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MITIGATING CLIMATE IMPACT THROUGH DESIGN: ENERGY PERFORMANCE IN SOUTH AFRICA'S SOCIAL HOUSING SECTOR

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ABSTRACT: Since low-income and social housing are among the most vulnerable built environments to climate change, this article evaluates the energy performance of social housing in the context of enabling net-zero carbon social housing in South Africa (SA). It seeks to investigate how improved and conscious energy-efficient design in the context of social housing contributes toward a climate change mitigation response in SA. The article analyses energy use and indoor comfort, based on ASHRAE 55-2004 Standard, of two social housing case studies to review the potential of the social housing sector to contribute to the national climate mitigating agenda. The findings highlight that the housing provision itself is not an adequate response, but that bio-climatic design solutions with appropriate spatial and material choices, along with efficient envelope articulation, play a critical role in lowering energy use and improving user comfort. There is, however, a need to challenge the growing advent of (energy-) inefficient and carbon-intensive social housing in SA and simultaneously address the parallel crisis of homelessness, to enable a sustainable future for the built environment.

KEYWORDS: Climate change, netzero carbon building, social housing, environmental sustainability, climate change mitigation

INTRODUCTION

The climate imperative is clear: we must act now and with an ambition to decarbonize human activities to meet global climate goals" (UNEP, 2017: 11). The earth's climate is changing as a consequence of various anthropogenic endeavours, primarily through the release of greenhouse gases (GHGs), causing the earth to heat up by the intensification of the greenhouse effect (IPCC, 2014; Zalasiewicz & Williams, 2009; Howard, Rowe & Tchobanoglous, 1985). The most recent climate predictions by leading international scientific organizations

Original Article

disclose that the window to avert threatening global climate change is rapidly closing, as the global carbon budget diminishes further every year (UNEP, 2017). According to the United States Green Building Council (USGBC) (2018: 2), the construction industry accounts for approximately 40% of worldwide energy usage and carbon dioxide (CO_2) emissions, out consuming both the industrial and transportation sectors and contributing significantly to climate change. Furthermore, housing is the single largest subsector of the construction industry and a substantial contributor to environmental degradation, with high levels of energy consumption and GHG emissions. Access to housing is, however, also a basic human right protected within the Constitution of SA (SA, 1996: 5). Moreover, its demand is substantial, making it a sector with considerable potential to mitigate the negative influence of the construction industry on climate change. The urgency to address the substantial growth of inefficient buildings has been widely recognized (UNFCC, 2016, in GBCSA, 2018), particularly in the South African context, where an energy-intensive building will mean a very carbon-intensive building, due to our coal-powered electricity grid. Internationally supported climate change mitigation strategies, in the form of renewable energy and energy-efficient projects implemented in developing countries between 2005 and 2016, are projected to reduce GHG emissions by 0.6 $GtCO_2e$ in 2020 (UNEP, 2017: 7). Likewise, SA's National Development Plan (NDP) 2030 aspires to progressively reinforce the energy-efficiency requirements within the South African building legislation to realize a net-zero carbon building standard by the year 2030 (SA, 2012). Spatial planning represents perhaps the most entrenched legacy of the apartheid era: the construction of a built environment characterized by both segregation and a concomitant absence of diversity (Low, 2005). Since the fall of apartheid in 1994, social housing delivery interventions in SA have continued to perpetuate the high carbon footprint of the apartheid urban form. Consequently, the formation of vast 'dormitory settlements' of mostly mass-produced, low-cost, and replicated houses located at the urban periphery ensued (Ramovha, 2017: 9). Their typically remote location limits economic opportunity and has resource-intense transport access (SA, 2006). The infamous Reconstruction and Development Programmed (RDP) housing landscape was subsequently born: A housing model guilty of extending the sprawling spatial form of the pre-democratic regime. Urban sprawl not only reduces biodiversity and causes the degradation of the natural environment (DEA, 2011), but it is also more energy-intense and the high emission of GHGs of the local energy supply constraints climate change mitigation.

The South African "Comprehensive Housing Plan for the Development of Integrated Sustainable Human Settlements", commonly known as the "Breaking New Ground Policy" (BNG) of 2004 aspires to, among other objectives, eliminate informal settlements within SA as soon as possible (SA, 2004). In response to the prevailing housing provision mode, this plan leaves behind the RDP commoditized focus on housing delivery and takes on a more responsive approach, focusing rather on the multifaceted requirements of sustainable human settlements. Accordingly, social housing (medium density) has been identified as a suitable mechanism for this approach in the BNG policy (SA, 2004: 2). The policy further states, in 'Section 3.7 Enhancing the Housing Product' (SA, 2004: 17), that there is a need for enhanced settlement and housing unit design and quality, which includes traditional and indigenous knowledge as well as alternative and innovative technologies and design, to alter the face of the stereotypical RDP house. Net-zero carbon social housing could realize this goal by providing energy efficient homes and environments in proximity to services, transport routes, clinics, schools, and economic opportunities, ensuring a more carbon-efficient solution. Hence, medium-density social housing has been identified as a sustainable housing strategy with significant climate change mitigation and adaptation potential, and a departure from the "40x40x40 housing paradigm: 40sqm house, 40km outside the city, where 40% of income is spent on transportation to work" (Fieuw, 2014: 2). Furthermore, the World Green Building Council (WGBC)'s 'Advancing Net Zero Projects' initiative's goal is to ensure that the global building stock is net-zero carbon by the year 2050 and that all new buildings' operational carbon emissions are net-zero by 2030 (GBCSA, 2018). Locally, the GBCSA's (2018) response to climate change and the Paris Agreement comes in the form of their latest certification scheme, the Net Zero/Net Positive Certification Scheme. Net-zero carbon housing has been recognized as a crucial component for the justifiable transition to a low-carbon future in the implementation of the UN's SDGs (UN, 2019). Net-zero carbon housing encompasses more than simply reducing carbon emissions and encouraging renewable energy; it also has broader social and economic advantages such as the reduction of energy poverty and the improvement of human well-being for low-income communities. Despite the obvious benefits of net-zero carbon social housing, currently, limited net-zero social housing has been developed in SA. As a result, an important opportunity for enabling a low-carbon future is lost (Gibberd, 2018). There is a significant gap between the impact of social housing on the environment and the development of green or net-zero carbon social housing, particularly where the climate change mitigation of a building is the primary concern (Brewis, 2012). Furthermore, the literature on net-zero carbon or green architecture within SA focuses almost entirely on technological developments, often for a green-building certification in the high-end building sector, with the rare inclusion of low-cost net-zero carbon development (ASSAF 2011; Harris *et al.*, 2012). This study consequently evaluates the impact potential of net-zero carbon social housing in SA as a climate change mitigation strategy. It seeks to investigate how the design solution and the materiality of the social housing case studies affect the cases' simulated energy use and carbon emissions, in order to determine how housing provision and its energy performance in the context of net-zero carbon can contribute toward a climate change mitigation response in SA.

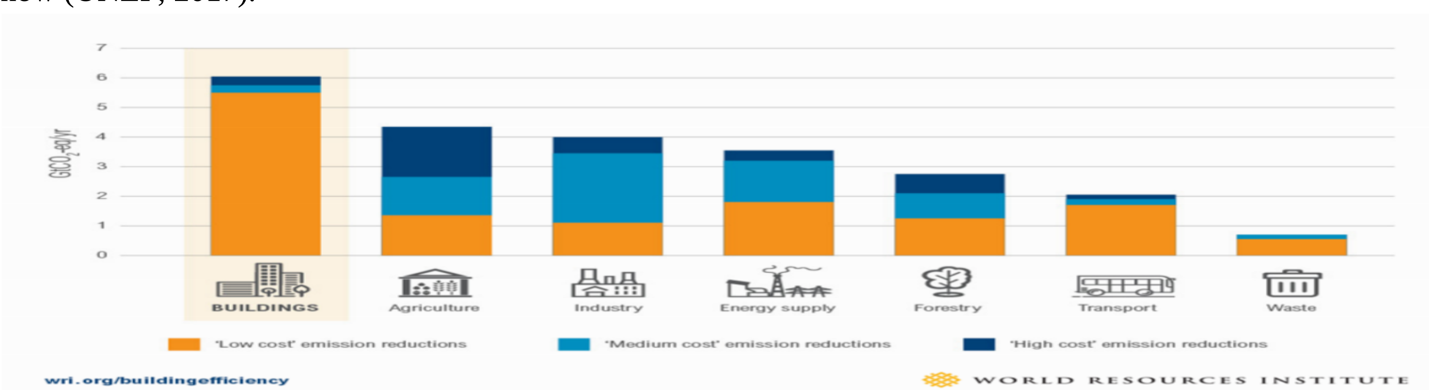
1. LITERATURE REVIEW

1.1 Climate change

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen" (IPCC, 2014: 2). The best available evidence indicates that climate change is already taking place and that it will continue throughout this century as a consequence of anthropogenic GHG emissions (Bolin, 1980; Heywood, 1995; Pearman, 2005; IPCC, 2014; NASA, 2019). The United Nations Framework Convention on Climate Change (UNFCCC) (2015: 7) defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods". Hence, the UNFCCC and Heywood (1995: 1255) differentiate between "human activities"-induced climate change and "climate variability due to natural causes" (IPCC 2014: 120). SA lines itself with a similar distinction. Research suggests that recent climate change is due to human actions related to industrialization, characteristic of human consumption and global domestic product (GDP) growth, and overwhelming anthropogenic ally induced environmental impacts (DEA 2011; Van Wyk, 2012 ; Dechezleprêtre, Martin & Bassi, 2016). In the period from the Industrial Revolution to 2018, the global average temperature anomaly reached 0.9°C, with the year 2016 ranking as the warmest on record (NASA, 2019). According to the Stern Review (Stern, 2006), if the most

Original Article

detrimental impacts of climate change are to be evaded, the increase in the global mean temperature should be kept below 2°C of the pre-industrial levels. This has been reiterated across the literature spectrum (IPCC, 2014; Ampofo-Anti, Dumani & Van Wyk, 2015; UNFCCC, 2015; GBCSA, 2018). The Intergovernmental Panel on Climate Change (IPCC) (2014) conveyed, through their Fifth Assessment Report (AR5), that the global average temperature increase could be in the range of 3.7°C and 4.8°C by the year 2100 with the current "business-as-usual pathway" (UNEP, 2017: 11). This degree of warming would be catastrophic for everyone (Pearman, 2005). In the Paris Climate Agreement, an agreement by the United Nations Framework Convention on Climate Change (UNFCCC) regarding the release of GHGs, climate change mitigation and adaptation as well as an investment came into effect in the year 2020. The Paris Agreement aims to establish a global commitment to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC, 2015: 3). SA is also a signatory to this Agreement. To meet the Paris Agreement's climate change goal, global emissions are required to have peaked by 2020 and would thereafter promptly decline to reach zero emissions by the year 2050 (UNEP, 2017). The United Nations Environmental Programmed (UNEP) Emissions Gap Report (2017: xvii) affirms that "for the 2°C goal, this shortfall could be 11 to 13.5 Gt CO_2e; for the ambitious 1.5°C goal, it could be as much as 16 to 19 Gt CO_2e". Thus, immediate and progressive climate change mitigation action is needed globally. SA's response to climate change, as stated in the National Climate Change Response White Paper (SA, 2011a: 5), primarily aims to effectively manage inevitable climate change impacts and make a fair contribution to the global effort to stabilize GHG concentrations. In addition, it aims to avoid dangerous anthropogenic interference with the climate system within a time frame that enables economic, social, and environmental development to proceed sustainably (SA, 2011a: 5). Global temperatures are anticipated to persistently rise, although the degree to which they are kept below 2°C, as recommended by the IPCC and stipulated by the Paris Agreement, may depend on the quantity of GHGs that the building sector continues to emit into the atmosphere (Ampofo-Anti *et al.*, 2015). The distressing incidences of recent extreme weather events intensify the urgency of immediate climate change action. These events highlight the importance of incorporating the Paris Agreement within the built environment now (UNEP, 2017).



1.2 Climate change and the built environment

Substantial cuts in GHG emissions in buildings could reduce the negative impacts of climate change, by reducing the amount of GHG in the atmosphere. It is also the sector with the most cost-effective climate change mitigation potential, as shown in Figure 1 (IPCC, 2014; Gibberd, 2017). Reduced emissions in the built environment would also improve opportunities for effective adaptation, reduce the costs and challenges of mitigation, and enable climate-resilient pathways for sustainable development. Inertia in the built environment, especially concerning socioeconomic aspects, impedes adaptation and mitigation opportunities, whereas innovation and investments in green and net-zero carbon building can decrease GHG emissions and improve climate change resilience (IPCC, 2014: 26; Blok, Afanador & Van Vuuren, 2017: 37).

Figure 1: The economic climate change mitigation potential by sector by the year 2030

Source: WRI, 2016: 17

The SA National Climate Change Response White Paper is yet to translate into legislation and policies that enable mitigation action in common practices and ongoing planning across all spheres of government, including the built environment. The South African National Climate Change Adaptation Strategy (NCCAS) was, however, promulgated in 2020 and supports the country's ability to meet its obligations in terms of the Paris Agreement. The strategy defines SA's vulnerabilities to climate change, its plans and required resources to reduce these vulnerabilities, whilst determining advancements in climate change adaptation. A significant analysis of this review finds that the mitigation strategies detailed in the White Paper have typically not yet been implemented and that extensive challenges are delaying their realization (Trollip & Boulle, 2017). However, emergent adaptation and mitigation responses are present in some industries. Critical urban-scale and policy based actions have, to some extent, been implemented, although industry challenges persevere. Furthermore, Stern (2006) suggests that a diverse range of economic studies have shown that the costs of delay and inaction far outweigh the costs of early action. This notion is reciprocated by the SA climate change White Paper: "Vulnerable low-income households and the marginalized unemployed will face the most severe impacts unless urgent steps are taken to reduce SA's vulnerability to climate and economic shocks" (DEA, 2011: 32). Thus, mitigation action in the low-income housing industry will have both environmental and social benefits. The intersection between the built environment and climate change is a relatively new but rapidly expanding field of research (Knieling & Klindworth, 2016 in Taylor, 2017; Gibberd, 2017), but the many gaps in literature relate to low-cost applications. Evidence, however, recognizes that climate change presents growing threats to sustainable development within the built environment as a threat multiplier (IPPC, 2014). It exacerbates existing threats to social and natural systems, placing additional burdens, particularly on the poor, and constraining possible developmental paths for all. Action should be pursued now that will move towards low and zerocarbon pathways for sustainable development, parallel to the facilitating of the betterment of social, economic, and environmental well-being. This leads to the suggestive gap in the literature on the interrelationship between climate change and social housing globally and particularly in SA. More so since "enhancing the capacity of low-income groups and vulnerable communities" is recognized as an effective and complementary urban climate adaptation and mitigation strategy (IPCC, 2014: 97).

Original Article

1.3 Climate change and social housing in SA

Homelessness and the need for housing for the indigent have posed a serious challenge for the vast majority of cities in the global south, especially in Africa. Over half of these cities' populations reside in substandard housing or informal settlements (Chiodelli & Moroni, 2014; Van Horen, 2000). On the other hand, social housing can address these communities' increased vulnerability to the expected impacts of climate change. Thus, the role that the government and other leaders in the social housing sector have to play in addressing climate change, as well

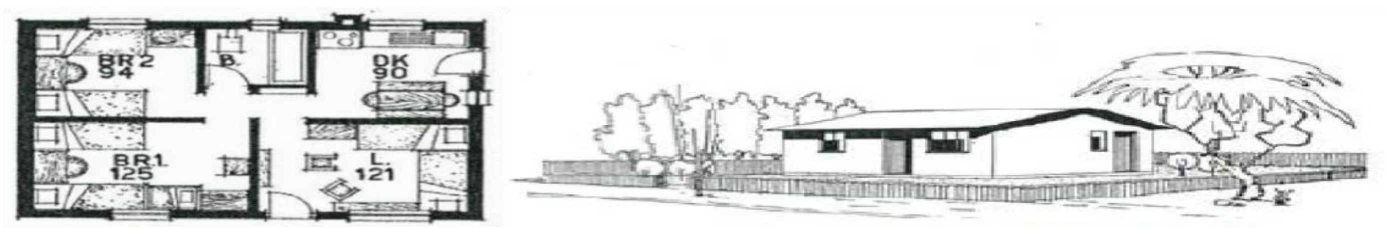


Figure 2: Perspective and plan of the NE 51/9 housing model

as the housing backlog, can be realised through a climate change responsive social housing approach within SA.

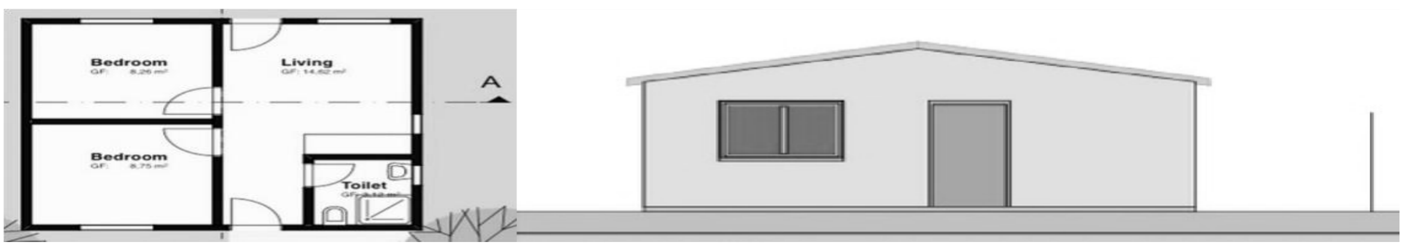


Figure 3: Plan and elevation of a typical 40m^2 RDP house

The NE51/9 housing model, produced and replicated for non-Europeans in the 1950s-1970s in SA, reinforced the spatial agenda of the apartheid regime, creating poorly situated and impoverished living environments (Low, 2005). Despite a more neo-liberal regime prevailing since 1994, the housing delivery in SA still promoted a "1-house-1-site" approach similar to that of the NE51/9 housing model illustrated in Figures 2 and 3. The result has been the fragmentation and compartmentalization of a reductive design and delivery process, which has resulted in large energy-intensive human settlements (Low, 2005: 1).

Source: Chipkin, 1998: 172

Source: EcoSun, [n.d.]: 3

The delivery of sustainable and affordable housing is a global concern, especially in developing countries such as SA, where the severity of the crisis is relative to the rapidly developing urban sector, in which over a million people are born in or migrate to cities in the global South weekly (UN-Habitat, 2015: 1). Furthermore, over one billion people, equivalent to 23.5% of the world's urban population, are housed in informal settlements (UN, 2019: 44). The UN (2019) predicts that, if no significant progress is made, an estimated 3 billion people will require adequate and affordable housing by 2030. The UN-Habitat (2015) further suggests that responses to housing should be holistic, interdisciplinary, and multi-level, and should be in response to local economic, environmental, social, and legislative aspects, including climate change. There is a need to unearth sustainable social housing solutions that not only counteract the rising carbon footprint of the building industry, but also do not increase the number of households that incur an unsustainable level of carbon emissions in terms of embodied and operational energy and the implied costs (UN-Habitat, 2015). Instead, solutions need to be established to address the crisis of inadequate housing, which also recognizes the global crisis of climate change. Social housing in SA can be a potential solution to these problems and is defined as "a rental or co-operative housing option for low- to medium income households at a level of scale and built form which requires institutionalized management, and which is provided by social housing institutions or other delivery agents in approved projects in designated restructuring zones with the benefit of public funding" (SA, 2008: 2). The objective of social housing is to also play a role in the national priority of restructuring South African cities and communities to address environmental, economic, social, and spatial dysfunctional ties. The Minister of Human Settlements, Mfeketo (2018: 3), in her 2018/2019 Budget Speech, reiterates the significance of creating integrated social housing to undo apartheid spatial planning in prime areas located close to economic opportunities, thus contributing to the SA government's vision of Sustainable Human Settlements (SHRA, 2020: 22). This is an integral part of a climate-responsive SA. The IPCC (2014) and UN Habitat (2015) share the stance that housing development has the greatest potential for climate change mitigation without significant additional initial costs in the future. Combrinck (2015) and Harvey (2012) argue that there is hardly any focus on the fact that cities can do well economically, while its people, apart from the privileged few, and the environment are persistently marginalized and degraded. Correspondingly, Low (2005) suggests that the simplification of design to a quantitative pursuit typical of the mass production of the previous RDP developments conflicted with the inherent requirements of sustainable development, and thus climate change response. The outcome of poorly designed, low-density, and isolated RDP settlements (Findley & Ogbu, 2011: 2) only further marginalizes the population it was meant to serve.

1.4 Net-zero carbon building for social housing in SA

According to the GBCSA, a net zero-carbon building is a highly energy efficient building, "and the remaining energy use is from renewable energy, preferably on-site but also off-site where necessary so that there are zero net carbon emissions on an annual basis" (GBCSA, 2018: 2). This definition is reciprocated by the World Green Building Council (WGBC) (Laski & Burrows, 2017: 8). The Paris Agreement of 2015 was hailed in the green building industry as a milestone in the plight against climate change (WGBC, 2018). It signified the setting of a timeline for how urgently the world needs to reform its carbon intensive path to enable all main business sectors to be operational with net-zero carbon emissions by 2050. Likewise, since the built environment is responsible for a major portion of global energy consumption and the associated carbon emissions, it can play a significant role in achieving the goals of the Paris Agreement. In the report, 'From thousands to billions: Coordinated action towards 100% net zero carbon buildings by 2050', the WGBC (2018) calls for an ambitious transformation towards a wholly zerocarbon global building stock through the objectives of their Advancing Net Zero Programmed (Laski & Burrows, 2017: 7):

- All new buildings must operate at net-zero carbon from 2030: Netzero carbon buildings must become a standard business practice as soon as possible, so we build right from the start, avoid the need for future major retrofits, and prevent the lock-in of carbon-emitting systems for decades to come.
- 100% of buildings must operate at net-zero carbon by 2050: Existing buildings require not only an acceleration of current renovation rates, but these renovations must be completed to a net-zero carbon standard so that all buildings are net-zero carbon in operation by 2050. In accomplishing these goals, the built environment may markedly assist in ensuring that the worst of climate change is avoided and simultaneously generate social

and economic co-benefits (Laski & Burrows, 2017). Consequently, highly energy-efficient buildings that satisfy their energy demands from renewable sources, whether on-site and/or off-site (*i.e.*, net-zero carbon buildings), are recognized as a more feasible goal for the scale needed to realize the Paris Agreement's target of GHGs emission reductions (WGBC, 2018). The two primary components of net-zero carbon buildings are energy efficiency and renewable energy. However, other zero-carbon strategies should also be considered when designing net-zero carbon buildings. For example, passive solar design can eradicate the need for carbon-intensive air conditioning and heating, while good day lighting can address artificial lighting energy demands (Hughes, Yordi & Besco, 2020). Implementation of energy-efficient buildings to propel the movement towards net-zero carbon (Gardner, 2020). The social housing sector is one where significant social and economic benefits, apart from the environmental and climate change mitigation implications, can be derived from incorporating net-zero carbon buildings. The concerted action of the private sector, government, and NGOs is essential to achieve the potential carbon emissions reduction possible in the social housing sector.

1.5 GBCSA's Net Zero/Net Positive Certification Scheme

The GBCSA is among the 24 green building councils contributing to the WGBC's Advancing Net Zero programmer, in the attempt to enable a 100% net-zero carbon global building stock by the year 2050 (WGBC, 2018). The GBCSA has subsequently established its Net Zero Certification Scheme in response to climate change and to achieving the goals set out in the Paris Agreement (GBCSA, 2019). The GBCSA certification takes it further, by recognizing buildings for net-zero (entirely neutralizing) and net-positive (positively restoring) environmental effects within four categories: carbon, water, waste, and ecology. Within the GBCSA's Net-Zero Carbon Certification Scheme, new buildings can achieve "Level 1 Net Zero certifications and Level 2 Net Zero/Net Positive certifications". Existing buildings can only attain "Level 2 Net Zero/Net Positive certifications". The certification is valid for 3 years. The Net Zero Carbon – Level 1: Building Emissions accreditation would require the non-tenant "Base Building Emissions (BEs)", when modelled over one year, to be equal to zero. This is meant to be the Regulated Emissions from the building's fixed services (GBCSA, 2019: 13). The "Net Zero/Net Positive Carbon – Level 2: Occupant Emissions" accreditation takes into account the measured or modelled operational energy emissions of the building and the tenant for one year and represents the Unregulated Emissions, which is the energy usage by the building and its occupants, including electrical loads ("Base Building Emissions + Occupant Emissions") (GBCSA, 2019: 13).

2. RESEARCH METHOD

This study followed the mixed-methods (qualitative and quantitative) research approach (Schoonenboom & Johnson, 2017) to describe, evaluate, and interpret the energy performance of social housing as a catalyst toward net-zero carbon building in the mitigation of climate change in South Africa. The research employed multiple case studies, complemented with secondary data analysis and simulation modelling. Case studies are the preferred research method when conveying an understanding of a multifaceted question; when the investigator has hardly any control over the subject matter, and when the focus is on a contemporary phenomenon within a real-life context (Yin, 1984: 13; Hofstee, 2006). The number of factors that are possible to consider is often substantial, relative to the number of case studies and opportunities available, which may produce limited sampling instants in the identification of statistical interaction. This study was delineated from the outset to examine carbon emissions contributing to climate change in the use phase of the cases only. Data were

Original Article

triangulated through secondary data, structured observation, and primary data from the simulation modelling IESVE software, which was also used in the analysis of the cases.

2.1 Case studies

The two case studies analyzed in this study are K206, Alexandra, Johannesburg, and Sandbag Houses, Cape Town. The case study selection was based on the following criteria:

- Time frame: Post-2004 (the year in which the BNG policy came into effect [DHS, 2010]).
- Geographic area: Urban areas of the Republic of SA.
- Type of case: Social (medium-density) housing project.
- Projects that have been recognized as sustainable initiatives, and at minimum exhibit climate change mitigation and adaptation strategies since there is currently no net-zero carbon social housing project. Both case studies are recognized as innovative projects with numerous publications discussing them.

K206 and Sandbag Housing unit plans (Figures 4 and 5) were used to develop the geometry in the IES VE simulation software.

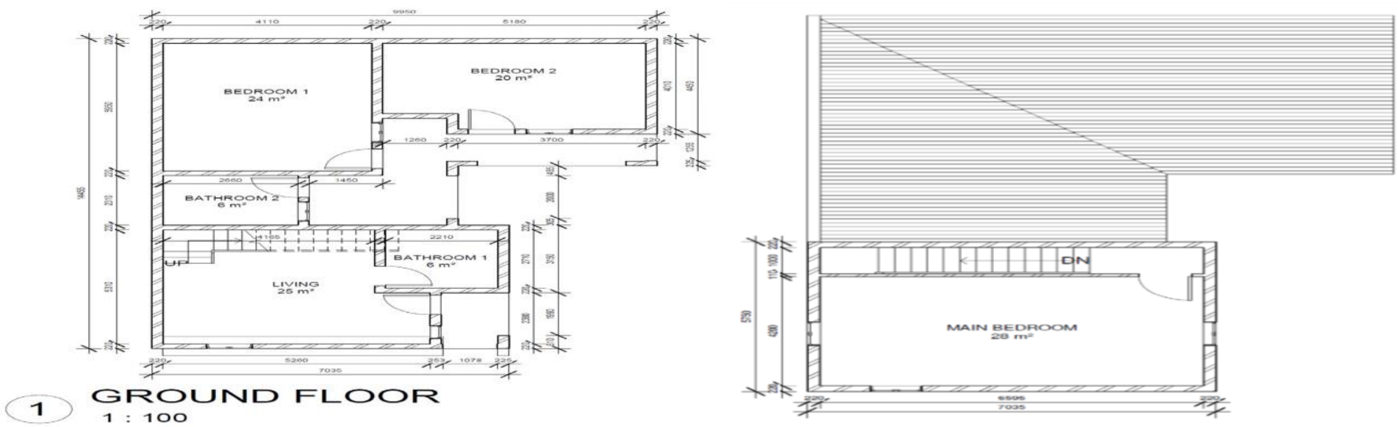


Figure 4: K206 Housing unit first-floor plans
Source: Adapted from Osman & Davey, 2011: 7

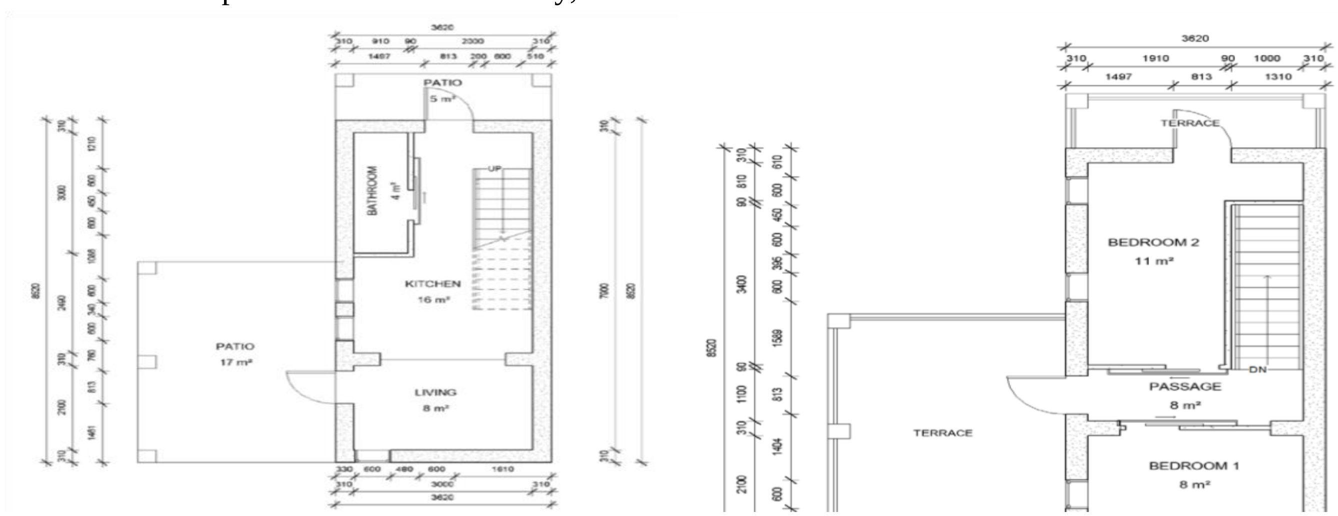


Figure 5: A 10X10 Sandbag House floor plans
Source: Adapted from Johnson, 2014: online

2.1.1 Simulation and statistical modelling

The study followed a simulation method "to capture the essence of a process by identifying key variables and then creating a representation of it" (Hosteen, 2006: 129). However, the prospect of over-simplification of reality presents a limitation, since the difficulty in capturing reality may get complicated on close observation. Therefore, the case studies were carefully limited to addressing issues of energy and carbon emissions. Residential buildings also tend to be problematic to model, due to broadly varying occupancy profiles and regularities, and the unpredictable precise use of the building (Skelhorn, Levermore & Lindley, 2016). The same predefined occupancy use profile was thus assigned to both case studies.

2.1.2 **Integrated Environmental Solutions Virtual Environment (IES VE) 2017 Software**

A building performance software, Integrated Environmental Solutions (IES) VE program was used to model the case studies and to analyses them in terms of energy use and interior comfort. IES VE has been extensively used to achieve net-zero carbon buildings, by enabling more effective design approaches in favor of others to achieve a net-zero building (Smith, 2016). The case studies were first modelled in the ModelIT application of IES, based on the data gathered through secondary data analysis and structured observations. ModelIT is the IES VE module that is used to create the geometry and orientation of the projects. The Weather file closest to the case study site was selected within the program (within a maximum of 50km from the site, as required by Greenstar). Thereafter, the Solar Shading Analysis application, Sun Cast, was run to include solar exposure and energy in the simulation. The relevant construction and thermal data, user profiles, and lighting were recorded in the Apache tool, after which a dynamic simulation of the model was run, and the results were viewed within the VistaPro tool in the software suite. The case studies' energy and carbon are then calculated, by processing a dynamic simulation in the "VE-Gaia Building Energy Navigator" (IES, 2018: 36). The simulation generates the estimated annual energy use, including a breakdown thereof, as well as peak heating, cooling, and humidification loads, including internal thermal gains (IES, 2018). This was used in the analysis of the case studies.

2.2 **Data**

The data consulted both secondary and primary sources and constituted a combination of textual and numeric data. Secondary data regarding climate change, carbon emissions, and energy was sourced from notable sources such as the UNEP, IPCC, StatsSA, WRI, Sabinet, as well as local, national, and provincial departments. GIS data, including site information, location, accessibility, and nearby amenities, were sourced from sites such as Google Earth, Maps and Street view, and AfriGIS, as well as previous studies on the social housing projects involved. The primary data regarding the case studies were gathered from the IES VE software and the structured observation of the case studies, to ensure further data triangulation.

2.3 **Technical data used to inform the modelling**

2.3.1 **The GBCSA Net-Zero Carbon Certification Scheme**

The GBCSA Net-Zero Carbon Certification Scheme was used as a guide to inform the modelling of the study. It entails the buildings to be modelled with the actual building's data and analyzed for energy use following specific parameters and with GBCSA-approved software. The IES VE program used in this study is among the approved software. The goal intended by the energy calculator is to decrease the quantity of GHGs produced through energy usage. Accordingly, the generated energy usage figures are converted to their respective CO_2 emissions

Original Article

for evaluation within the energy calculator. Table 1 presents the kgCO_2/kWh conversions used in the energy calculator. Renewable energy sources, not including biomass, are to be considered carbon emissions-free. The calculator produces an estimate of the GHG emissions in kgCO2/m²/year.

Table 1: CO_2 emission of energy sources

Energy sources	*kgCO2 /kWh*
Mains electricity	1.2
Diesel	0.267
LPG	0.227
Natural gas	0.202
Coal	0.354
Biogas	0.025
Town gas (coal)	0.160

Source: GBCSA, 2019: 3

The energy modelling protocol required only one instance of each dwelling type to be modelled, as outlined in the GSSA MURT (GBCSA, 2011a). The specific modelling parameters used for the simulation are as follows:

- Weather data: A Test Reference Year (TRY), where the building location is within 50km of a TRY location (GBCSA, 2011b: 8).
- Space types: The correct space types and areas (GBCSA, 2011b: 8).
- Geometry: The actual geometry of the building, including building form, shading, overshadowing, and orientation (GBCSA, 2011b: 9).
- Building fabric: The construction make-up of walls, ceilings, and floors, as well as insulation.
- Glazing properties: The windows and doors are modelled using the actual solar transmission, internal and external solar reflectance and emissivity, as well as the correct sizes and modulating types (GBCSA 2011b: 11)
- Air exchanges:
  - Infiltration: 0.5 L/s·m^2 (GBCSA, 2011b: 12).
  - Operable window: 2 L/s·m^2 (SA, 2011b: 22).
  - Non-operable window: 0.31 L/s·m^2 (SANS 204, 2011: 22).
  - Door: 5 L/s·m^2 (SANS 204, 2011: 22).
- Lighting: 4 W/m² or as the actual design.
- Equipment loads: 4 W/m² or as the actual design.
- Kitchen loads: 150 W/occupant sensible and 90W/occupant latent (GBCSA, 2011b : 13).
- Fresh air rate: Actual design rate.
- Occupancy: Dwelling occupants = no. of bedrooms + 1 or actual occupancy (GBCSA, 2011b: 13).
- Internal thermal gains and energy loads:

Table 2: Internal thermal gains and energy loads for the case studies

Room CODE	*Internal gain*	*Use profile*	*Count*	*Energy load (Watt)*	*Total (kW)*

Original Article

All	People	Social Housing	4	60	0 , 24
Bedroom 1	Cell phone charger	SH equipment	2	10	0 , 01
Bedroom 1	Radio alarm	Constant on	1	5	0,005
Bedroom 2	Radio/alarm	Constant on	1	5	0,005
Bedroom 3	Cell phone charger	SH equipment	1	10	0 , 01
Kitchen	Stove	SH cooking	1	3000	3
Kitchen	Kettle	SH cooking	1	1500	1 , 5
Kitchen	Fridge	Constant on	1	250	0 , 25
Kitchen	Microwave	SH cooking	1	700	0 , 7
Living area	Iron	SH equipment	1	500	0 , 5
Living area	Television 32	SH equipment	1	148	0,148
All	Lighting	Social housing	8	40	0 , 32

Source: IES VE, 2018

Since the case studies are passive buildings, the simulation modelling was further used to analyses whether the case study model complies with the GBCSA's Thermal Comfort (IEQ-9). The operative internal temperatures for bedroom and habitable areas must be within the ASHRAE Standard 55-2004 80% Acceptability Limits, in line with the Green Star SA Multi-Unit Residential v1 DTS and Energy Modelling Protocol Guide (GBCSA, 2011b). This translates to ASHRAE recommending an indoor air temperature range of 19°C-28 °C for thermal comfort purposes.

2.3.2 Construction data

Tables 3 and 4 provide the construction material and its thermal conductivity and resistance thereof of each building component of the case studies.

Table 3: Construction components of the K206 housing units

Component	*Construction materials*	*Thermal conductivity U-Value (W/m.K)*	*Thermal resistance R-Value (K.m^2/W)*
External wall	220mm fly-ash concrete brick wall	0.856 (BEE 2017)	0.2570
Ground floor Slab	85mm cast in-situ concrete floor slab	0.4 (Eng. ToolBox 2003)	0.2125
First floor slab	170mm cast in-situ concrete floor slab	0.4 (Eng. Toolbox 2003)	0.4250
Roof	0.47mm corrugated steel roof sheeting	20 (Eng. Toolbox 2003)	0.0001
Ceiling	None	-	-

Original Article

Interior wall	220mm fly-ash concrete brick wall	0.856 (BEE 2017)	0.2570
Door	Steel framed 40mm timber door	0.13 (Eng. ToolBox 2003)	0.3077
Windows	Steel framed 6mm single pane window	0.96 (Eng. ToolBox 2003)	0.1559 (U-value: 7.9)

Source: Osman & Davey, 2011: 1-4

Table 4: Construction components of the Sandbag housing units

Component	*Construction materials*	*Thermal conductivity U-Value (W/m.K)*	*Thermal resistance R-Value (K.m^2/W)*
External wall	270mm sandbag wall; plastered	0.135 (ecoBuild 2009)	2
Groundfloor slab	100mm sandbag and screed floor	0.135 (ecoBuild 2009)	0.74
First floor slab	170mm cast in-situ concrete floor slab	0.4 (Eng. ToolBox 2003)	0.4250
Roof	0.47mm corrugated steel roof sheeting	20 (Eng. ToolBox 2003)	0.0001
Ceiling	12.5mm gypsum ceiling and 100mm insulation	0.03 (Isotherm 2019)	3.6
Interior wall	90mm dry-walling	0.17 (Eng. ToolBox 2003)	0.59
Door	Steel framed 40mm timber door	0.13 (Eng. ToolBox 2003)	0.31
Windows	Steel framed 6mm single pane window	0.96 (Eng. ToolBox 2003)	0.16 / U-value :7.9

Source: Mpahlwa, 2011:1

2.3.3 Model assumptions and inputs

The TRY weather file used in the K206 Housing Simulation is the JohannesburgIWEC.fwt. The weather file is based at the Johannesburg International Airport and is within 50km of the site (GBCSA, 2011b). It is located 13.25km away (Google Earth, 2015a). The TRY weather file used in the Sandbag Houses Simulation is the CapeTownDOE2.epw. The weather file is based at the Cape Town International Airport and is within 50km of the site (GBCSA, 2011b: guideline). It is located 10.4km away (Google Earth, 2015b).

The thermal template used in the IES VE, designated 'Social Housing', has the parameters set as shown below:

- Orientation: Actual observed on site.

- Use profile: SH Residential: 4 People occupancy (the higher of the two: the design occupancy of Sandbag Houses and occupancy in line with the GBCSA (2011b: 13) energy modelling protocol, which estimates occupant numbers as follows: Dwelling occupants = no. of bedrooms + 1). See Figure 8.

The cooling and heating set points are calculated as per the ASHRAE-55 (2004) Adaptive Comfort 80% Acceptability Limits:

- Cooling set point:
  - K206: 26.279°C.
  - Sandbag: 26.345°C.
- Cooling system: Natural ventilation.
- Heating set point:
  - K206: 19.279°C.
  - Sandbag: 19.345°C.
- Heating equipment: 800W electric resistance heater.

2.4 Analysis

Inductive analysis of the case studies was undertaken based on first examining the context of each project, then conducting an architectural design analysis focusing on the project's materiality and design in terms of environmental sustainability, energy efficiency and carbon footprint, utilizing primary observational data as well as secondary data. Lastly, an analysis of the building operation-related carbon emissions of both case studies and its simulated energy loads and carbon emissions, to determine the potential of the net-zero carbon building in the social housing context as a climate change mitigation response. The project's compliance with the Green Star IEQ-9: Thermal Comfort requirement was also determined with the IES VE software and analyzed.

2.5 Limitations

While the results may be useful in other developing country contexts, the researcher limited the study geographically to urban SA, and projects incepted since 2004.

3. FINDINGS AND DISCUSSION

3.1 Evaluation and comparison of the case studies

The two social housing projects, the K206 and Sandbag Houses, are explored to determine their energy performance in facilitating social housing to contribute to the overall SA climate change mitigation initiative. This is done by attempting to evaluate the cases by modelling the energy and carbon emission loads of the projects to understand how a net-zero carbon social housing landscape can be achieved in SA. Table 5 represents the observational data collected on the researcher's site visits to each of the case study projects. Tables 6 and 7 represent the simulated energy loads of the case studies. The K206 housing unit's total electricity per annum is calculated to be 8.9642 MWh per 84 m^2 unit, 106.71 kWh/m^2/annum and 128.06 $kgCO_2/m^2$/ annum; the Sandbag houses' total electricity per annum is calculated to be 2.9692 MWh per 54 m^2 unit, is 54.98 kWh/m^2/annum and 57.3 $kgCO_2/m^2$/ annum. The K206 housing unit's energy (Case study 1) consumption, as shown in Table 6, reveals that the space heating load is substantial and higher than any other electrical use type (3.7681MWh/annum – 42% of the total energy use). However, the housing unit does not satisfy the *Thermal Comfort IEQ-9 ASHRAE 55-2004 80% Acceptability Limits* for 85% of the year. The lighting (K206 – 17.5%; Sandbag – 39%) and cooking electric resistance loads (K206 – 13%; Sandbag – 38%) in both projects are also high and could be minimized by better day-lighting strategies and alternative renewable energy sources. While the Sandbag housing unit (Case study 2) almost satisfies the IEQ-9 Thermal Comfort requirement (only the living room falls short and is within the comfort temperature range 75.8% of the time), this could be easily achieved through passive heating measures such as a shaded north-facing window. The use of an innovative and alternate building material with a high R-value (2 $K.m^2/W$), together with adequate roof insulation, has enabled the Sandbag Houses to have a more comfortable thermal interior. The observational study revealed that natural lighting is inadequate in both projects, as electrical lighting is often used even during the daytime.

Table 5: Building data collected or verified through the observational study

Building component	*K206 housing project*	*Sandbag houses*
Building exterior finish	Fly-ash face brick walls; plastered and painted in some instances.	Plastered and painted; portions of ship-lapped timber cladding that are painted.
Roofing and overhang	Steel channel rafters and corrugated roof sheeting; approximately 200mm overhang. No gutters or downpipes.	Eco beam rafters and corrugated roof sheeting; approximately 600mm and 300 mm overhangs. Gutters and downpipes are present.
Window treatment	Steel window frames; operable: side-hung.	Steel window frames; operable: top-hung.
Natural ventilation	No cross ventilation or other ventilation initiatives are present in units. Windows are located along the same or adjacent walls, except for the first-floor room (Osman & Davey, 2011). All habitable rooms have sufficient operable window area, i.e. minimum 5% of floor area as per SANS 10400-O (SA, 2011b).	Cross ventilation is present in units. Windows are located along adjacent and opposite walls. All habitable rooms have sufficient operable window area, i.e. minimum 5% of floor area as per SANS 10400-O (SA, 2011b).
HVAC	None.	None.
Solar water heaters	Solar water heaters are present.	Solar water heaters are present.
Renewable energy	None.	None.
Space heating	Electric plug-in heaters (assumed).	Electric plug-in heaters (assumed).
Lighting	One light and electrical outlet per habitable room. High mast security street lighting for residential purposes as per the minimum level of service for new housing projects within the Department of Human Settlements (PMG, 2013).	One light and electrical outlet per habitable room. High mast security street lighting for residential purposes as per the minimum level of service for new housing projects within the Department of Human Settlements (PMG, 2013).

Original Article

Natural lighting	Low natural day lighting; electrical lighting is used during the daytime.	Low natural day lighting; electrical lighting is used during the daytime.
Cooking appliances	Electric stove, plug-in microwave, and kettle.	Electric stove, plug-in microwave, and kettle.
Energy-efficient appliances	Fridge (assumed).	Fridge (assumed).
Noise level	High noise levels due to the adjacent main road (London Rd).	Low noise level.
Interior wall finish	None; some units have been plastered and painted or painted internally by the owner (Osman & Davey, 2011).	Plasterboard and painted (Mpahlwa, 2011).
Building component	*K206 housing project*	*Sandbag houses*
Floor finish	Screed floor (Osman & Davey, 2011).	Screed floor; some units have been finished by the owner/ tenant (Mpahlwa, 2011).
Ceiling and insulation	None.	100mm isotherm insulation and gypsum board ceiling (Mpahlwa, 2011).
Private outdoor space	Semi-private communal courtyard space is provided; some units have added yard walls or fences, creating private outdoor space (Google Earth, 2015a, Osman & Davey, 2011).	Private back garden space is provided; some units have added yard walls or fences in front, creating additional private outdoor space (Google Earth, 2015b).
Renovations/ Additions	Backyard shacks were added in some instances.	Additional rooms have been added to the back garden on 6 of the 10 houses. None of the balconies has been converted into an additional bedroom, as was the intention of the design (Mpahlwa, 2012).

Source: Authors

The total energy consumption of the K206 housing unit is simulated to be 8.9642 MWh/year, of which 3.7681 MWh/year is owed to space heating, whereas the Sandbag houses' energy consumption amounted to 2.9692 MWh/year, almost a quarter of the K206 housing unit's consumption. The case studies have similar mean annual temperatures (IES, 2108), thus the heating and cooling requirements are comparable.

Original Article

The K206 housing projects also do not comply with the later Energy Usage in Buildings regulations, the SANS 10400-XA (SA, 2011b), and would require insulated roofs and hot-water pipes to comply, whereas the later Sandbag houses do comply. The positive communal nature of the medium-density K206 housing units employing shared walls and courtyard space (Osman & Davey, 2011) addresses the negative impacts of urban sprawl and lowers the total mass of materials used and thus the carbon footprint of the project. The later incorporation of solar water heaters contributes to the energy efficiency of the project, a pathway to net-zero carbon building. However, the inefficient design, the lack of any insulation, cross-ventilation, adequate day lighting, and renewable energy initiatives are attributed to the high-energy intensity of the project. The incorporation of the Eco Build Sandbag system in the construction of the Sandbag houses provided superior thermal stability and thus a more energy-efficient and lower carbon footprint project. The support of unskilled labor and the use of sandbags in building taps into indigenous construction techniques well-suited for the South African context and sandy areas such as the project's site (Thompson-Smeddle, 2009). The integration of community involvement and education in the construction phase, and the decision to build up and increase the density of the houses improved its overall pathway to a net-zero carbon building. A net-zero carbon building could be achieved in the case of the Sandbag house if the building is improved through more energy-efficient appliances and lighting, adequate daylighting and solar gain, and a low-cost renewable energy system (Gibberd, 2017). Winter solar gain through shaded glazed openings on the north can reduce the projects' heating and lighting load and improve daylighting. A solar PV cell with a backup battery or fed into the electrical grid could bring the Sandbag housing project to net-zero carbon, thereby contributing to the overall SA climate change mitigation initiative. The purpose of net-zero carbon building is to decrease the amount of GHGs emitted through energy usage and address the fast-growing, inefficient, and carbon-intensive buildings, particularly within developing country contexts such as SA. Furthermore, the 2050 WGBC's international Advancing Net Zero project endeavors to ensure that all buildings are to be net-zero carbon by the year 2050, and to support the development of net-zero pilot projects within SA (GBCSA, 2019). However, to warrant that all buildings are net-zero carbon by 2050, the net-zero carbon initiative developed to achieve this goal needs to include all building types, including low-cost and social housing. Social housing projects in SA have a considerable energy load, as shown in the K206 project. Considering the energy poverty present in the recipients of social housing and the high energy footprints of poorly designed housing, a specific focus on developing efficient and bio-climatically appropriate design responses must be undertaken.

4. CONCLUSIONS AND RECOMMENDATIONS

Although there is an increasing demand and a large housing backlog in SA, social housing projects in SA do not address the substantial climate change mitigation potential that they could achieve. On the other hand, social housing projects undertaken by formal funding or governmental development initiatives can achieve mitigation objectives with immediate effect and are not dependent on factors such as social acceptance, environmental consciousness, and individuals buying into the concept. It has significant potential to perform as a climate change mitigation strategy, and help SA achieve its NDCs, while lowering energy poverty in SA. Unfortunately, the sectors that are most vulnerable to climate change are often the ones that have contributed the least to climate change. They often also have hardly anything to do with the decision-making and planning processes of the homes in which they reside. As a result, they have hardly any control of the carbon emissions they consequently emit. The carbon intensity of social housing projects is mostly in the hands of the decision-makers in the housing sector and can either set the precedent for a low carbon SA or further embed vulnerability to climate change for the poor. Thus, the interrelationship between social housing policy and the implementation of net-zero carbon building has an important role to play in optimizing the potential that social housing can have in mitigating climate change in SA. Based on the case studies and social housing research in SA, the current net-zero carbon building action in SA does not address the low-cost nature of social housing projects. The economic and technological limitations of social housing projects in SA may be a contributing factor. The lack of action in this sector, apart from the climate change mitigation and social justice implications associated with the implementation of a net-zero carbon social housing sector, also misses the opportunity for the government to lead by example. As a result, it does not acknowledge the significant potential this sector has in performing as a climate change mitigation strategy and contributing to local and international climate change mitigation goals. Government and other role players could consider the following recommendations:

- Low or zero-carbon housing development in SA needs affordable, adequate, and sustainable social housing solutions to respond to the local housing backlog and climate change crisis.
- A net-zero carbon social housing in SA could be achieved through the incorporation of sustainable building materials with high thermal resistance and thermal mass, adequate glazing and orientation, energy-efficient equipment, renewable energy systems, and passive solar design, among other energy-efficiency strategies.
- An appropriate combination of research into social housing government regulation, energy-efficient technologies, renewable energy, and human behavior could significantly contribute to the development of net-zero carbon social housing in SA and consequently reduce GHG emissions from the building industry.
- Net-zero carbon building action in SA could benefit from recognizing the importance and potential of the inclusion of social housing in climate change mitigation strategies and addressing the method and extensiveness in which energy use and thus carbon emissions are calculated accordingly.
- Other means or indicators to assess the carbon intensity and sustainability of low-cost projects could also be beneficial, along with the development of guidelines and government policies on building regulations on the achievement of net-zero carbon social housing in SA.