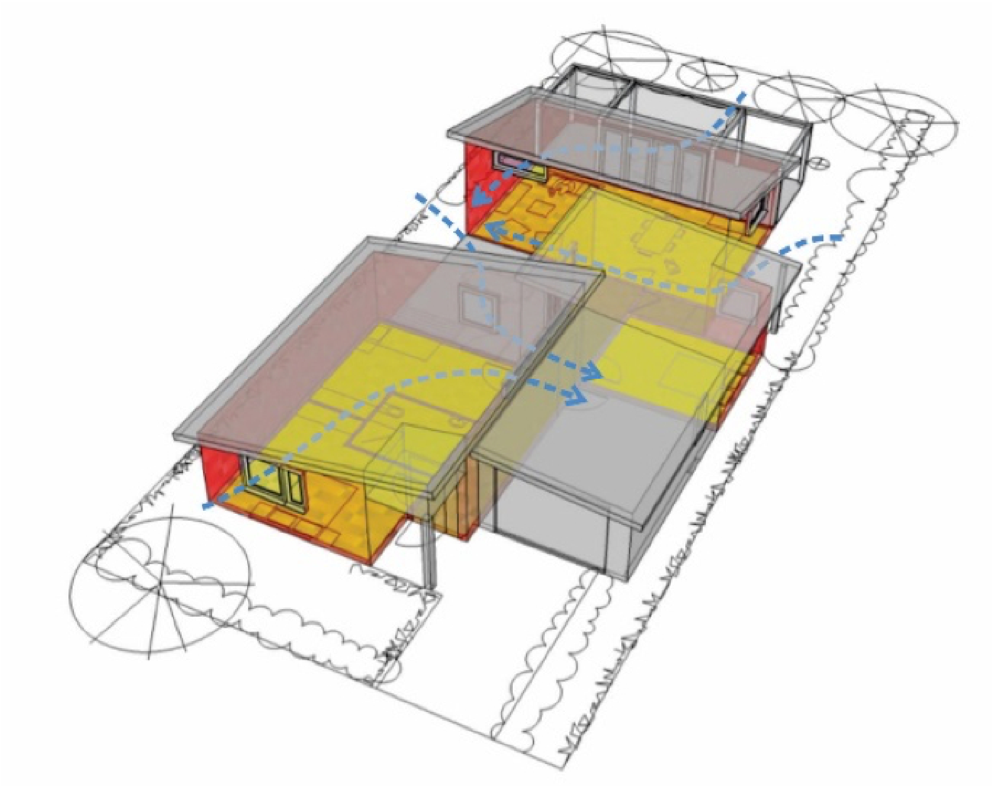

Figure 10. Design PH model with skillion roof option (purge ventilation indicated in blue)

116x92mm (150 x 150 DPI)

Specific building characteristics with reference to the treated floor area

					Criteria	Alternative criteria	Fullfilled?[2]
	Treated floor area	m²	96.5				
Space heating	Heating demand	kWh/(m²a)	17	≤	15	-	yes
	Heating load	W/m²	10	≤	-	10	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-	-
	Cooling load	W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C)	%	8	≤	10		yes
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	20		yes
Airtightness	Pressurization test result n_{50}	1/h	0.6	≤	0.6		yes
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	119	≤	120		yes
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	63	≤	-	-	-
	Generation of renewable energy (in relation to pro-jected building footprint area)	kWh/(m²a)	41	≥	-	-	

[2] Empty field: Data missing; '-': No requirement

Figure 11. PHPP assessment results with basic configurations failed to achieve the Passive House standard.

148x53mm (150 x 150 DPI)

Specific building characteristics with reference to the treated floor area

	Treated floor area	m²	96.5		Criteria	Alternative criteria	Fullfilled?[2]
Space heating	Heating demand	kWh/(m²a)	**41**	≤	15	-	**no**
	Heating load	W/m²	**18**	≤	-	10	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	**-**	≤	-	-	**-**
	Cooling load	W/m²	**-**	≤	-	-	
	Frequency of overheating (> 25 °C)	%	**4**	≤	10		**yes**
	Frequency of excessively high humidity (> 12 g/kg)	%	**16**	≤	20		**yes**
Airtightness	Pressurization test result n_{50}	1/h	**0.6**	≤	0.6		**yes**
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	**176**	≤	120		**no**
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	**92**	≤	-	-	**-**
	Generation of renewable energy (in relation to pro-jected building footprint area)	kWh/(m²a)	**0**	≥	-	-	

[2] Empty field: Data missing; '-': No requirement

Figure 12. PHPP assessment results with revised configuration achieved the Passive House standard.

147x52mm (150 x 150 DPI)

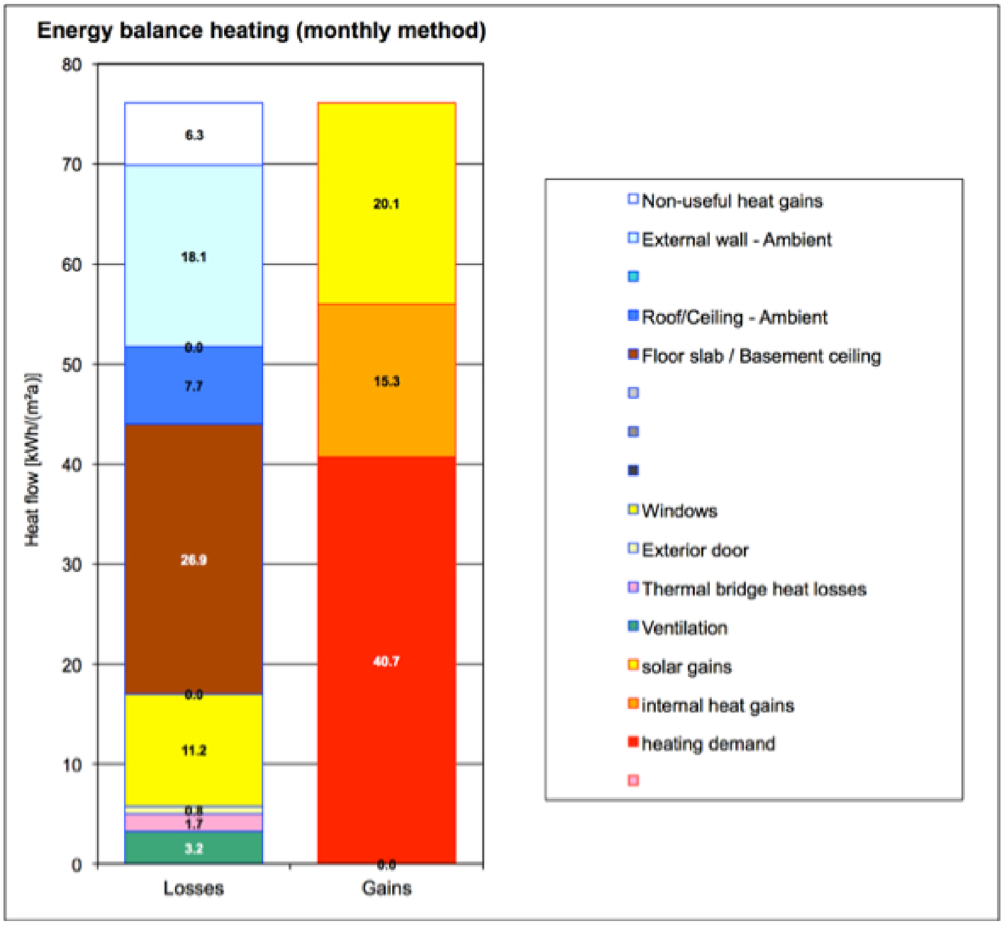

Figure 13. Energy balance heating for initial configuration that did not meet the Passive House standard.

99x91mm (150 x 150 DPI)

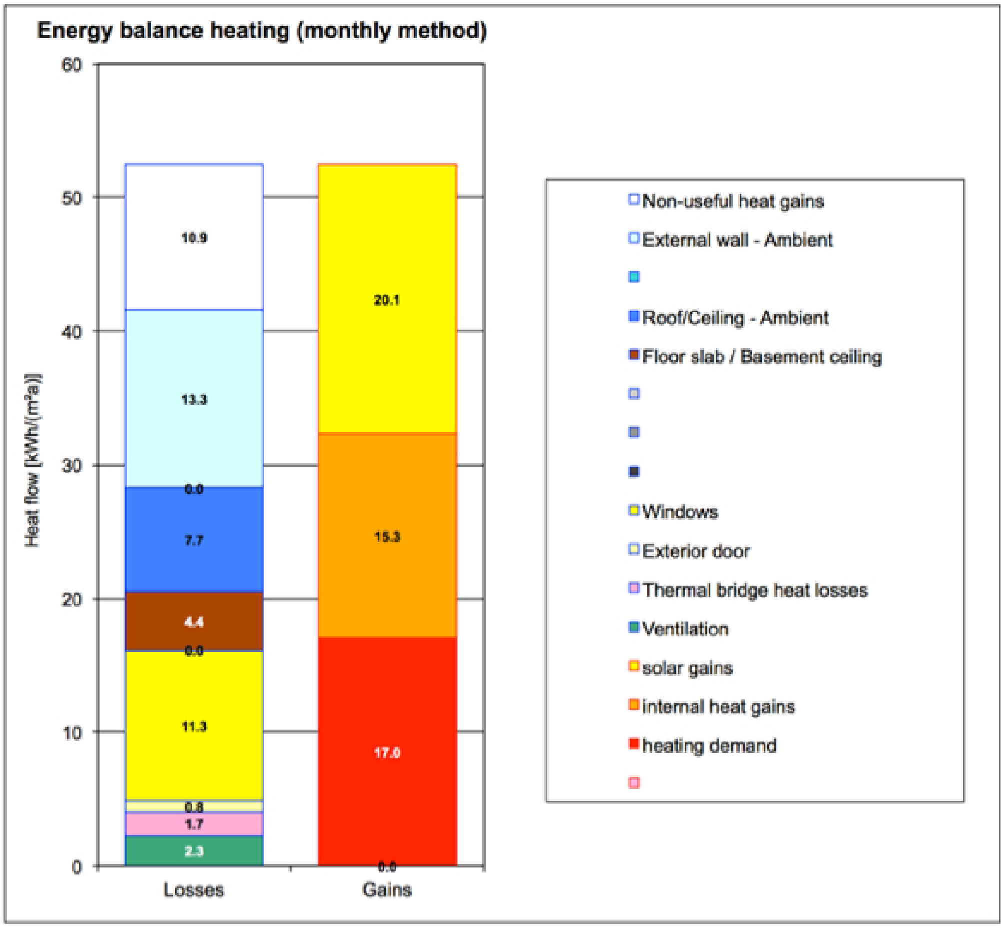

Figure 14. Energy balance heating for revised configuration that could achieve the Passive House standard.

98x91mm (150 x 150 DPI)

Passive House vs. Passive Design: Sociotechnical Issues in a Practice-based Design Research Project for a Low-energy House

Building performance simulation tools such as the Passive House Planning Package (PHPP) can be invaluable for improving energy-efficiency in housing design. However, achieving improved energy performance is also a sociotechnical issue, and how this is dealt with during the architectural design process is less well studied. This collaborative design research project for a low-energy prefab house with an industry partner, a manufacturer of Structural Insulated Panels (SIP), is used as a case study to show that it is possible to achieve high energy performance while addressing specific socio-technical concerns within Australia's volume homebuilding market. A key issue that emerged in this project was perceived tensions between passive design expectations in Australia and those promoted through the Passive House software tool.

Keywords: sustainable; housing; prefab; energy-efficiency, sociotechnical

Subject classification codes: include these here if the journal requires them

Introduction

Building performance simulation tools can be invaluable during the design process to improve the energy-efficiency of proposed buildings. The available body of literature on energy performance of buildings is extensive, exploring both technical aspects, such as the efficiency of building envelopes (De Boeck et al. 2015), as well as social aspects, such as user evaluations and preferences (Hauge, Thomsen, and Berker 2011). How sociotechnical factors play a role in the design process itself, however, seems less well studied and understood. In order to effectively integrate performance assessment tools into architectural practice, it would be important to examine how these factors interact during the design process. This could also help shift the focus from prioritising energy-efficiency above all else, which has been criticised for example by Shove (2017), to take a broader view of building performance.

The focus of this paper is to highlight and discuss sociotechnical issues that emerged during a collaborative and industry-linked, government-funded design research project (LP13). The LP13 project was set up as a collaboration between an industry partner, a manufacturer and supplier of Structural Insulated Panel (SIP) construction systems, and the Innovation in Applied Design Lab (IAD Lab) at the University of Sydney with an integrated multidisciplinary team of researchers in architecture and engineering. The aim of the project was to develop an energy-efficient and cost-effective prototype dwelling for the Australian volume housing market (), which was to be built with the industry partner's wall system. Such a prototype could help to demonstrate the effectiveness of a prefabricated SIP walling product as part of an overall more energy-efficient offering. After the construction of a smaller prototype of the SIP walling system in the factory (Figure 1), the project ultimately did not proceed to construction of the actual building because of changes in the commercial circumstances of the industry partner. However, the design development described here still provides a valuable case study of socio-technical issues that arose during that process.

In practice, architectural design balances multiple factors and interests such as site, orientation, flexibility (for future use), customer expectations, planning guidelines, development covenants, building performance, as well as technical and construction systems. If energy-use minimization is approached from a purely technical point of view based on performance simulation, then the most efficient form would be as compact as possible. However, as this case study illustrates, the problem is more complex in practice.

The LP13 project was influenced by complex demands of the volume house building industry and specific requirements from the industry partner. The interdisciplinary team also inevitably involved negotiations between disciplinary ambitions and ideals. The tension between technically desirable solutions and user requirements was part of this process. As the industry partner's client and target market, the volume house builder and its customers as the end-users also indirectly played an important role. A significant sociotechnical dilemma that emerged during the design development in the LP13 project were discrepancies between the ideal solution suggested by the PHPP software tool of a compact form and isothermal environment, on the one hand, and of local thermal habits and preferences of an 'indoor/outdoor' lifestyle in an Australian market on the other. The design outcome of the project was a hybrid approach that combined benefits of both passive housing and passive design.

In terms of methodology, the study takes a practice-based research approach. This approach draws on the reflective practice research model (Schön 1991), which can be used to examine processes in architectural design where knowledge is often applied in an exploratory manner by developing options for possible solutions rather than a deductive and logical application of scientific knowledge (Lawson 1979, 67). This approach meant that the authors were themselves part of the design process rather than outside observers, as is often the case in traditional scientific research (Cross 1993). This could be considered a limitation of practice-based research but, in this case, the reflection on real-world dynamics can serve to highlight issues within complex socio-technical environments that may be overlooked in other research. In this case, the socio-technical tensions between the energy-efficiency assessment tools and occupant concerns is a problem that emerged during the project development and that needed to be addressed in the proposed designs.

The project was developed through bi-weekly co-design workshops where progress was discussed and solutions were developed. Each discipline focussed on part of the overall problem and aimed to develop improved solutions within the boundaries set by the house builder and market. The SIP manufacturer led the development of the prefabricated wall system. The architectural designers researched the target market, the site design guidelines and restrictions, and developed design solutions in collaboration with the other team members. The engineering team tested the performance of the SIP, provided feedback and, together with the architectural team, simulated the overall building performance.

Figure 1. Prototyping of the SIP walling system for the LP13 project.

The Passive House standard was identified as one of the criteria to verify the aim of achieving a high level of energy performance. The Passive House Planning Package (PHPP) was used to assess the energy performance of the building and to ensure that the design would be able to meet the criteria of a stringent performance standard. The Passive House approach still encounters a level of scepticism in Australia if it is suitable to the local context or if it is more appropriate to colder climates, such as those in Northern Europe. This scepticism is evidenced, for example, in the Australian media in articles about the passive house standard (Marlow 2016). If the Passive House standard is applied to Australia, further research and conversations would be useful to better understand what caveats and changes may be required.

Passive house vs. passive design

Numerous studies underline that occupant behaviour in warmer Australian climates can be at odds with approaches to energy-efficiency that aim to create an isothermal environment for the whole house (such as Passive House). A study from 1991, for example, showed that very few people in Adelaide heated (only 4%) or cooled (only 11%) the whole house but that the vast majority relied on conditioning selected areas like the bedroom or living room only when needed (Coldicutt, Williamson, and Penny 1991, 257–258). While these choices may simply reflect existing habits (how they have always used their homes) and do not necessarily mean they are appropriate in buildings with highly efficient thermal envelopes, such learned behaviour is still a social factor which seems likely to have an influence on user preferences and understanding of energy efficiency in dwellings in Australia.

Another factor is a connection between indoors and outdoors and a desire to be able to open windows for good cross ventilation, which is seen as important by occupants (Coldicutt, Williamson, and Penny 1991). Opening windows is also more commonly used as a thermal control strategy than air conditioning (Soebarto and Bennetts 2014, 19). A study of occupant behaviour of a housing development near Adelaide showed that "(…) resorting to air-conditioners was the least preferred strategy due to implications for their energy bills. Turning on ceiling fans, opening or closing windows and doors, and opening or closing curtains were the first set of actions taken by most occupants when they wanted to be cooler" (Soebarto and Bennetts 2014, 19).

Such behavioural patterns, whether technically justifiable or not, do not always neatly align with energy performance models and can have an impact on preferred built form. A compact form is less important if the whole house is not usually heated or cooled, and if the aim is to achieve good cross-ventilation and connection to the outside through opening of windows. Social practice theory recognises strong links between habits and preferences and that it is intrinsically difficult to change these for sustainability reasons (Shove 2010, 1276). To make energy-efficient building appealing to an Australian audience, it would need to take account of local dwelling habits of an indoor-outdoor lifestyle and of being able to heat or cool particular areas.

In contrast to approaches to energy-efficient design that aim for constant indoor conditions, the above described behavioural patterns of opening and closing windows seem more suited to an adaptive approach as "(…) 'passive buildings', where the control of temperature is achieved largely by thoughtful climatological design, and by giving control of the thermal environment back to the occupants" (Humphreys, Nicol, and Roaf 2015, 7). Such an approach to sustainable design has a longstanding tradition in Australia and is exemplified by the work of Glen Murcutt, for example. Rather than separating the indoor and outside climate as effectively as possible to minimise energy consumption, the kind of 'passive design' or 'passive building' approach taken by Murcutt aims to create buildings that are connected to the outside, with good natural cross-ventilation, good shading and ceiling fans (Lecaro et al. 2017). His designs promote 'permeability'(Vaughan and Ostwald 2014), often with living areas that are partly outdoors. One of the best-known Murcutt designs, the Marie-Short House (Kempsey, New South Wales, Australia) for example, emphasises this "link between the inside and outside” (Lecaro et al. 2017, 2) and integrates two large shaded verandas that provide expanded living space linked to the indoor living and dining rooms.

These local habits and predilections also influenced the design development for the LP13 house. The most compact form was rejected in favour of a less compact floorplan that allows for more ‘permeability’, cross-ventilation and interaction with the outside. A compact form is less important if the whole house is not usually heated or cooled (only specific areas) and if the aim is to achieve good cross-ventilation and connection to the outside through opening of windows. This could be a reasons why energy-performance standards that favour constant indoor conditions (such as Passive House) are sometimes seen as conflicting with such Australian ‘indoor-outdoor’ dwelling ideals exemplified in Glenn Murcutt’s house designs, where the whole house is not seen as one thermal envelope but instead as areas to be heated or cooled when needed. In the design development of the prototype house, such concerns were taken into account. Rather than simply applying the Passive House standard, the design was developed to ensure that both the adaptive approach as well as the constant indoor environment can be accommodated.

Suburban volume housing

The industry partner supplied and collaborated closely with a major house builder who operates primarily in the suburban Australian volume housing market (Figure 2). The preferences and demands of the suburban volume housing market therefore played an important role for the LP13 project. The industry partner liaised closely with the volume house builder in choosing the site and house typology. Based on their input, the industry partner developed the project brief for a single-storey house on a suburban site. The target market was a significant social and cultural context within which the project operated and which it depended on.

The environmental impact of low-density detached suburban housing development has long been a cause for concern. From an urban design and planning point of view, this type of development has been criticised for being inherently car-dependent and less walkable than more compact housing (Burton, Jenks, and Williams 2003). More compact medium-density typologies, such as terraced housing, are often seen as a more sustainable and energy-efficient alternative (Moore, Clune, and Morrissey 2013). Medium-density housing has also recently been promoted by planning bodies in Australia through a series of competitions and new guidelines ("Winners Announced: NSW's Missing Middle Design Competition" 2017). From a building envelope point of view, a more compact form is also seen as more efficient and tends to achieve a better energy-performance rating with tools such as Firstrate5 (NatHERS) or PHPP (Newton, Tucker, and Ambrose 2000).

Figure 2. Suburban volume housing near Sydney.

The correlation between built form and energy efficiency, however, is also complex and controversial, with some studies suggesting that the compact city idea is too deterministic (Neuman 2005), and that, in certain scenarios, low-density housing can be as, or more, energy efficient (Ahmadian et al. 2018). However, irrespective of such debates about sustainable densities, the reality of the house building industry in Australia is that the detached suburban house is still among the most common types of new housing in Australia and often one of the most affordable options for larger or growing households, such as young families (Rosewall and Shoory 2017, 1). The reasons for it may be both cultural and historical, with a long-standing tradition in Australia of comparatively large building plots for its houses (Dalton et al. 2013). This reality of the market was also a determining factor for the LP13 project brief in terms of site and typology.

Design of prototype house

The main project task was to develop a low-energy prototype house that would be suitable for the industry partner's target market. Design proposals of a single-storey dwelling were developed for a building plot of 30 x 12.5m provided by the industry partner based on the house builder's input. The criteria that drove the site and type selection determined by the market that the house builder operated in. The house builder constructed a large number of suburban houses particularly of that typology (single storey house on a 10-15m wide site) in outer urban suburbs. This site and its dimensions (12.5 x 30m) were therefore seen as common and 'typical' enough that the design could be potentially be adapted to other sites. The first design iterations for discussion in the team focussed on creating a compact form to optimise energy-efficiency, which would make it easier to achieve a high NatHERS rating and potential Passive House certification (Figure 3).

Figure 3. Initial floor plan design studies.

However, purely technical arguments based on the ideal compact form for energy simulation tools were rejected based on qualitative, more subjective dwelling preferences, related to those mentioned above. During design development discussions, the industry partner and members of the project team raised concerns about initial proposals with a compact form. Less compact proposals with strong links between inside and outside were favoured by most members of the project team as a more acceptable and appealing option for warmer climates in an Australian market. Other factors were the specific qualities of the SIP system. The system achieves higher insulation values at a lower cost per m^2 than traditional construction, allowing for longer perimeters within a similar budget.

To take account of these concerns, options were investigated to understand if a less compact form could offer other advantages. This idea was explored in a series of diagrams, drawing on research about flexible housing (Schneider and Till 2007). The starting point was a compact form with key spaces (e.g. living/dining area, bedrooms) grouped into distinct volumes which could then be pulled apart (Figure 4). Such an arrangement would have several advantages over a simpler and more compact form.

Figure 4. Design strategy diagrams

The first advantage identified is ‘slack space’, seemingly extraneous areas that could be used for example as outdoor living space, for possible future extensions, as a yard or for drying laundry. The second advantage is that the functions within these volumes could be interchangeable if they are sufficiently large. A $30m^2$+ volume could accommodate a living/dining/kitchen area, for example, or 2 x bedrooms + 1 x bathroom, a small studio apartment, a live-work studio or flexible garage. That means the arrangement could support future floor plan changes and be adapted to the best sun orientation. As seen in the diagrams, the volumes would have non-loadbearing internal walls so that the layout could be adapted in the future if needed (Ramirez-Lovering 2013). Such a floor plan would challenge the kind of mono-functional suburban housing designed for ‘typical’ families, but not for most other household types. Each of the volumes could be heated or cooled separately, to suit the thermal preferences mentioned earlier, as the walls are constructed with the industry partner’s insulated SIP system.

The volumes could be adapted to suit various site dimensions (e.g. of 10m, 13m or 15m width), without invalidating the basic idea and principle. This means that the design could be transferable to other sites within a reasonable range. The first designs based on these diagrams tried to avoid an internal garage and instead provided an option for car parking in the front, for example as a car port. However, many developments require the provision of at least one internal garage in their design guidelines.

A site in Claymore near Sydney in a suburban development was identified as suitable for LP13. In the Sydney context, this development is at the more affordable end of the market. The design guidelines for the development include requirements for an internal garage, as well as for specific setbacks from the site boundaries and street. The initial floor plans were developed and refined to comply with the area design guidelines as well as the Livable Housing Design guidelines (Livable Housing Australia 2017).

Figure 5. Three floor plan configurations (3 bed house with garage; 4 bed house; or 2 bed house and studio).

The prototype floor plan was designed as a family house for 2 adults and 2 children. The house has 3 bedrooms, a living/dining/kitchen area, laundry, bathroom and the required garage (Figure 5). However, if circumstances change, the house could be adapted to suit other tenancy types. In the future, for example, personal car ownership may not be needed anymore, or one car parking space in front of the house might be considered adequate. In that case, the garage could be adapted to provide an extra bedroom for example. The slack space could also be used to extend the house and to add a bedroom if needed. Another floor plan option is a separate studio apartment in the front. The studio apartment could be used by grown-up children or could be rented to a student or young couple. This design would allow for more diverse suburban densities and tenancy types. The house would also be age-friendly by allowing for future downsizing and ageing in place.

User customisation options

To suit a suburban volume housing market, the prototype was designed to be customisable to personal tastes and budgets. Volume house builders typically offer a floor plan type with several façade and style options. Example variations of the design were developed with different styles for the external envelope, for example with a hipped roof, a skillion roof or a gable roof – both with garage or without (Figure 6).

Figure 6. External envelope with a skillion, hip and gable roof option.

The type that was chosen for Passive House testing was one with a skillion roof (Figure 10). The principles would work with the other types but the skillion roof was preferred for several reasons. One was the possibility of using the slope of a raked ceiling to support night purge ventilation. The other was that a skillion roof type is a common and cost-effective construction type in volume housing in Australia. It was important to prove the concept for a house type that would not require too many non-standard and potentially cost-prohibitive details.

Construction system

The volume house building industry in Australia is traditionally risk-averse and tends to prefer established methods like brick veneer and timber-frame construction (Dalton et al. 2013, 14). Cost of construction per m^2 is a crucial consideration in an industry in which house value is primarily determined by location and size. (Clune, Morrissey, and Moore 2012) The industry partner currently offers SIP wall systems with an Expanded polystyrene (EPS) insulation core and Magnesium Oxide (MgO) boards externally. The system uses different ‘spline’ options to join the panels. One system uses fibre-reinforced plastic (FRP) channels (Figure 7), another uses SIP splines or timber studs to join the panels (Figure 8).

Figure 7. House in Adelaide Hills under construction with industry partner’s SIP wall system.

An advantage of the SIP wall system with timber studs as splines is that it is easier to achieve compliance with the Australian building code without the need for more custom structural engineering. The additional structural design costs could otherwise be a barrier and disadvantage over more established wall systems such as brick veneer. For the scope of this case study, the SIP wall system with timber splines was therefore used as the baseline for PHPP testing. Thermal bridging from the timber supports was taken into account. However, further testing would be recommended to assess interstitial condensation risks, which was also expressed to the industry partner.

Figure 8. SIP wall panel by industry partner with timber splines.

The tested design uses detailing that can be constructed efficiently with the industry partner’s SIP wall system (Figure 9). The skillion roof has insulation between the rafters and below the roof, which was chosen as a cost-effective construction with an overall high insulation value. Thermal bridging could be reduced further if needed.

Figure 9. Key details for external envelope

PHPP software tool

The PHPP software tool was used to verify the thermal performance of the project. The project team also used other software tools in architecture and engineering. However, the PHPP was used as a key tool for assessing the energy performance of the prototype. The challenge that emerged out of the collaborative design process was to apply the Passive House standard to a less compact house typology which allows for good cross ventilation, a connection to outdoors and a more diverse interaction with its site within the customer expectations of the volume housing market.

Taking into account the thermal bridging from the timber framing, the external envelope with the detailing shown in Figure 9 achieved the following overall U-values:

- External wall: 0.341 W/(m²K)
- Roof: 0.201 W/(m²K)
- Floor: 3.074 W/(m²K)
- Windows: 1.70 W/(m²K)

All thermal conductivities were taken from the PHPP handbook apart from the values for MGO Board, Insulation Batts Bradford Gold HI-P and Insulation Blanket Bradford Anticon 60, which were taken from the manufacturers. This configuration, however, did not achieve Passive House certification in the PHPP (Figure 11). Heat losses through the floor are particularly high, which can be seen in the heat balance graph in Figure 13.[1] The Heating Demand is 41 kWh(m^2a) and the Primary Energy 176 kWh(m^2a), clearly exceeding the Passive House criteria.

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[1] Domestic Hot Water is electric.

Figure 10. Design PH model with skillion roof option (purge ventilation indicated in blue)

Figure 11. PHPP assessment results with basic configurations failed to achieve the Passive House standard.

After testing different configurations, the following modifications were made to achieve Passive House certification:

- 100 mm of insulation added to the floor to achieve U-value of 0.5 $W/(m^2K)$
- Wall insulation to be improved to achieve U-value of 0.25 $W/(m^2K)$.
- Solar thermal[2] and PV[3] added to the north-facing roof

To achieve the minimal heat loss in winter, the added insulation has the effect of increasing the overheating risk in summer. The ventilation and shading strategy therefore involve opening the corridor windows to reduce the risk of overheating. With this ventilation strategy, the frequency of overheating (> 25 °C) is below 10%.[4] With this revised configuration, the Heating Demand could be reduced to 17 $kWh(m^2a)$ and Primary Energy to 119 $kWh(m^2a)$ (Figures 12 & 14).

Figure 12. PHPP assessment results with revised configuration could achieve the Passive House standard.

[2] $4m^2$ of roof area (requires storage cylinder)

[3] 10 modules 1.658 x 0.994m on north facing roof – 32.96 m^2 in total

[4] Mechanical cooling could be added for periods of overheating, if required.

Figure 13. Energy balance heating for initial configuration that did not meet the Passive House standard.

Figure 14. Energy balance heating for revised configuration that could achieve the Passive House standard.

Discussion and conclusion

This industry-linked project illustrates how the challenge of achieving more energy-efficient architectural design and construction is part of a complex socio-technical environment with diverse influences. The project team needed to consider factors such as the context of the suburban volume housing market, user concerns and perceptions, technical properties of the SIP system, results from the PHPP to assess energy performance, as well as site, planning guidelines, orientation, and flexibility of future use. Conflicts between these factors had to be addressed in the design process and technical solutions had to be reconciled with perceptions and behaviour. The LP13 design demonstrates "trade-offs" that take account of complex sociotechnical concerns raised in the design process *and* still meet the Passive house criteria.

One of these complexities were occupant concerns and divergent approaches to energy-efficient design mentioned earlier. On the one hand, the design provides an example of how the Passive House standard can be applied to a warm temperate climate on a site near Sydney and combined with the ideal of 'passive design' and 'indoor-outdoor' living. The design incorporates the Passive House concept of creating a consistent thermal environment for the whole house and of separating the indoor and outdoor climate as effectively as possible. On the other hand, the proposal also had to take account of local occupant preferences that favoured a less compact form and more adaptive approach to passive design, with a building envelope that supports a good connection between inside and outside, good cross or purge ventilation, and good shading with outdoor living spaces.

The case study also provides an example of how the Passive House standard could be applied to the suburban volume housing market in Australia with a cost-conscious house design using a prefabricated SIP wall construction for a site near Sydney. While the project has to deal with the conditions and demands of a low-density volume housing market, the proposed house type challenges current suburban volume housing typologies with more flexible and adaptable floor plans. The industry-linked and multi-disciplinary process that has been employed here can serve as a helpful example for future low-energy housebuilding projects with opportunities for architects, engineers and other disciplines for collaboration.

While this paper demonstrates how the Passive House standard can be achieved even for less compact suburban house types, the project also suggests that performance assessment tools such as PHPP could do more to take account of local user preferences and habits. For example, options to only heat or cool certain areas of the house and to open windows much of the time could be more actively addressed. Adjustments could be enabled in the software tool to account for different thermal preferences and cultural or local specificities. In future research, a comparison between PHPP and Australian specific energy-rating tools like AccuRate could be useful to understand the differences in approach and energy performance. However, any such software tools used during an architectural project have 'biases' that are not always aligned with user preferences but that need to be negotiated in practice. Addressing these issues has the potential to highlight such biases, even if some tension between technology and people is bound to remain. Architects and designers could be well positioned in their design coordination role to facilitate this process of better engagement between the complexities of different sociotechnical elements to achieve improved energy performance.

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Referee 1 comments	Responses
This paper follows a design project conducted through practice-based research with an industry partner. Post-design, a sociotechnical systems lens is used to observe the design decision-making process. The topic is potentially of relevance to ASR Journal, but I believe the paper needs significant work in reframing and strengthening the connections and arguments in the current manuscript.	The connections and arguments have been reframed and strengthened by placing the focus onto the findings and the actual tasks, rather than on the model. The paper now focuses on socio-technical issues involved in the design process, in particular the tension between passive house and passive design.
The literature reviewed is limited at present. There is limited explanation of how STS theory has previously been considered in relation to the architectural design process. Whilst a conceptual diagram for STS in a workplace is presented, this is the extent of the STS literature reviewed.	The STS theory model seemed to be a distraction from the discussion of the actual issues involved. It has been therefore been removed and the literature review instead concentrates on the discussion around passive house vs passive design (p. 5-7) as well as on the discussion around compact urban form (p.7-8), which are at the heart of the main issue addressed in the title and abstract.
The same conceptual diagram is developed by the authors to represent the STS in relation to their case study project. The authors make (and labour) the point that it is not intended to describe all of the sociotechnical issues in the case study project. However, at present the diagram seems to be too specific to be general and yet not detailed enough to inform the reader. I would suggest that the authors amend this figure to 'aim for completeness'.	The STS theory model is no longer used but instead the focus is on the discussion of the project in relation to the key socio-technical issues identified.
In the introduction of the case study project, I think the paper would benefit from the addition of a figure which represents the project team structure. A lot of words are used throughout the paper describing the relationships of the team, with industry partner and key stakeholder (volume housebuilder) and the potential end users. If the authors could conceptualise and express these relationships in a diagram, this would help support the text.	The team structure is now explained succinctly in paragraph 6. We feel that a diagram will not be able to add more information for this revised version of the paper. But please let us know if you would like us to provide a diagram.
Where the project brief and target market are discussed on p6, what criteria were used/how were these selected? Are there any implications from this selection on the research outcomes? This has either not been expressed or not been considered by the authors at present.	This section has been amended to clarify the criteria.
There is a lengthy section in the paper on 'thermal preferences' and Glenn Murcutt's concept of permeability. I would question whether these are	This section has been amended and reframed. The reviewer's comments have been incorporated that such occupant behaviours are not necessarily

thermal preferences or instead functional or spatial preferences? Or are these instead cultural preferences which have thermal implications? Or are these even preferences at all? Is it a case of this being how people use their homes/make design decisions because this is how they have always used their homes (heating individual spaces, indoor/outdoor living etc.)? I suggest the authors reconsider this discussion and reflect on literature which might better support their argument or allow them to reframe this.	preferences, but rather existing habits or patterns. At the same time, the point has been added, referring to social practice theory, that such habits often inform user predilections and assumptions. Care has been taken, however, to point out the distinction.
The title of the paper starts with ‘Passive House vs. Passive Design’, and yet the paper presents the final outcome of the design process which is in fact a combination of passive design and passive house. Or it is a passive design which achieves passive house certification. I therefore find myself questioning at the end of the paper whether there was in fact such a tension between the social and the technical systems as is suggested by the authors. And whether the model did indeed help to highlight these conflicts as claimed? How has using STS theory after the event helped the practice-based researchers? How could the models presented help design teams as they conduct design projects or design/research projects? I believe the authors need to address these points as the stated, otherwise, how does this benefit the building design and construction industry rather than simply being business as usual.	The main body of the paper and the conclusion is now more closely linked to the title premise ‘passive house vs. passive design’. Taking on board the reviewer’s comments, the model seemed to be a distraction from the main issues explored in the paper and through the project. The model has therefore been removed and the emphasis has been placed onto the findings and the actual tasks. The paper illustrates that achieving improved environmental performance in practice during the design process is not just a technical issue, it is also a social issue. Prioritizing numerical outcomes over a more integrated approach focused on occupant need not be an either/or problem. Using a practice-based design research approach, the project shows that it is possible and desirable to address both technical performance as well as occupant concerns with respect to a housing design within Australia's volume homebuilding market. The proposed design is a combination of passive design and passive house to take account of the occupant concerns highlighted.
In the introduction (p3, lines 22-24), what are the limitations of practice-based research? Are you able to support the claims in the rest of this sentence/paragraph with references?	The sentence has been amended for clarification. The limitations are now explained in the sentence and referenced.
There are many awkward sentences in the paper that need to be identified and rewritten (e.g. p5, lines 6-10; p5, lines 57-59; p9, lines 15-19, p10, lines 6-8).	p5, lines 6-10 and p5, lines 57-59 have both been removed as they are no longer relevant. p9, lines 15-19, p10, lines 6-8 – both sentences have been simplified.

There are a number of grammatical errors that the authors should identify and address (e.g. singular/plural form on p4-5, lines 58-5; p10, lines 15-17).	p4-5, lines 58-5 – sentence has been removed. lines 58-5; p10, lines 15-17 – grammatical error has been fixed.
Not all figures are referred to within the text (e.g. Figure 4) are they all therefore necessary?	All figures have now been referenced. The sociotechnical model figures have been removed to reflect the revised framing of the argument. The number of figures could be further reduced if required. Figures 2, 13 & 14 could potentially be omitted if required.
P9, line 21 – (location) – is this a note to authors not addressed?	Location added
P10, lines 8-10 – states that this is highlighted in Figure 2. This is not clear to me, do the authors instead mean Figure 3? If this is the case, with the current generic format, the industry partner's target market is not currently highlighted in the conceptual model.	P10, lines 8-10 – comment has been removed.
Avoid use of first person (we).	Use of first person removed.

Referee 2 comments	Responses
Overall a very well produced paper. The introduction did build it up to a bit of a let-down in terms of socio-technology, I was very interested to read the outcomes here but they did seem to fizzle. However the paper is so nicely structured and written that I think it should be accepted as is, with a few small amendments listed below. Perhaps if the authors could look through all of the things they promised to do in the outset and maybe update the end of the paper to meet those promises, or otherwise reduce them a little to reflect the actual outcomes presented.	The end has been updated and the promise in the beginning reduced, also by removing the sociotechnical system model, and instead by simply reframing it as sociotechnical issues that are then traced through the project.
Further research could include comparisons of PHPP and Accurate (for example) to see what the energy uses would have been. Accurate allows for separated spaces, it is based on the way Australians expect different climatic experiences in different rooms of the house.	This point has been added to the conclusion.
References 1st sentence needs citation	1st sentence has been simplified and amended. It should now be a factual statement that can stand without citation. Additionally, references have been added to the following sentences.
Limitations Introduction-is the literature presented only Australian? Explain in the text. P8, make clear if / or that it is only Australian examples, otherwise also add locations	This section has now been amended and begins with “Numerous studies underline that occupant behaviour in warmer Australian climates can be …” This should make it clear to a reader that the following referenced studies are about warmer Australian climates.
P3 para starting 42, provide name of institution hosting innovation lab	Institution has been added
P9 line 22 ..missing Marie Short location	Location has been added
P9 line 29 clarify which house-the murcutt house or the study house?	LP13 has been added to clarify that it is the study house
P15 onwards, would be good to have absolute clarification if all of the values were reached using PHPP or another tool …	Information has been added to clarify where the values derived from. A table from PHPP can be added to show the values and how they were calculated.
P12 line 26. Change “kids” to “children”	Has been changed