Greening the Urban Housing: The Impact of Green Infrastructure on Household Energy-Use Reductions for Cooling

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Abstract

Housing energy efficiency is currently a minor part of energy efficiency debates, but is recognised as a major opportunity for energy use and CO_2 reductions, optimised development patterns, technological advances, integrated solutions and behavioural changes, in many countries, regions and municipalities. With a focus on the context of China, this study focuses on the impact of green infrastructure (GI) on potential household energy-use reductions.

The primary technique for energy reduction in buildings or households to be considered is Green Infrastructure (GI). As such an important role for buildings is the reduction of high energy use, which reduces environmental impact. Moreover, an important role, especially for households, is the economic viability and health implications related to such high energy use. This study proposes for a comparative analysis of cases for housing development and GI in the contexts of China (with models from both the EU and China).

Finally, this study serves as a strong platform for discussions and cases of 'housing energy efficiency' between the two contexts of EU and China; where we can argue for twofold benefits with: huge possibilities and lessons-to-be-learnt from the EU and a huge – partly unexploited - market in China.

Key words: Green Infrastructure; Urban Housing; Energy-use Reduction; Cooling.

1.0 Introduction

Global population increase has inherently meant the requirement of energy demand to be met by the increase in primary energy and resource consumption. This situation is further compounded by the fossil based fuel which is the primary source of energy globally, and is identified to be not only limited in supply but also detrimental to both environmental and human health (Yaghoobian and Srebric 2015). The best ways of addressing this, has been to reduce energy demand, find alternative means of producing energy (renewable energy) and improving efficiency of fossil based generation technologies (Boyle, Everett et al. 2003).

One of the major contributors has been linked to cities and within cities the individual buildings that constitute cities. As such the core focus is the reduction of energy demand in these building with a focus on households. Energy is generally consumed to maintain indoor temperature and thermal comfort in households (Lehmann 2015). To achieve this mechanical ventilation and heating systems are utilized which produce a significant amount of greenhouse gas emissions during operation. This situation becomes particularly detrimental in locations of extreme cold and heat (Wong and Baldwin 2016). For example, high temperature gains through external walls in generally quite significant and air-conditioning is required to mediate this temperature gain and provide thermal comfort. However this is not only environmentally detrimental, it can also be economically costly (Bonta and Snyder 2008).

To this end, the effectiveness of GI within housing communities is the focus of this paper and is seen as reduction energy strategy. GI is defined in macro, meso and micro contexts as a network of either planned or unplanned green spaces which provides various benefits (Wang, Bakker et al. 2014). GI includes parks, gardens, street and private trees, golf courses, as well as more engineered options such as green roofs, green walls and rain gardens (Cheshmehzangi and Griffiths, 2014). The benefits associated with these include reducing the urban heat island effect (UHIE), reducing dust accumulation, minimizing noise pollution, optimizing storm water management and providing natural habitat for wildlife. However, the most important is decreasing building energy-use consumption (Hashem et al. 2001).

Considering the GI dimension in various perspectives, during summer periods trees and bushes provide shade against solar radiation as well as reduce the surface temperature of the surroundings; thus, improving thermal comfort and reducing cooling load and invariably at night block access of cooler winds and prevent heat flow from buildings. Another popular function of GI is through evaporation and transpiration from vegetation and surrounding soil. This, generally, is termed evapotranspiration, which reduces moisture in the atmosphere; thereby increasing humidity in building. This is further strengthened by the function of trees to lower and direct wind speed, which not only reduces temperature in buildings but is a major form of discomfort (Akbari et al. 2001, Wong and Baldwin 2016). Notwithstanding, these techniques, if not used appropriately may actually increase energy demand. For instance with low speed wind particularly in warmer climates, GI may impede upon heat dissipation through windows as well as other sunlight surfaces. In addition increasing or reducing humidity within a building determines human comfort and is significantly dependent on location i.e. hot or dry therefore careful consideration of the type of GI methodology is required, methodology here meaning through the use of green roofs and walls and other such processes (Yaghoobian and Srebric 2015). Using an example of green roofs, they are used for reducing building energy consumption by increasing insulation thickness of roofs; they provide natural shade against solar radiation and decrease the inner and outside temperatures of the roof invariably reducing energy consumption in buildings.

Moreover, it is important to highlight the benefits of GI in housing sector for various actors and users. The benefits are shortlisted as ‘Energy and Climate Change’, ‘Health’, ‘Environmental’, and ‘Socio-economic’.

Table 1 - Priorities or/and benefits for consideration of Green Infrastructure in housing sector for Various Actors and Users

Benefits	Policy Makers	Planners	Developers	Owners/residents
Energy and climate change	Promotion of GI as a natural element against issues such as Urban Heat Island Effect (UHIE) and etc.	Integrated planning for better microclimate urban design and enhancement of energy efficiency	Energy-use reduction as not only a selling point but also as the shared responsibility of developers	Energy-use reductions through cooling and shading; Cost effective in a longer term

Health	Promotion of GI for healthier urban living	Development of GI as a primary element for healthy living environments	GI as multi-functional spaces in a typical development	More dependency on natural ventilation and cooling
Environmental	Preservation of greenfields and green spaces in city environments	Greening housing communities; Balancing the natural and built environments	Greening housing communities; Lessening environmental degradation	Better environmental quality for residents in the community
Socio-economic	Consideration of GI from multi-perspectives and benefits	Enhancement of functionality of GI in practice	Provision of better accessibility to green spaces for users	Leisure or socialising feature of living environments

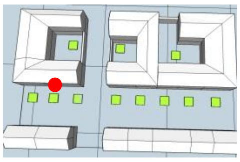
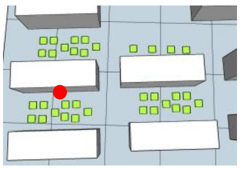
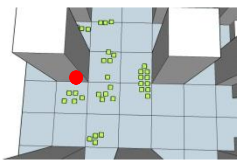
Green infrastructure in housing sector plays a major role in achieving better quality design and planning of housing units. There are substantial advantages for health, environment and social factors as well as energy and climate change issues. While policies can promote benefits of green infrastructure in housing sector for better environmental quality, they can surely elaborate on energy-related aspects of green infrastructure in practice. The planning system should emphasis on functionality of green infrastructure, beyond its ecological, aesthetical and socio-economic benefits. Balancing the profitability for developers is very essential and green infrastructure should play a positive role in not only advertising quality living environments, but more importantly, green and energy efficient living. The owners/residents, as the end-users, should consider the importance of green infrastructure in their housing areas as a natural element for cooling and shading effects.

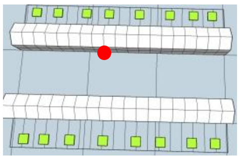
2.0 Case Study Analysis

In order to avoid key parameters related to the actual building detailed design, the models are considered with the same material use, orientation, wall thickness and construction methods. All trees are considered as 5m high trees with a same shading effect. The simulation is based on the scenario of cross- or double-sided natural ventilation for each of the units. However, this is unlikely for high rise blocks since nearly half of the units are left with single-sided natural ventilation only.

A unified context is proposed for all six cases in which outdoor temperature is set at constant temperature of 30°C at 14.00pm. All models are simplied to same level of occupancy (for energy-use simulation which is not shown here), same range of openning ratio (to building façade), same floor-to-ceiling heights and similar spatial layout of having three zones at least (with direct sunshine, with in-direct sunshine and with no sunshine to indoor spaces). It is important to note that these simulations are merely used for simulating the effect of green infrastructure (mainly trees and similar plantations) and not to fully assess the performance of buildings. The below table provides findings of these simulations at two levels (lower and higher for low-rise models; and lower and middle for mid-to-high rise models). All simulations are done in the EnergyPlus programme. The findings are indicative for the purpose of this paper and do not offer detailed information about temperature and energy-use details.

Table 2 – comparison analysis of six studied cases: three existing Chinese cases, and three European cases implemented in China as mock-up cases.

Model	**Model**	**Low Level – Temp Range**	**High Level – Temp Range**
1. A Chinese low-rise urban housing (2 storey)		On ground floor: Min. indoor 24.3°C Max. indoor 28.2°C	On first floor: Min. indoor: 24.9°C Max. indoor: 28.5°C
	Floor Area Ratio (FAR) is appximately 1.5; Surface Coverage (SC) is medium to high; Green Infrastructure is limited to individual trees and small patches of green spaces		
2. A Chinese low-to-mid-rise model (6 storey slab housing block)		On first floor: Min. indoor 24.0°C Max. indoor 27.8°C	On fourth floor: Min. indoor: 24.4°C Max. indoor: 28.6°C
	Floor Area Ratio (FAR) is appximately 1.12; Surface Coverage (SC) is medium to high; Green Infrastructure is limited to clustered trees in between slab blocks		
3. A Chinese high-rise housing model with		On first floor: Min. indoor 25.4°C Max. indoor 29.0°C	On fifteenth floor: Min. indoor: 25.5°C Max. indoor: 29.1°C

high density (30 storey block)	Floor Area Ratio (FAR) is appximately 4.0; Surface Coverage (SC) is low; Green Infrastructure is mainly clustered trees and large spaces of green spaces		
4. A Parisian Parameter model (8 storey block)		On first floor: Min. indoor 25.6°C Max. indoor 28.6°C	On fourth floor: Min. indoor: 25.8°C Max. indoor: 28.8°C
	Floor Area Ratio (FAR) is appximately 2.56; Surface Coverage (SC) is medium; Green Infrastructure is mainly inidividual trees or internal green spaces (if not services)		
5. A UK terrace housing row model (2 storey)		On ground floor: Min. indoor 25.0°C Max. indoor 28.3°C	On first floor: Min. indoor: 25.2°C Max. indoor: 28.3°C
	Floor Area Ratio (FAR) is appximately 1.0; Surface Coverage (SC) is low to medium; Green Infrastructure is limited to inidivual trees and patches of green in back gardens		
6. A typical European semi-detached model (2 storey)		On ground floor: Min. indoor 24.7°C Max. indoor 28.1°C	On first floor: Min. indoor: 25.2°C Max. indoor: 28.8°C
	Floor Area Ratio (FAR) is appximately 0.8; Surface Coverage (SC) is low; Green Infrastructure is mainly green and trees of front public space and back gardens		

It is important to note that the effectiveness of [tree] plantation is very different between individual plantation and clustered plantation. The individual plantation layout, mostly seen in the European models, provides minimal effect on cooling the surfaces. While, the clustered plantation layout creates a larger shaded area, it can potentially reduce the air flow as a negative impact. It is, therefore, suggested to provide a layout which is clustered but can also create air flows in between the individual trees, or by having a variable tree sizes. For all cases, the tree plantation cannot be effective for mid-to-high rise buildings, unless the building design includes set-backs, upper gardens and balconies that can provide more shading for indoor areas. Some successful examples are seen in Singaporean buildings, where provision of public spaces at upper floors often includes tree plantation and greenery.

The other key factors that need to be considered are:

- *Internal spatial size*

This plays a major role in air movement, spatial use and configuration. While semi-detached European housing models offer a large internal space of two stories, most Chinese high-rise buildings offer a smaller internal space in one storey (and often with no cross- or double-ventilation). As a result, the simulation is done based on a similar internal spatial size of $75m^2$ to $100m^2$.

- *Occupancy Level*

Household energy use is very much dependant on number of occupants per sqm and their behaviours towards consumption. Both household occupancy and energy-use consumption patterns are very different between the EU and China. However, with current increase of China's household consumption and family size changes, it is likely to see China levelling up the EU in an early future. For this study occupancy level of 3 people is considered. The energy-use consumption is not considered as a variable in this study.

- *External Façade detailed design*

As part of material use and wall thicknesses, detailed design of external façade plays a major role in reduction of household energy-use. This is not only through the materiality of the façade, but also the consideration of detailed design to include shading devices, canopies and similar effects that are not necessarily provided by trees. While we witness a larger amount of glazing use in contemporary Chinese houses, the final detailed design of façade remains important in how direct solar gain can be reduced to avoid internal heating of housing units. For this study, all models are considered with flat surfaces with small openings, accounting for 20 to 30% of the external surfaces.

- *Plantation type*

This is often neglected by architects and designers, but should be given a careful consideration in detailed design and at landscape planning. The type and how tree plantation is positioned in respect to buildings play a major role in how it can be effective for provision of natural cooling and shading. While there are limitations in practice, in terms of positioning trees in the housing areas (i.e. distance to buildings) and number of trees, the role of such plantation could play and effective role in cooling and lessening the solar radiation on surfaces and indoor areas. Previous studies in this field have already shown that the maximisation of shading in the built environment would lead to reduction of surface temperature; and therefore, reduction of cooling demand.

3.0 Discussions: Green infrastructure Analysis

If to consider all six models in the context of China (including the three European models), we can then point out advantages and disadvantages of each model on the basis of how green infrastructure can be utilised in common practice. The so-called common practice, however, is mainly in favour of developers, for which key issues of FAR and SC are very important. Table below, points out these elements and elaborates on opportunities for development. In all cases, detailed design aspect (from layout to internal design and façade design) can play a major role in utilising green infrastructure for housing communities.

Table 3 – Advantages, disadvantages and opportunities for development for all six models

Model	Main advantages	Main disadvantages	Opportunities for development
1. A Chinese low-rise urban housing (2 storey)	Preferable scale and fairly compact at a same time; Walkable and permeable layout.	Lack of spaces for significant green spaces; Almost no provision of green infrastructure in most cases.	Mixed-used and greening opportunities; Improvement of internal courtyards to gardens.
2. A Chinese low-to-mid-rise model (6 storey slab housing block)	Provision of shading for most of housing units; High performative and reasonable density for housing units.	Low quality construction in most cases; Green spaces are either not functional or limited.	Enhancement of ground spatial functionality; More land-use dedication to green spaces.
3. A Chinese high-rise housing model with high density (30 storey block)	High provision of land-use for green spaces (low SC for the buildings); Internal pleasant green environments.	Excessive underground infrastructure; Green infrastructure not very effective for upper floors.	Green can be adapted on facades or in between floors; Maximising the overall permeability of GI.
4. A Parisian Parameter model	Relatively high FAR and effective planning; Potential communal indoor	Culturally not suitable; Variable orientation, and East-West ventilation;	Maximising GI for internal spaces; Open spaces to be more

(8 storey block)	spaces.		than just for services.
5. A UK terrace housing row model (2 storey)	Private green spaces for all units; Relatively balanced built and non-built spaces.	Not profitable density; Expensive units if applied to the context of China.	Redesign of private spaces into communal spaces; Reduction of roads/streets between units.
6. A typical European semi-detached model (2 storey)	Very low surface coverage; Private green spaces for all units;	Non-profitable density; Expensive units if applied to the context of China.	Redesign of private spaces into communal spaces; Reduction of roads/streets between units.

4. Conclusions

Green infrastructure at neighbourhood or housing community scale offers low-cost solutions to better urban microclimate and urban environmental quality. The reduction of surface coverage and balancing the density of built units will highly impact the quality of spatial planning and green spaces in city environments. With focus on households, this study verifies the impact and effectiveness of GI in practice. The temperature difference between the simulated models – although not very significant – highlights the role of green infrastructure as means of natural cooling and shading.

This study has listed a platitude of advantages that not only reduce cooling load but also increase thermal comfort while taking responsibility for the environmental impact. GI affects indoor environment through climate and air quality, it also affects human well-being and economic welfare (Bonta and Snyder 2008). This is based on the reduced energy cost due to indoor air modifications, which for most households would be a primary incentive to imbibe such techniques. From a policy Standpoint, various governments are increasingly encouraging the utilization of GI on both cityscape through local authorities and developers and household implementation by private home owners. This is due to not only the environmental challenges mentioned above but in particular the effects of UHIE (Wang, Bakker et al. 2014). The Use of GI by households extensively, could potentially help reduce urban air and surface temperatures thereby addressing economic and environmental challenges simultaneously.

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