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THE KEY-COMPONENTS OF SUSTAINABLE HOUSING DESIGN FOR AUSTRALIAN SMALL SIZE HOUSING

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ABSTRACT: The building industry has a substantial potential for short-run and cost-effective greenhouse gases emission mitigation with long-term positive sustainability impacts. There are, however, a variety of human-based barriers, detracting from the leverage of the mitigation plans in this industry. The impacts of human-based factors are especially critical in the small size residential buildings, whereby a wide range of stakeholders plays serious roles in the housing development. In Australia, one critical human-based factor in the residential sector is the occupants' preferences, increasing substantially diversity and complexity of the dwelling units' physical characteristics. This paper intends to explain the role of feasibility assessment and design process in improving the energy performance of the Australian residential sector. Accordingly, an overview of the Australian housing characteristics assists in addressing the key characteristics of the Australian housing preferences. The analyses show that typological monotony, high range of owner-occupied housing, alongside occupants' affordability are a number of characteristics of the Australian housing, which facilitate the implementation of housing efficiency plans in the early stages of housing provision. Some other characteristics, e.g. floor area, number of bedrooms, and number of people per dwelling units are some inefficient housing preferences, stressing the significant role of designers in encouraging the residents toward efficient choice behaviors. Accordingly, the design process has the potential to impact the energy demands of Australian housing through Housing-Resident Fit, by the implementing the key components of sustainable housing design, impacting the occupants' preferences, and simplifying their domestic activities.

Keywords: Sustainable Housing Design; Australian Housing; Energy Efficiency; Housing-Resident Fit.

1. INTRODUCTION

A successful emission mitigation action plan requires bottom-up flexibility rather than top-down fixed rules, to achieve accountability and ambition through a broad participation [1]. However, in achieving the Australian target baseline, the building industry has a critical role, because of the amount of energy consumption, carbon emission, and exceptional potentials for cost-effective emission mitigation of the industry [2-4]. In small size residential buildings, typological diversity of the products, the complexity, and diversity of stakeholders, the direct impacts of occupants' attitudes and preferences, as well as the spread and magnitude of energy use activities detract from the effect of the mitigation actions plans [5,6].

In the residential sector, end-users are, indeed, the key driving forces in the development of the housing sector compared with the other industries. Therefore, improving the energy performance of the sector depends strongly on a proper attention to the bottom-up approach as the key concept in maximizing the occupants' participation parallel to taking into account the development of the efficiency rules alongside the investment on the technical aspects. This paper intends to explain the contribution of the housing design process in improving the energy performance of the Australian housing sector and in overcoming the challenges.

The spatial, functional, and physical characteristics of the residential buildings influence substantially the energy performance and emission production of the sector [2]. The housing design process has a lot to contribute to the mitigation, not only by the direct effects on the dwelling units' physical characteristics, but also by the indirect effects on the occupants' environmental perceptions, attitudes, and choice behaviors [7,8]. By maximizing congruity between the dwelling units physical characteristics and occupants' perceptions, attitudes and preferences, the energy performance of these dwellings are expected to be improved substantially. This paper makes initially an overview of the literature on the effects of the design process on the energy performance of the residential buildings, then explains briefly the capacities of the housing design in enhancing the energy performance of the dwelling units in Australia, and eventually overviews the key components of the sustainable housing design of the Australian small-size residential buildings.

2. LITERATURE REVIEW

According to UNEB SBCI [2], the main factors in the energy performance of the residential buildings are the building spatial and physical characteristics, along with the end-users' perceptions, attitudes, and behaviors. Richard [9] believed that in the Australian residential sector, the current benchmark of the energy consumption in the residential buildings is substantially far from the sustainable level. It is believed that the feasibility assessment and design stages are highly responsible for improving the energy demands of the building industry for both embodied and operation energies [2,3,10,11]].

Allwood et al. [3] stressed that it is necessary to develop a sustainable production process, which is based on efficient use of materials and is able to keep the function and service quality. In the housing production process, the decisions about spatial and physical characteristics, and the function and service quality are mostly made in the feasibility assessment and design process.

Sattary and Thorpe [11] also revealed that the sustainable use of the building materials would make it possible to reduce the embodied energy of the buildings up to 64 percent. The building materials are mainly selected at the early stages of the feasibility assessment and design process.

It is also evident that the energy-efficient techniques and bioclimatic principles, e.g. orientation, courtyard, window to wall ratios, geographical location of windows, as well as cross ventilation and shading devices have serious contributions in improving the energy performance of the residential buildings during the operational phase [10]. Nasrollahi, et al. [10] stated that an efficiently well-designed residential building is able to cut down the operation energy of the units up to 65 percent.

The feasibility assessment and design process are also responsible for arranging the buildings spatial characteristics, structure, and organization, alongside regulating the end-users' choice behaviors toward more efficient energy consumption actions [12,13]. Although the housing design process has substantial responsibility for improving the energy performance of the residential buildings by improving the arrangement of the spatial layouts, and the end-users' preferences, so far the research works have paid little attention to this area. In Australia, the current direction of housing development overrode the outcomes of the mitigation plans in the building sector [14]. This paper, therefore, aims at explaining the potential contribution of feasibility assessment and design stages in improving the energy performance of the Australian housing sector through improving housing physical characteristics and moderating end-users' housing preferences and energy demands, as will be discussed in the next sections.

3. RESEARCH METHODOLOGY

In Australia, a number of online databanks, e.g. Australian Bureau of Statistics (ABS) and Beyond Zero Emissions (BZE) provide reliable data related to the Australian housing characteristics, which are appropriate sources for tracking the Australian housing trends. This research compiled the secondary data from these online sources.

The conducted analyses facilitated the representation of key characteristics of the Australian housing; hence, made it possible to explain the potential contribution of the design process in enhancing the energy performance of the residential sector. The analyses indeed explain the role of feasibility assessment and design process in improving spatial layout arrangements and physical characteristics of dwelling units, enhancing the energy performance of the buildings by improving the physical characteristics of the dwelling units and facilitating the occupants' daily life activities.

The next section initially explains the key characteristics of the Australian housing by merging the compiled data through Microsoft Excel, and discusses the critical aspects of occupants' housing preferences, then makes a comparison between Australian residential and non-residential sector to explain the substantial role of energy performance of the housing sector in overall energy consumption of the building industry.

Referring to the Australian projected population [16], the section also calculates a number of future trends of the Australian housing, representing the impacts of the current direction of housing development on the future energy performance of the residential sector. In final, addressing a previously conducted research work, a feasibility assessment is made to briefly estimate the potential contribution of the design process in enhancing the energy performance of the Australian housing. The section ends up with a brief explanation of the different components of sustainable housing design and the techniques related to each component.

4. RESULTS AND ANALYSES

In discussing the responsibility of the feasibility assessment and design stages in enhancing the energy performance of the Australian residential sector, it is initially necessary to make an overview of the Australian housing characteristics. Table 1 provides a brief picture of the key characteristics of the Australian housing.

Table 1 Key Characteristics of Australian housing

Characteristics	Description
Housing Type	Separate house standing on its own block: 79% (2012).
Number of Rooms	3 or more bedroom house: 70.3% (2012). The number of rooms increased from 2.8 to 3.1 (1976 – 2014).
Housing Size (1984-2013)	Average floor area of dwelling units increased from $149m^2$ to $207m^2$. Average floor area of separate houses increased from $162M^2$ to $241m^2$. Average floor area of apartments increased from $99M^2$ to $134m^2$.
Owner-Occupancy	67% (2013-2014).
Mortgage	31% without a mortgage, 36% with a mortgage (2013-2014). The decrease in the outright owner-occupied housing from 42% to 31% (1994-2014).
Average Floor Area per Person	Almost $90m^2$ (2012).
Number of Person per Household	Decreased from 3.1 to 2.6 (1976 – 2014).
Number of Bedroom per Person	Increased from 0.9 to 1.2 (1976 – 2014).
Spare bedrooms	Almost 80% of the households have more than 1 spare bedroom (2013-2014).
Lone Households	Almost 2,100,000 Households by 2011 (24.3%), estimated to be increased to almost 3,300,000 households by 2036 (2013-2014).

Source: [15,17-19],

One of the factors that assist in explaining the housing characteristics is the housing tenure and ownership. 67 percent of the Australian households live in owner-occupied houses, and from this population, 31 percent are without any mortgages, and the rest of them (36 percent) mostly uptake the mortgage for other financial purposes rather than the housing purchase [19]. According to ABS [17], the proportion of owner-occupied houses in separate houses is 88 percent of the total owner-occupied houses. This means that the owner-occupied separate houses are the most preferred accommodation destination of the Australian population. It is also evident that the outright owner-occupation has been dropped from 42% to 31% in the period of 1994-95 to 2013-2014. The descending order of outright owner-occupied housing makes it evident that the current direction of housing development has been achieved with the cost of loaning and mortgaging.

In sum, 3 or more bedroom separate houses are the most popular dwelling type and have significant responsibility in the energy performance of the residential sector in Australia. However, a number of multiple non-technological barriers, e.g. diversity and complexity of the building types and characteristics, the diversity of the stakeholders along with the absence of the end-users during housing provision and the separation of and the distance between the costs paid by the owners and benefits received by the occupants make the implementation of the energy efficiency plans in the residential buildings quite complicated and practically difficult [2,5,6]. The most preferred housing type and tenure in Australia provide an exceptional opportunity for eliminating these barriers.

Considering the opportunity provided by the housing type and tenure preferences in Australia, the next step is to have a look at the spatial organization and physical characteristics of the residential buildings. Monitoring the changes happened to the Australian housing characteristics over the last few decades makes it possible to highlight the direction of housing development and to explain the critical aspects of the occupants' housing preferences. The changes in the spatial and physical characteristics make it evident that the average floor area has increased from $170m^2$ to $241m^2$ from 1985 to 2013[20]. The average floor area per person has also increased in the separate houses from $50m^2$ to $90m^2$ over the same period. The changes in the average floor area of the separate dwelling units from 2003 to 2013 shows a significant increase in the average floor area of the separate houses (from $235m^2$ to $241m^2$) comparing with the decrease in the average floor area in the other housing types (from $142m^2$ to $134m^2$) [20]. From 1976 to 2013-2014, the number of bedrooms per dwelling has increased from 2.8 to 3.14, while the number of persons per household has decreased from 3 to 2.4 [19]. 49.9 percent of 3 or more bedroom separate houses were occupied by less than two people's households, 16.9 and 33 percent respectively for one person and two people's households [15,17]. The amount of lone person households has grown from 11 to 25 percent during the period of 1911 to 2011 [15]. The number of lone person households is also estimated to significantly increase from 2'100'000 households in 2011 to more than 3'300'000 households in 2036 (1'300'000 households with a growth rate of almost 63% growth) [16]. According to ABS [17], 79 percent of households had spare bedrooms.

Accordingly, the households mostly have preferred more spacious accommodations, and the housing units are mostly not fully utilized. The most popular housing type, the accommodation preferences, the demographic of lone person households, along with the average number of people per dwelling in 3 or more bedroom separate houses stress the lack of diversity of the Australian housing industry in relation to the different lifecycle stages of the Australian populations. The necessity of flexibility and diversity of the new dwelling units is more evident by considering the ascending order of the proportion of lone person households in the Australian projected population (2026 and 2036) [16].

The most preferred housing type and tenure, along with size and economic performance of the housing units in Australia, are also indicators of the socio-economic characteristics of the end-users, their ability, capacity, and power in joining to the energy efficiency action plans. These characteristics show the critical responsibility of the designers in enhancing end-users' daily life activities, behaviors, preferences, and perceptions.

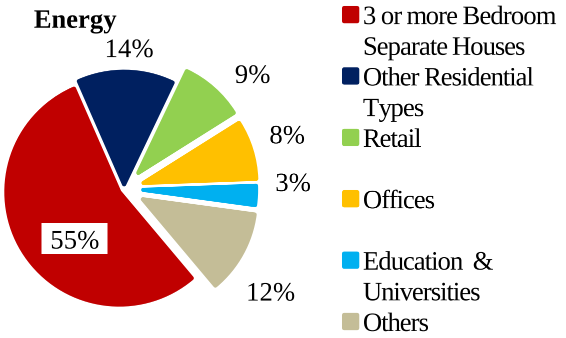
To visualize the importance of the residential sector in the energy performance of the Australian building industry, a brief comparison was also made between the floor area and energy consumption of the residential buildings and non-residential buildings. In 2012, the floor area of the Australian residential buildings was almost 87 percent (Office 2.3 percent, Retails 3.3 percent) of the total building sector of the country [14,18], [20]. The total floor area of separate houses was 79 percent, almost 75 percent of which were 3 or more bedroom units [18,20]. At the same time, the residential sector consumed almost 69 percent of the total energy usage of the building industry (office buildings 8 percent, and retails 9 percent), while most of this amount was consumed in 3 or more bedroom separate houses (Table 2; Figure 1).

From 300 PJ/Annum energy consumption of the 3 or more bedroom separate houses (55% of energy consumption of the Australian building sector), 120PJ/Annum (40%) was consumed for heating and cooling purposes [21]. Addressing the study of Nasrollahi, et al. [10], an efficiently well-designed residential building is capable of improving the energy performance of the building up to 65%.

Table 2 National residential and non-residential building characteristics

Building Category	Flor Area (000 000 m^2-%)		National Energy Use (PJ/Annum)	
Residential	1 645.2	87%	375	68.2%
Non-Residential	245.3	13%	175	31.8%
Total	1 890.5	100%	550	100%

Source: [14], [18], [20]



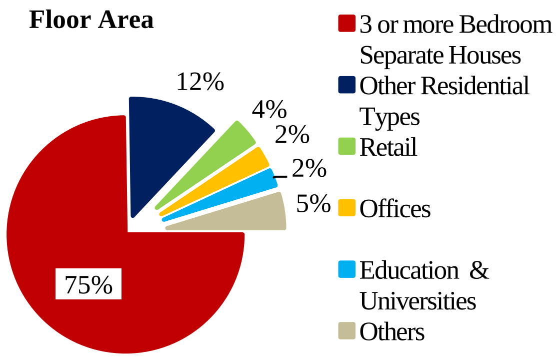


Fig. 1 National residential and non-residential building flat area and energy consumption. Source: [14,18]

Therefore, lack of proper energy efficient housing design would be substantially responsible for losing up to 78 PJ/Annum in the area of heating and cooling in the Australian housing sector, higher than the total energy consumption of the non-residential buildings, e.g. retails, offices, and education and universities.

The number of the Australian households is projected to be increased from 9'250'000 to 12'600'000 million in 2036 (3'350'000 or around 35 percent increase over the period of 2016-2036), while Australia's population is estimated to increase by 33 percent in the same period, from 24'300'000 people to 32'400'000 people [16]. The projected population and household composition make evident the future demands for the new houses and the critical role and responsibility of the housing design process in enhancing the housing characteristics and regulating the end-users' preferences towards more efficient housing choice behaviors.

According to the projected number of households, during the next two decades (from 2016 to 2026 and 2036) more than 3'000'000 dwelling units should be constructed (an average of 1'500'000 units for each period) [19], 2'250'000 (75%) of which would be from 3 or more bedroom separate houses. Accordingly, with assuming the average floor area of 240m^2, the floor area of the 3 or bedroom dwelling units would be up to 550'000'000m^2. The energy consumption of the projected dwelling units would be up to 2'300PJ (an average of 115PJ/Annum) over the period of these 20 years. Regarding the study of Nasrollahi, et al. [13], the potential of the energy consumption reduction through the implementation of bio-climatic techniques and principles, e.g. using natural elements, e.g. vegetation and water features, cross ventilation, window to wall ratio and openings, shadowing devices, geographical orientation, external wall dimensions, building mass and density, height and 3D proportions, just in the area of heating and cooling, would be up to 600PJ (an average of 30PJ/Annum).

5. DISCUSSION

The conducted overview of the current direction of Australian housing development indicated that there are a number of insufficient characteristics, which have substantial responsibilities in a wide range of energy consumption growths in the different energy usage areas of small size residential buildings and thereby should be improved, as it is partly stated by BZE [14]. In this regard, the optimization of housing characteristics, e.g. physical characteristics, interior layout arrangement, building materials, and employment of bioclimatic principles in early stages of feasibility assessment and housing design has the substantial potential in producing energy efficient housing by positively affecting the energy performance of the dwelling units. Accordingly, the architectural design and planning should positively impact the occupants' choice behaviours in the selection of sustainable and green housing products [22,23], especially by encouraging the selection of sustainable and green envelope materials and building technologies which have essential responsibilities in enhancing thermal performance of the buildings and would have serious impacts on heating and cooling energy consumption reduction [14].

The housing design should also be able to simplify residents' domestic activities by optimizing the spatial and functional structure and organization as well as improving the interior layouts arrangement of the dwelling units [24], which has an essential role in improving the energy performance of the units. It is also necessary to enhance the flexibility of the dwelling units with respect to the different lifecycle stages of the occupants [25] to make it possible to fit the energy consumption of the dwelling units with the number of households and their domestic requirements. Employing the bioclimatic principles, e.g. shadowing devices, openings, courtyard, and balcony, and vegetation has also a lot to offer by facilitating ventilation, daylight, and passive cooling and heating [10,11]. The design process has also the potential for improving the energy performance of small size residential buildings by facilitating the sustainable usage of building materials [3,11]. Table 3 overviews the different components of sustainable housing design.

Table 3 Key-components of sustainable housing design

Components	Techniques	Advantages
Bioclimatic Techniques Principles	Natural elements	Improving passive heating & cooling
	Cross ventilation	
	Window to wall ratio	
	Shadowing devices	
	Orientation	
	External wall dimensions/materials	
	Building mass /density	
	Height/3D proportions	
Building Physical Characteristics	Floor area	Enhancing the building energy performance
	Building size	
	Number of rooms	
	Floor area per person	
Interior Layouts Arrangement and Spatial Organisation	Spatial & functional structure	Improving occupants' housing choice behaviors
	Interior layouts arrangement	
	Flexibility of the units with respect to occupants' lifecycle	
Sustainable Usage of the Building Construction Materials	Reducing the waste materials	Reducing embodied energy of the residential buildings
	Reusable & recycled	
	Environmental friendly	
	Climate compatible	
	Resources availability	
	Manufacturing	
	Transportation	

This aim would be achievable by enhancing the degree of congruity between housing physical characteristics and occupants' motivational tendencies, entitled Housing-Resident Fit (HR Fit). This, in turn, depends on providing suitable structural strategies to overwhelm the external barrier (e.g. availability, product quality, actual costs and benefits, reward) alongside information strategies to eliminate the internal barriers (e.g. motivation, perception, attitudes, and social support), enhancing end-users' pro-environmental behaviours and involvement in the optimization of housing characteristics [26,27] (Fig 2).

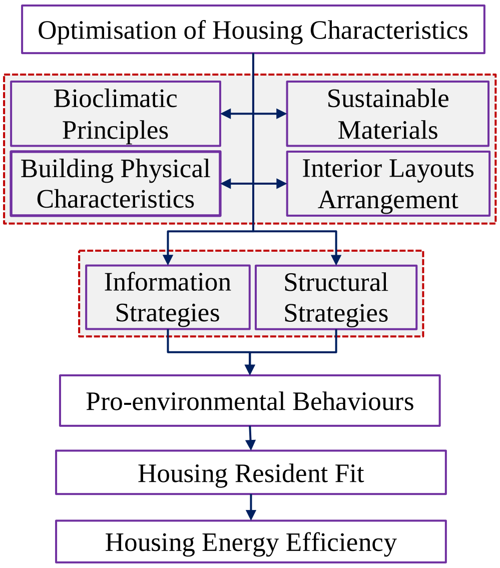


Fig. 2 The implementation of sustainable design components in achieving HR Fit

6. CONCLUSION

Regarding housing spatial, physical, and functional characteristics, end-users' preferences, and direction of housing development, sustainable housing design has a substantial potential to improve the energy performance of the Australian housing. The responsibility of feasibility assessment and design process is highly crucial by considering the 2036 projected households and the future energy demands of the new residential units. The implementation of the different components of housing design enhances the energy consumption of the dwelling units directly by affecting the buildings physical characteristics and indirectly via improving HR Fit, which should gain centrality in the housing energy efficiency action plans. The implementation of the different components of sustainable housing design depends strongly on the interest and involvement of end-users. Therefore, the second level of indirect impacts of sustainable housing design depends on the supervisory role of the designers in enhancing end-users' housing choice behaviors, which needs further investigation in the future research.

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