# ARE GREEN BUIDINGS ALWAYS GREEN?

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## Introduction

The building and construction industry has long been criticised for its extensive impacts on the environment, regardless of greenhouse gases emission, construction waste, pollution (including noise, air and water pollution), habitat destruction, depletion of natural resources, or destroying the balance of biodiversity. According to GABC (2016), energy consumption in buildings and for building construction takes more than one third of global final energy use and gives rise to nearly 25% of global greenhouse gases emission. The building sector therefore has the biggest potential in mitigating impacts to the natural environment. Being green has evolved as a new trend in the built environment, and it particularly plays a vital role in contributing to environmental sustainability.

In response to the call for climate change mitigation, an increasing number of green buildings have been built to reduce greenhouse gas emissions. On one side, there are 36,259 certified BREEAM projects, with 22114 BREEAM new construction projects as of 24 November 2023 (BREEAM, 2023). On the other side, U.S. Green Building Council has also recorded a total of 167,854 LEED-certified projects globally as of November 2023 (USGBC, 2023). The exponential increase of green buildings however does not guarantee superior performance of the built environment in creating a greener and more comfortable environment to live and work. Over the past few decades, more studies (Goh, 2022; Newsham et al., 2009; Thatcher and Milner, 2016) revealed that green buildings may not necessarily live up to people’s expectations in delivering the sustainable development goals, thus demurring the status quo of green buildings. This paper therefore will review the state-of-the-art of green building performance and debunk the myth of green buildings for meeting net zero carbon goals in a very short term.

## Green Buildings and Their Development

Green building is recognised as a flagship for creating a more sustainable built environment, as an effort to transform the carbon intensive construction industry into a more environmentally friendly sector. As defined by U.S. EPA (2016), green building is a practice of creating structures or buildings with the use of environmentally responsible and resource-efficient processes throughout a building life cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction. This definition regards green buildings as a process of pursuing green standards, instead of an end product. From here, it is clear that green building is a dynamic process that should not rest or end, until it reaches the end of the building life cycle.

In the green movement, several green building assessment schemes have emerged in the market to guide construction stakeholders in the delivery of green buildings. These assessment schemes give measurement indicators to stakeholders in determining how green a building is. Due to geographical and cultural consideration, each of the assessment schemes has different emphases on the criteria for green buildings in. The popular assessment schemes in the market include LEED (US), BREEAM (UK), Green Star (Australia), BEAM Plus (Hong Kong), Green Mark (Singapore) and GBI (Malaysia).

Green buildings need to be designed, constructed and managed in an environmentally friendly manner. Green features are introduced to minimise negative impacts of the built environment on climate, natural environment, biodiversity and surrounding communities. The introduced green features intend to encourage efficient use of resources; adopt renewable energy; reduce carbon emission and pollution; decrease water use; improve indoor environment quality; promote reuse and recycling of materials; and improve biodiversity. Innovation also bears a credit by creating new ways of making the structure and built environment more resilient and flexible in order to accommodate changes of people's needs for building use over time, hence minimising the need to renovate and demolish buildings due to being obsolete.

The performance of green buildings could be examined from different perspectives in terms of building life cycle and stakeholder. Each green building has its own unique design and management characteristics based on regional, cultural, economic, political and institutional factors and this leads to different expectations for the attainment of green building goals. Regardless of the differences, the main purpose of adopting green building approaches is to greatly reduce environmental impacts of the building construction industry. The main criteria of assessing the performance of green buildings include energy, materials, water, waste, indoor environmental quality, health and wellbeing, land use/sites, transportation, management and innovation. In most instances, green buildings are designed to reduce carbon emissions throughout the building life cycle, with improved comfort and wellbeing without compromising the desired functionality and durability.

**Overall Positive Performance of Green Buildings**

With the incorporation of green design features, green buildings could have performed better than conventional buildings in terms of energy efficiency, environmental impacts, and comfort level. In 2008, the US General Services Administration (GSA) commissioned a post-occupancy evaluation to 12 green buildings to examine environmental performance, financial metrics and occupant satisfaction and found that the studied buildings on average perform better in occupant satisfaction than the national average for US commercial buildings (GSA Public Building Service, 2008). In 2010, the same research team reassessed the green building performance with additional 10 green buildings and the whole building performance are observed as follows: a) aggregate operating costs are 19% lower than the baseline; b) carbon dioxide equivalent emissions are 34% lower than conventional buildings; c) energy use intensity are 10% -25% better than multiple referenced baseline (Fowler et al., 2010).

Similar trends are also observed in other studies. Newsham et al. (2009) found that LEED buildings on average used about 18 -39% less energy per floor area than their conventional counterparts while Thatcher and Milner (2016)'s study shows significant improvements in air quality elements in green buildings. In a more recent study, Liu et al. (2018) also revealed green buildings generally have higher user satisfaction in the areas of cleanliness, lighting, air freshener, visual privacy, acoustic, temperature and the overall satisfaction, regardless of cold zone, hot summer-cold winter zone and hot summer-warm winter zone. Overall, green buildings would have better user comfort and improved environmental impacts if they are properly administered in accordance with the recommended design and operational manual. It is, however, important to note the aforementioned green building performance is examined in aggregate to give the promising results of green performance.

In a recent study conducted by Zhou et al. (2022), green buildings in Beijing were found to have achieved good performance in aspects of land use, energy efficiency, indoor environment quality, and user satisfaction. Green residential buildings in Beijing have an improved performance in air quality, thermal environment, sound environment and overall user satisfaction. The same study also revealed that green buildings achieve good quality of public space and optimal land use, in which the investigated green residential buildings have an average centralised green space area of 1.8$m^2$ per capita, with an average green space rate exceeding 35%.

**Are Green Buildings Always Green?**

With the above examples, can we assume that all green buildings always live up to people's expectations towards green or environmental sustainability? Surprisingly, there is no consistent success attained by the green buildings and research demonstrates that green buildings do not necessarily bring positive performance in their life span as anticipated by the project parties and long awaited by the public. The following gives some examples of deviated green building performance with regards to their environmental and social targets.

As for energy and environmental related performance, Newsham et al. (2009) unveiled that 28-35% of LEED buildings used more energy per floor area than their individually matched buildings in the 2003 Commercial Building Energy Consumption Survey database. No statistically significant relationship between LEED certification level and energy use intensity was found, although there are correlations between energy credit and the awarded certification levels (Newsham et al., 2009). On the other hand, Goh (2014) also found several certified green buildings did not achieve their desired green goals in the post occupancy stage. In her study, the wind turbine installed at the rooftop of green buildings experienced some failures in harvesting and converting wind energy, not to mention the closure of the wind turbine system for a period of time due to unexpected malfunctions. Geng et al. (2019) also reported a significant deviation in green building performance in which some buildings perform even poorer than their traditional counterparts, not to mention the baseline performance.

Zhou et al. (2019) conducted a post occupancy investigation in 40 certified green buildings in China and uncovered that most implemented technologies in green buildings are poorly rated, and these include utilisation of renewable energy, non-traditional water source, HVAC automatic monitoring and controlling system, as well as power (cold & heat use) metering and charging. The same study also revealed that the average energy use intensity (EUI) of the studied green shopping mall buildings was higher than the city average baseline, although the average EUI of green residential buildings was almost the same as the city's average.

At the same time, green buildings may not perform satisfactorily in meeting their social related expectations. Paul and Taylor (2008) found no clear evidence that green buildings are more comfortable than conventional buildings. Thatcher and Milner (2016) also revealed that green buildings demonstrated no significant improvements related to psychological well being, job satisfaction, propensity to stay in the organisations, organisational image and absenteeism.

These indicate that not all green buildings are more successful than others in delivering satisfactory results for environmental or social sustainability.

**Why Failed to Deliver the Promised Green Performance?**

Green buildings need to be evaluated based on the actual performance, instead of the assumed results or modelled performance. Most people assumed that green buildings would definitely perform greener and better than traditional buildings. However, literature above has suggested a gap for numerous green buildings in delivering their green targets. During the design stage, green building performance is normally simulated with flat assumptions, speculations and extrapolated principles and this simulated result did not turn out in reality. Gaps are therefore resulted from the designed model result and real building performance when the buildings are in use later. Conniff (2017) put the blame on the overly optimistic energy modelling and found it as the root cause of the performance gap of green buildings. As revealed by Conniff (2017), refurbished apartment buildings in Germany missed the predicted energy savings by 5-28% while fifty leading-edge modern buildings in the UK were reported to use up to 3.5 times more energy than the design had allowed for and produce approximately 3.8 times the predicted carbon emission. These again suggest that the promising performance of all green buildings is not fully supported, and sometimes the result could be contradictory.

Geng et al. (2019) pointed out that most of the previous green building studies were in fact design-oriented, in which the studies mainly highlighted what green buildings “should” perform during the operation. The “designed” building performance shall not, in any way, represent the real performance results of green buildings, hence concluding the superior performance of green buildings as a silver bullet to meet the global net zero carbon target.

Researchers also reported conflicts in delivering multiple objectives in green buildings. For instance, air tightness for improved energy performance in green buildings has resulted in poor indoor air quality and overhearing in the transition seasons (Geng et al., 2019). The use of a centralised HVAC system also puts the user's thermal comfort at risk with the loss of personalised control (Goh & Yang, 2022). Privacy in open design, overheating risks from natural ventilation, humidity and occupant wellbeing are amongst the controversial issues reported in literature of green building studies in recent years.

## Discussion

The above performance gaps of green buildings could arise from a failure of putting humans at the centre of planning and designing green buildings (Goh, 2022; Goh and Chong, 2023). Green building comprises numerous interconnected systems made up of various technologies, materials, and information systems for creating a resilient and sustainable environment to live and work. Multidimensional socio-technical aspects should be taken into account in the design and operation of green buildings (Goh, 2022). Interplay between humans and the environment in green buildings should not be neglected. Green buildings are often designed based on the desires of designers and developers, while the actual demands, needs and expectations of end users in the operation stage have not been fully considered (Goh, 2022; Zhou et al., 2022). These result in the performance gaps, technology abandonment, and investment waste of green buildings, hence raising doubts in the cost benefit analysis of the green built environment. The interplay between end-users and environment in green buildings is a key factor to determining the success of green buildings. Human behaviour variability is one of the main drivers that may counteract the intended green building outcomes, particularly when end users operate the green buildings in an inappropriate manner.

According to Zhou et al. (2022), most construction organisations are pursuing the publicity value and have insufficient enthusiasm to apply green (with wait-and-see attitudes). In absence of direct immediate economic benefits, there is no urgency and enthusiasm of stakeholders in the construction value chain to vigorously apply green in their buildings. The authors also revealed that there is a lack of people-oriented service consciousness in green buildings. Most of the operation teams have a low expertise level, low green cognition, a low informatisation level, and frequent personnel flow and the traditional property management models, thus leading to the poor implementation of green buildings (Zhou et al., 2022).

A value proposition to shift green buildings from energy-focused or carbon-oriented projects to people-oriented projects has therefore emerged. Engaging and empowering users is of urgent importance to optimise the performance of green buildings. In addition to advance green technologies, interactive information systems shall be incorporated into the building system, hence allowing users to communicate their needs and requirements constantly. Feedback can ensure the building management systems respond to the changing user needs and environmental conditions in a dynamic manner. Human-centric approaches are therefore advocated to make green buildings more adaptive, responsive and resilient based on physical, physiological, and psychological characteristics (Goh, 2022). By deploying human-centric solutions, building functions in green buildings can be improved with more contextualised operational strategies in accordance with the site, functions and user requirements. Goh (2022) emphasised the integration of two main principles of human-centric solutions in green buildings to leverage green building features for seamless connections between users and environment: i) accessibility and availability, and ii) functionality, serviceability, and flexibility. Additionally, the support of information and communication technologies with sensing, inferring and communication abilities is critical to make green buildings more perceptual and cognitive (Goh and Chong, 2023). With the strengthened green management capacity of end-users, the integration of human-centric solutions provides a measure to make green buildings more engaging and adaptive. This would ultimately help mitigate significant variance of green buildings between the design and the operation and solve the underperforming issues of green buildings.

**Conclusion**

There is no constant guarantee of success that green buildings will outperform conventional buildings. Although no direct victory can be assured by green buildings, this paper in no way suggests the green building movement should be discontinued. Green building, or a broader term - sustainable building is always the right thing to do and it is critical to do it right, with efforts from all the parties. An aspiration of green buildings can only be fulfilled with the full support and commitment of green users, green facilities managers, green communities, etc. The interactions between users and buildings are of great importance to determine how successful a green building is. An integrated life cycle approach would be a valuable model to reap full benefits of green buildings. Human-centric approaches have therefore been proposed to provide synergies between users and environment in green buildings, hence reducing performance gap issues associated with green building over the past few decades. The move towards green buildings and sustainable cities is no longer a scientific and technological transformation but also a social transition. However, more research is necessary to develop a holistic human centric approach in green buildings to necessitate the delivery of net zero carbon goals by 2050.

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