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Performance evaluation of eight contemporary passive solar homes in subtropical Australia

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ABSTRACT

Subtropical south-east Queensland's expanding population is expected to lead to a demand for an additional 754,000 dwellings by 2031. A legacy of poor housing design, minimal building regulations, an absence of building performance evaluation and various social and market factors has lead to a high and growing penetration of, and reliance on, air-conditioners to provide comfort in this relatively benign climate. This reliance impacts on policy goals to adapt to and mitigate against global warming, electricity infrastructure investment and household resilience. Based on the concept of bioclimatic design, this field study scrutinizes eight non-air conditioned homes to develop a deeper understanding of the role of contemporary passive solar architecture in the delivery of thermally comfortable and resilient homes in the subtropics. These homes were found to provide inhabitants with an acceptable level of thermal comfort (18–28 °C) for 77–97% of the year. Family expectations and experiences of comfort, and the various design strategies utilized were compared against the measured performance outcomes. This comparison revealed issues that limited quantification and implementation of design intent and highlighted factors that constrained system optimisation.

1. Introduction

The current reality and future threats of climate change, constrained natural resources and infrastructure, and increasing urbanization, are forcing many world governments to quantify the impact that our built environment is having on these challenges. This has lead to the identification and implementation of regulatory measures intended to change the way we design, construct and operate buildings in order to reduce their negative impacts [26,54]. One common pathway adopted by governments has been to regulate the thermal performance of the building envelope. In developed countries the space heating and cooling requirements to meet real or perceived thermal comfort needs of housing inhabitants typically consume more energy than any other household service. For example, space heating and cooling in Australian houses is estimated to account for 38% of household stationary energy [5]. Residential dwellings in Australia, predominantly detached housing, have not historically been constructed with energy efficiency or thermal comfort in mind. For example, 43% of Queensland homes may have no insulation [1]. Presumably these homes would have been constructed prior to the implementation of minimal energy efficiency measures in 2003.

South-east Queensland is located on the subtropical eastern coast (latitude 26–28° south) of Australia and meeting expected population growth requires an additional 754,000 dwellings [51]. Despite a relatively benign subtropical climate where 65% of annual hours are within 18–28 °C, the region has more than 1.6 million refrigerative air-conditioners servicing about 1.2 million dwellings. Seventy-four per cent of the region's homes are thought to have air-conditioners and the rate of installations in 2010 was around 3000 systems per week [52].

There are strong arguments that the pervasive reliance on air conditioning and related thermal comfort standards tend to lead to high energy use and the promotion of 'closely controlled' environments as superior [54]. This tendency has had dramatic impacts on building forms and the lifestyles that they support [16,25], impacting on cultural expectations of comfort [10,64] and social practices [56].

Most people are tolerating a narrower temperature band, as well as rejecting former ways of achieving comfort, such as opening

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windows, taking showers or baths, using blankets and appropriate clothing, building thermally efficient housing, or taking siestas on hot afternoons. Therefore, expectations about what type of thermal comfort is desirable … as well as how that comfort should be achieved, are converging towards air-conditioned environments [60].

The lifestyles and building forms that rely on air conditioning in turn impact on the requirements for utility infrastructure capacity, increasingly resulting in large capital investments in higher capacity infrastructure that is utilized for short periods of time. Residential demand is estimated to contribute 43% of south-east Queensland's peak demand that occurs in either (or both) summer and winter [37], with 13% of the electricity network required to help the network meet the demand on extreme temperature days – and it is typically used for less than 1% of annual hours [20]. Approximately $15.6 billion will be invested in Queensland's electricity network from 2010 to 2015 to keep up with demand, and these costs need to be recovered from non-residential and residential customers. This is reflected in household electricity bills as 49% of residential electricity charges are associated with network costs [53]. Household physical, social and financial resilience (i.e. the ability to maintain essential functions through resistance or adaptation to ecosystem or resource changes) is also impacted by reliance on air conditioning. Comfort must be purchased from energy suppliers and the cost of that comfort continues to rise (e.g. electricity prices in this region have risen 53% in the last five years [49]). Household comfort becomes reliant on the stability of the electricity network and if the network fails, families have to find alternative means of managing comfort as well as other basic services of refrigeration, cooking and lighting.

The changing climate, the associated policy responses and increasing energy costs combine as powerful drivers to re-examine our approach to housing design and construction in the subtropics, particularly in relation to thermal comfort expectations and the manner in which we intend to meet these expectations in housing now and into the future. There is much we can learn from the past. Passive solar architecture, practiced by the ancient Greeks, relies on consideration of orientation, window positioning, ventilation, insulation, sun control, construction materials and layout of the building. In subtropical Queensland, traditional passive solar design strategies include light weight construction (with some recommendation of thermal mass where diurnal range is significant); narrow floor plans with long side facing the equator; complete shading in summer and solar access in winter; bulk and foil insulation; elevated construction (to capture breezes); abundant natural light; and shaded outdoor living spaces [6,8]. Additionally, good design is encouraged to reflect the region's cultural values of openness, informal lifestyle and connection with the natural environment. Such design strategies, in relation to thermal comfort, arguably need to (a) enable buildings to be adjusted to suit weather or social conditions; (b) provide multipurpose outdoor spaces; and (c) allow awareness of seasonal variations and respond to specific climatic characteristics of sub-regions [30].

These suggested design strategies are consistent with the concept of adaptive comfort, conceptually incorporating the social constructs that impact on perceptions of comfort [57] and the physiological, behavioural and psychological adaptations that people make to achieve comfort [54,61]. They are consistent with bioclimatic design that explores the dynamic relationship between the climate, building form and fabric, and inhabitants [29]. Bioclimatic design can be combined with methods used in standards, such as ASHRAE, to determine climate control design strategies [65] and to capture the energy efficiency benefits of passive design strategies for new buildings [33,62] and major retrofits [28].

Knowledge of building performance is valuable for informing future design and guiding policy, regulation and incentive programs [15]. The use of Building Performance Evaluation (BPE) has grown in the public and commercial buildings sectors as a means of measuring performance against expectations, but there are comparatively few examples of performance evaluation of housing, especially evaluations that span building science and social science by relating physical monitoring with occupant feedback [24,59]. In practice building evaluation developed as a means of measuring efficiency and productivity against design intent, but should arguably include a much broader range of considerations: personal and individual contexts and circumstances; dealing with extremes rather than averages; design quality; value; wider sustainability issues [36] and evaluation of the design and construction approaches and processes [31].

The purpose of this research is to gain a deeper understanding of the role of contemporary passive solar architecture in the delivery of thermally comfortable and resilient sustainable homes in the subtropics. Based on the concept of bioclimatic design, this study explores the extent to which design intent and implemented design strategies influenced the thermal performance of those homes in relation to the expectations of the homes' inhabitants.

2. Methodology

This paper is part of a broader research study which utilizes an extended case study method to investigate the whole process (product, delivery, performance) of sustainable housing, from the perspectives of the end-users (the household). This paper's field evaluation of passively designed naturally ventilated homes uses quantitative and qualitative methods to collate and examine multiple data sets within a clearly defined climatic and social context, a typical real-world approach of building evaluation [36] and enabling comparison of building attributes with inhabitant's perceptions [27]. The methodology is based on a concept of holism that addresses both the sense of dwelling within a home and the home's environmental performance [29], and the adaptive model of thermal comfort [17].

2.1. Climate context

The physical context of the case study is a residential Ecovillage in subtropical Queensland, Australia (latitude 28° south). The Ecovillage is located in a short, narrow, east–west valley 8 km inland from the coast (Pacific Ocean). Table 1 displays the key climatic data (historic averages) for the closest Bureau of Meteorology (BOM) weather station – Coolangatta Airport (from www.bom.gov.au) – which is located on the coastal plain approximately 8 km south-east of the ecovillage.

2.2. Housing context

The housing estate, still in staged development and construction phase, allows for, and consists of, detached housing of 1, 2 or 3+ bedrooms, for either single family housing or co-housing. An extensive Architectural and Landscape Code (A&LC) governs the design and construction of housing in the estate. These codes are contractual obligations in addition to state and local government building regulations and can be broadly categorised into three goals: environment protection, resource management and social cohesion, reflecting the triple bottom line of sustainability. Energy is one of 12 main areas addressed in the codes:

A primary objective of The Ecovillage is to minimize the use of energy and to seek energy self-sufficiency through the appropriate