International assessment of the environmental performance of housing, and prospects for sustainable cities

R. Horne
Centre for Design, RMIT University, Australia

Abstract

Ecologically sustainable development (ESD) principles are widely accepted as important components of building standards, urban planning and development. From the incorporation of energy modelling performance into building regulations, to the concepts and principles of Transit Oriented Development, sustainability terminology now litters both international and national policy environments. The logic of aspiring to sustainable urban systems implies that we can define and measure such systems.

This paper focuses on the progress to date in housing environmental performance assessment, and compares the energy performance of Australian housing with that in the UK, United States and Canada. The comparison is based on energy ratings of over fifty house designs currently being used which comply with regulatory requirements in the host countries. Issues in design of both the buildings and the assessment tool used are highlighted, and the results of this large Australian Government-funded study are presented. Analysis allows conclusions to be drawn on the reasons for wide variations in house energy (and environmental) performance, and the implications for sustainable cities.

A review of design guides and assessment tools aimed at the building and urban scales is also undertaken, including the prospects for new Australian building assessment tools such as AccuRate, BASIX and the Australian Green Building Council's 'Green Star' suite of tools. International comparisons are drawn, and critical analysis is undertaken of the limitations of such tools. Prospects for the incorporation of ESD principles into the planning and design of sustainable cities are presented.
Keywords: sustainability, energy, buildings, urban design, environmental assessment.

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1 Introduction

Sustainable cities are a bold and necessary aspiration. To make them a reality, the term must be defined and the political strength gathered to provide and deliver appropriate policies. While much progress has been made (and remains to be made) in both regards, there is also an important step within the definition-policy process which requires considerable further development; assessment. Even given a consensual definition of the sustainable city, which is not a trivial matter in itself, the determination of how sustainable the constituent parts of the city are is clearly an important one. Indeed, the logic of aspiring to sustainable urban systems implies that we can define and measure such systems.

Any assessment of sustainability is necessarily complex and, while this paper focuses on the environmental sustainability aspects of housing, thus constraining the problem, there nevertheless remain a range of issues to be overcome. These issues can be split into three categories; definitions of outcomes; establishment of the appropriate metrics and benchmarks; and factors in regional and international comparability. Definitions required include what constitutes a sustainable house. This and related sustainable city concepts are discussed in section 2.

Establishing the appropriate metrics and benchmarks is clearly related to definitions, although it raises further questions, which are addressed in section 3. While some metrics may be demonstrably measurable and significant, such as heating and cooling loads (in most climates), others may be less well determined, or less measurable. Clearly, it is important to be able to achieve some relative performance measure, but it is equally important not to confuse things that are countable with things that count. Questions of selecting metrics introduce the issue of regional and international comparability. For example, an Australian housing environmental performance tool emphasises water efficiency, with an overall weighting of 40%, applied as it is to a water vulnerable region, whereas equivalent tools in the UK and the USA provide equivalent ratings of 7% and 14% respectively (Horne *et al* [1]). The extent to which international comparability or standardisation is achievable or desirable in the context of achieving sustainable cities is discussed in section 4, and the results of a comparative study of energy in housing comprises section 5.

The aim of this paper is to assess developments in the assessment of the environmental performance of new housing and present results of recent studies comparing this performance. The perspective for this paper is Australian, while the context is the development of assessment frameworks and metrics to inform policy processes in the drive towards sustainable cities.

2 Defining outcomes

Sustainable cities have been variously defined and, in common with preceding terms such as 'sustainable development' and 'sustainability', not without controversy. Since the origin of the term 'sustainable development' in the World Conservation Strategy, published in 1980, there has been a focus within definitions on the conservation of living resources (Baker *et al.* [2]). The strategy demonstrated that "conservation is entirely compatible with the growing demand for people centred development" which could be achieved by maintaining ecological processes, preserving genetic diversity and through the sustainable development of species and ecosystems (Adams [3]). The Bruntland report, published in 1987 [4] then attempted to provide a more practical context, and developed the now widely quoted definition of sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to met their own needs"*. Three concepts embedded within the Bruntland report have been carried through to discourse on sustainable cities. Firstly, *needs*, which are socially and culturally determined; secondly, *limits,* which are imposed by the natural environment, technology and social organisation (Kirkby et al. [5]) and thirdly, that there is *no blueprint* for sustainability, as economic, social and ecological conditions vary temporally and spatially.

Over almost two decades, post-Bruntland debate has contested definitions; Mawhinney [6] presents 17 varying definitions of sustainable development from significant sources to illustrate this diversity in the theory, demonstrating that 'sustainable development' appears to be an over-used and misunderstood phrase. Despite the controversy, sustainable city and development concepts are well-established both in collective consciousness and in policy mechanisms, and the challenge is to provide the means for their practical application. As a starting point for this, Giradet [7] modifies the Bruntland definition: *"A 'sustainable city' enables all its citizens to meet their own needs and to enhance their well-being, without degrading the natural world or the lives of other people, now or in the future."* Newman and Kenworthy [8], note that this can be achieved by reducing resource inputs (land, energy, water and materials) and waste outputs (gaseous, liquid and solid waste) while simultaneously improving liveability of citizens (such as health, employment, income, housing, leisure activities, accessibility, public space, and well-being). In implementing our sustainable cities, it is critical to note that cities are dynamic systems, and sustainability should be viewed as a process rather than an endpoint.

2.1 Practical application to housing

The development and application of ecologically sustainable development (ESD) principles to housing gained ground during the 1990s, with a range of 'ecohome' demonstration projects (for example, see Low *et al* [9]). There is general consensus that a sustainable house, developed using ESD principles, will perform well in conserving water and energy and use low-impact materials, compared to an 'average' house. Invariably, links to ecological carrying capacity are not drawn explicitly in guiding specific performance criteria. One way to approach this in practical terms is to use Life Cycle Assessment (LCA) methods, using which, a sustainable house built today should satisfy the following general requirements [1]:

- High thermal comfort;
- Maintain and enhance the health and wellbeing of building users;
- Consumption of minimal non-renewable energy;
- Cost-effective design, minimising life cycle operating costs;
- Low life cycle environmental impact; and
- Eco-design measures incorporated (location, orientation, passive design, appropriate materials and construction techniques, efficient appliances).

While this list of requirements does address Bruntland's concepts and provides a basis for practical application, clearly, more detail is required before houses can be assessed against such a list of criteria. Terms such as 'minimal' and 'low' require definition, for example, in terms of environmental carrying capacity or what is deemed achievable in performance terms, while 'cost-effective' and 'comfort' are more related to human capacities and needs. Regarding the latter, clearly, house environmental performance is also related to the knowledge and behaviour of the occupants. Therefore, while the list above provides a basis for identifying the main metrics of housing environmental performance measurement, explicit assumptions must be made about occupant knowledge and behaviour when developing these metrics in detail.

Table 1: Potential environmental burdens of an urban residential building.

Burden factor	Construction	Operation	Renovation and end-of-life
Non-renewable energy (climate change and fossil fuel depletion)	Embodied energy in building materials and site water. Energy used on site and in transport of materials and labour.	Heating and cooling. Lighting and appliances.	Direct energy in renovation or deconstruction (and embodied energy in new materials associated with the former).
Water and materials	Potable use, stormwater runoff. Non-renewable building materials resource depletion.	Garden water use and strormwater flows. Potable use and foulwater discharge (including appliances). Use of non-renewable materials.	Potable use, stormwater runoff during works. Non-renewable building materials resource depletion (renovations).
Pollution and toxicity – humans	Worker OHS on site and in mining, processing and manufacturing phases of materials, water and energy service provision. Communities subject to pollutants as above.	Indoor environment quality – a result of building materials offgassing and use of toxic substances in the home. Worker OHS in mining, processing and manufacturing phases of materials, water and energy service provision. Communities subject to pollutants as above, and noise.	Worker OHS on site and, for renovations; in mining, processing and manufacturing phases of materials, water and energy service provision. Communities subject to pollutants as above.
Pollution and toxicity - environment	Ecosystems subject to change from site use and in mining, processing and manufacturing phases of materials, water and energy service provision.	Garden and house pesticides, leachate from landfilled wastes, lighting, and ecosystems change from mining, processing and manufacturing phases of materials, water and energy service provision.	Non-recovered waste to landfill. For renovations; ecosystems subject to change from site use and in mining, processing and manufacturing phases of materials, water and energy service provision.

3 The main metrics

Viewing the house as a system with a life cycle, we can identify the constituent parts of the life cycle and subsequent environmental burdens as indicated in Table 1. This shows that key input-related environmental factors include energy, water and materials depletion, and the related environmental impacts of mining, processing and supply of each. Output factors include pollution and climate change, foul and stormwater discharge, and toxicity effects on humans and ecosystems. All factors vary across the building life cycle.

4 International benchmarking

Questions of selecting metrics introduce the third issue, of regional and international comparability. From a theoretical carrying capacity perspective, it is logical that housing performance requirements should vary according to environmental impact. Therefore, in countries or regions where reticulated water supply and treatment is more environmentally vulnerable, for example, in areas where the demand outstrips environmentally sustainable supply, water use performance level should be more stringent than elsewhere. In other words, site specific factors need to be considered in any effort to establish international benchmarking. Notwithstanding, many factors are inter-regional or global in nature. Non-renewable energy use creates fossil fuel depletion and global climate change – both are clearly global impacts, and so it is logical to benchmark performance internationally (see section 5).

4.1 Building rating tools and comparisons

Having posited the main metrics from a theoretical basis, as far as is currently possible, it is now appropriate to assess the extent to which these are addressed in existing building environmental performance assessment tools internationally. Many building rating tools now exist with differing scope and objectives. Indeed, the author has counted over 35 such tools, including individual tools within groups, although a number of these are targeted at commercial buildings. All such tools are performance-based rather than carrying capacity based, so they take as their performance benchmarks targets that are likely to improve performance from the present, rather than a required level of performance based on environmental sustainability endpoints; logically, given their (often) voluntary, market-based origins (Cole *et al* [11]). Invariably, they set performance for criteria such as operational energy and water use, materials environmental performance and indoor air quality separately, although most also incorporate a points weighting for individual elements.

Recent developments in Australian tools include AccuRate, BASIX and the Australian Green Building Council's (AGBC) 'Green Star' suite of tools. AccuRate is the second generation successor of the NatHERS operational heating and cooling load energy modelling software, with a more advanced ventilation model, which allows buildings to cool down faster via. open windows and doors, therefore reducing the cooling loads. It also allows the user to select the colour of the external and internal walls, and change the thermostat settings. The total amount of energy required to heat and cool the house is estimated in MJ/m²/yr, and the software estimates a value for total energy usage and then provides the associated 'star' rating (0-10 stars), which is calibrated for different climatic zones.

BASIX is the Building Sustainability Index, a planning development control-based assessment tool developed following the New South Wales Government's positive experiences in "greening" the Sydney Olympic Games. Since July 2004 (Sydney) and July 2005 (NSW), all proposals for new residential development must be submitted with a BASIX Certificate, which indicates that it satisfies the requirements of the online BASIX, meeting performances indices for energy, indoor thermal comfort, water and stormwater (landscape, waste, materials, transport and social indices have been identified as future additions). Apart from building design, evaluation points are attributed for appliances, and optimum reduction technologies include gas hydronic heating, ceiling fan cooling, gas boosted solar hot water, and standard or compact fluorescent lighting with natural lighting to kitchen and bathroom. Water consumption is a major BASIX component, and is location-sensitive according to drought conditions, and evaluation points focus on water efficient showerhead, toilet and tap fittings.

AGBC currently has a range of commercial Greenstar ratings tools. While a residential tool has not yet emerged, the commercial tools can provide some indication of the likely focus of a future residential tool. Eight categories are impact weighted and include (from highest to lowest ranking); Indoor Environment Quality, energy, materials, emissions, water, management, transport and land use and ecology. This suite of categories, along with those of BASIX, can be compared to the main categories and weightings used in equivalent tools in the USA, UK, Canada and an international tool, the International Initiative for a Sustainable Built Environment (IISBE). Such a comparison shows that the majority of the tools' scope are captured within five main areas; materials; Indoor Environment Quality (IEQ); greenhouse gas and energy; water use; and stormwater management.

As indicated in Table 2, it can be inferred from the weightings that the main impact burdens of concern are greenhouse gas and energy use (operational), followed by operational water use, then materials selection and IEQ. The latter two categories broadly reflect output-related pollution and toxicity factors in Table 2, while the former reflect operational inputs. The main materials issues in these tools are house size, durability, local sources of materials, timber certification, eco-preferable materials selection, and reuse and use of recycled materials. The main IEQ issues are ventilation (including in garages), daylighting and sky views, and emission standards, such as of volatile organochlorides. The main GHG and energy issues are seals and 'tight' construction, insulation, windows specifications, equipment type, and passive solar and ESD features. The main water conservation issues include appliances and fittings specifications, garden design and water reuse.

Table 2: Summary of rating tool weightings (adapted from Horne *et al* [1]).

Tool	Materials	IEQ	GHG and energy	Water use	SWM
LEED (USA)	18%	15%	28%	14%	4%
BREEAM Ecohome (UK)	38%	9% *	22%	7%	2%
GREEN GLOBES (Canada)	5.5%	17%	38%	8.5%	2%
IISBE (global)	6%	6%**	15%	6% ***	
BASIX (NSW, Australia)	0%	0%	25%	40%	In process
Summed weighting	67.5	47	128	75.5	8

Notes: *' health and wellbeing': **Q1 – air quality and ventilation: ***R3 – consumption of potable water
IEQ= Indoor Environment Quality: GHG= greenhouse gas: SWM=stormwater management

Differences highlighted by this comparison include the UK emphasis on materials and the Australian emphasis on water use. Also, while such differences may be explained in regional impact terms, given the global nature of the energy and GHG impact category, there is a logical argument that weightings should be more similar internationally for this category. Notwithstanding that, from a sustainability perspective, links between environmental carrying capacity and weightings are insufficiently clear at present, this summary comparison provides critical information regarding the theoretical gaps (*vis a vis* Table 1) and the areas of emphasis and variation across tools internationally.

5 International comparisons of energy use

As discussed above, energy is the most logical candidate for direct international comparisons of housing sustainability performance, because both fossil energy depletion and resultant global climate change impacts are clearly global in nature. This section summarises a study undertaken for the Australian Federal Government Department of Environment and Heritage, Australian Greenhouse Office (Horne *et al* [12]; the author wishes to acknowledge the co-authors and sponsors of the study). Energy ratings of new houses in Australia are compared with those currently being built overseas, using AccuRate software (see section 4.1). Overseas locations in the UK, Canada and the USA, are mapped across to similar climate zones in Australia, and 51 house plans designed to comply with relevant local building codes are rated using AccuRate. A review and analysis of the local 'deemed to satisfy' building codes is also undertaken as an aide to explaining any significant differences in house energy performance between different countries and locations.

The backdrop to the study is the proposed introduction of a 5-star minimum performance requirement for new Australian housing. Results are presented in

Table 3 showing a mean score of 6.843. This indicates that the overseas equivalent housing is significantly out-performing the proposed Australian 5-star national requirements. Within each climate zone, there are variations, although all mean climate zone comparison performance levels are above 5 stars and there is no significant pattern of performance according to warmer or cooler climates, or dry or humid climates. Generally, apartments and townhouses perform better than detached houses, and the higher performing climate zones reflect comparison localities with more stringent local building codes.

Table 3: Summary analysis of international house energy performance AccuRate results (after Horne *et al* [12]).

Australian equivalent climate zone	Comparison location	Total number of plans rated	AccuRate stars Range	AccuRate stars median	**AccuRate stars Mean**
Zone 1 Darwin	Florida	6	6-8.5	6.5-7	**7**
Zone 2 Brisbane	Texas	5	4.5-9	5	**6**
Zone 3 Longreach	N. Carolina	5	4.5-6.5	5.5	**5.4**
Zone 4 Dubbo	Arizona	4	6.5-7.5	7	**7**
Zone 5 Perth	California (Bakersfield)	3	7-8	7.5	**7.5**
Zone 6 Melbourne	California (SF Bay)	4	6-9	7.5-8	**7.6**
Zone 7 Hobart	UK: Canada	16	6.5-8.5	8	**7.2**
Zone 8 Thredbo	Pennsylvania: Mass.	8	4.5-9.5	6.5	**6.8**
ALL ZONES	-	**51**	**4.5-9.5**	**7.5**	**6.8**

The house designs obtained from the UK and Canada indicate that, in these countries, substantial houses are built to relatively very high standards, in compliance with relatively stringent building code requirements. The more typical format of lightweight construction on slab seen in current new housing in Australia is also seen in the USA. Neither country insists on sustainable design principles outside of high performance building elements. However, according to the Deemed to Satisfy requirements in the building codes, houses in the USA are insulated to (on average) R2.5 in the walls, R5.5 in the ceilings, and have double or double low E glazing. Some houses in Texas have single glazing, but otherwise all are double or double low E glazed. In addition, the USA uses vinyl frames (PVC) with benefits in the energy ratings, despite raising questions over other environmental impacts. Typically, from the USA designs used in this study and previous experience of the authors in rating Australian house designs, USA glass to floor area ratios are significantly lower than those in Australia. On the basis of the comparisons in this study, the main exception within the USA is the building control regime in California. This has a long history, and current standards are significantly advanced when compared to the other states, and to Australia. The two climate zones which provide Californian comparisons in this study (Australian zones 5 and 6) show clear differences in the performance results from having more stringent building codes, adding further weight to the general conclusions that the higher performing climate zones reflect comparison localities with more stringent local building codes.

6 Conclusions

Within the context of policy and regulatory development in the drive to more sustainable cities, there is a need to establish international consensus over housing environmental performance and its assessment. In pursuing the aim of this paper, examples of recent developments and studies which can contribute to meeting this need have been presented.

In conclusion, while clear theoretical links can be drawn between sustainability definitions, environmental carrying capacity, and potential metrics for assessing housing performance, it is clear that the tools currently in use are works in progress, and only partially satisfy theoretical requirements. Specifically, pollution and toxicity issues, and the identification of appropriate environmental carrying capacity based limits on environmental burdens arising from housing require significant further research effort. Only then will we know we are approaching housing sustainability along the appropriate route.

Also, amongst tools currently in use internationally, there are differences in emphasis which can only partly be explained in theoretical environmental terms. This is unsurprising given that they are generally performance-based, and have been developed within different policy dynamics and contexts. The extent to which international comparability or standardisation is achievable is clear: where impacts are global, responses should logically also be globally co-ordinated, whereas, where impacts are local, local responses can be made, preferably with global co-ordination. Just as the polluter pays, so, all those who are polluted should have a say in how pollution control is achieved.

The clearest candidate for international comparison and standardisation is energy use, and the study of modelled operational heating and cooling loads in new housing shows that there are significant variations in performance internationally. The fact that such information is now available provides a basis for the transformation of hitherto piecemeal policy and practice development in housing sustainability, into a more long term, internationally co-ordinated approach, ensuring both intergenerational and international equity. Only then will we know we are approaching housing sustainability consistently, globally, and at the appropriate velocity.

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