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RESEARCH ARTICLE:

Digging up the Past: Re-Visiting the Potential Role Green Roofs can Play in Mitigating the Urban Heat Island (UHI) Effect: A Case Study of the Central Business District (CBD), Durban, South Africa

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Abstract

Across the world, cities and densely populated areas are striving to both uplift the quality of the environment as well as enhance their sustainability. Part of this endeavour entails the promotion of urban greening. In Durban, on the east coast of South Africa, rooftop greening practices are gaining some traction with a view to achieving the sustainable development of a greener environment for the city and surrounding areas, although on a smaller scale than many other cities. There has been little empirical research done on green roofs within a local context, especially concerning green roofs as green infrastructure in urban planning tools for creating sustainable resilient city spaces by helping them mitigate against climate change. The quantitative analysis of this research measured temperatures and the urban heat island effect (UHI) of green roofs, as well as control sites over a seven-year period. The total average temperature differences over a seven-year period during the summer months (January/February) witnessed one green roof measuring 9.2 degrees Celsius lower than the control roof. The rationale for this research was to offer support for the benefits of green roofs in mitigating against an increase in inner-city heat islands in the case of Durban's Central Business District (CBD).

Keywords: *urban greening; green roofs; green infrastructure; urban heat island (UHI); climate change mitigation*

Introduction

Despite several climate change adaption plans acknowledging heat as a significant threat to South Africa, it has done little to produce a response or potential solutions for city preparedness or sustainable response plans. In addition, recent headlines found in national mainstream newspapers such as the Mail and Guardian (Phillips, 2021) state that 'Higher temperatures will put a strain on infrastructure such as roads, pavements and railways and ultimately have negative effects on human health and comfort,' and le Roux (2021) claims that 'The potential for SA cities to suffer the urban heat island effect is an increasingly deadly threat and with an estimated 30,000 deaths in South Africa being directly attributable to increased temperatures from 1997 to 2013, warrants further understanding of potential solutions'. These statements are concerning and with Durban's recent signing of the urban nature declaration to expand, reduce urban heat risk, and increase urban green spaces and urban canopy cover as part of its climate change planning, (C40 Annual Report, 2021:6) requires a revisitation of an old Green Roof Pilot Project (GRPP) started in 2010.

This project was a locally based climate change mitigation project that was administered from 2010 to 2017. Its relevance is such that currently built environment practitioners need to ask how their work can be used to solve a specific problem and, in this case, how the designing of a green roof in a local context can be used to mitigate the effects of climate change, namely the UHI. In so doing, it requires both engaging with past research as well as future research into the benefits of installing green roofs in urban areas to minimise the risk of trying to reinvent the wheel. In this context, the GRPP research is the only study to date that has provided significant data over an extended time frame, and it has not been published yet. This older data and research provide important and interesting information about how green roofs have and still can play a significant role in mitigating the UHI. Adams

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(1972) pointed out that many years can pass before the results of the research can have a meaningful impact on development in dealing with real-world problems. Historical records that inform risk assessments are often not consulted and this could result in some difficulty in managing urban heat extremities. This historical data was collected and analysed from 2010 to 2017 in a local case study, which researched an urban-based solution to the increasing UHI that as a result of climate change has become more relevant than ever before. It researched the role that green roofs can play as both a type of urban resilience through green infrastructure and as a climate change mitigation and adaptation tool. The rationale is two-fold for utilising a past pilot project. Firstly, as mentioned above, in 2021 Durban signed the C40 Annual report and secondly, there is no other local study that has managed to record seven years of data, which provided a significant scope of the benefits of green roofs in reducing the UHI effect in a local context.

Throughout history humans have constructed landscapes, gardens, parks and even buildings aiming to enrich their bond to the earth. With environmental challenges becoming more apparent every day, sustainable urban innovative retrofits are being called for as cities try to incorporate both beneficial and pioneering tools that will form part of the physical, social and ecological functionalities of integrating nature into urban management systems and municipal frameworks as interventions to mitigate against an ever-changing climate. During the coming decades, Durban, like other cities around the world. will be challenged to conserve natural biodiversity, provide sufficient food, shelter, basic goods, services and jobs for all its urban residents. This challenge is compounded by the necessity to fulfil these needs whilst simultaneously building more sustainable resilient cities that mitigate, rather than add to, global warming and climate change. There is growing consensus that how we engage with nature will determine our future urban identities and the drive to change these urban forms into functioning ecological spaces is a prerequisite. With strategic and creative planning solutions from corporations, municipalities, national governments and citizens, the urban ecological development question could offer a vision of a healthier and more sustainable urban space, for people and the environment.

The increasing built environment forcibly removes permeable ground spaces and replaces them with hardened impervious spaces. Unfortunately, evidence linking the role that local green roofs have played in mitigating the urban heat island effect is lacking as a long-term climate mitigation and adaption green infrastructural construction. These lack of studies of the benefits of green roofs to alleviate urban temperatures are exacerbated by the lack of statistics and green roofs under observation in local climate mitigation studies. With an increasing interest in resilient infrastructure green roofs can offer urban developers and municipalities an approach for mitigating and alleviating increased heat found in cities. One way of enacting this transformation is using empty rooftops. Large, flat and empty rooftops are abundant throughout Durban on institutional, private, residential, industrial, municipal and commercial buildings. These underutilized spaces are ideal locations to create rooftop greening initiatives such as green roofs. Buildings with suitable roof structures could be developed into a network of green spaces, which can provide a mixture of city greening and well as providing opportunities to mitigate and adapt to climate change. Rooftop greening is currently happening in South Africa and more specifically in KwaZulu-Natal on such a small scale, as to be almost non-existent in comparison to other countries around the world, such as Germany, Japan United States of America, Switzerland, and a host of others (Theodosiou, 2009: 284).

According to IUCN (2022) cities such as Wuhan have adopted more eco-friendly approaches when developing city infrastructure as part of their adaptation measures. In so doing it has minimised the need for paying for expensive grey infrastructure, whilst simultaneously benefitting urban biodiversity and the health and wellbeing of urban communities. As a result of South African cities falling behind in this form of urban development, it has proved challenging to provide an analysis of rooftop greening and its ability to help mitigate against the increase in urban heat within a local context. The difficulty in this regard is offering a critique in response to where and what significance rooftop greening has as a form of urban greening and green infrastructure for urban development. The contribution of this article is two-fold, firstly to re-ignite the role that green infrastructure in the form of green roofs can play in mitigating and adapting against climate change challenges and rapid urbanisation in a South African context where this is significantly lacking. As mentioned previously, green roofs can lower the temperature of buildings and therefore reduce the use of air conditioners which utilise electricity. Green roofs are an example of how a single intervention can provide mutual benefits in terms of biodiversity enhancement and climate regulation. Secondly, it re-visits the only green roof and UHI data collected over a seven-year period that has yet to be published and in turn, contributes to how South African urban planners and built environment professionals, from both the municipal and private sectors, could start implementing them into policy and design approaches. In so doing, they could offer better utilisation of existing inner city rooftop spaces and contribute towards how these areas could become resourceful spaces that help mitigate increasing UHI effects.

Literature Review

Urbanisation is typified by both the destruction and development of habitats and associated infrastructure facilities. Yet these are required for economic and social activities necessary for creating sustainable, healthy livelihoods that cater for a growing urban population. One development of primary importance in an increasingly urbanised world is that of increased urban temperatures, known as the urban heat island effect (Cui *et al*., 2016). The UHI effect is a product of how we build and design cities where hard concrete, brick, stone, and blacktop surfaces are the primary materials used, which absorb and retain heat (Nowak, 2004: 11). Cities trap and store the sun's heat in paved surfaces, roof tiles, protective water membranes on flat roofs, asphalt, concrete and tar surfaces, which subsequently release it back into the surrounding environment. There are several factors at play regarding the intensity of an UHI in a city. These range from its geographical location, size, energy consumption, day or night, presence or absence of green space, seasons, and synoptic weather conditions. This is because as urban temperatures increase, so too does electricity usage to cool buildings. According to Phillips (2021) researchers at the Centre for Scientific and Industrial Research (CSIR) agree that an increase in urban temperatures directly relates to an increase in energy demand to cool them. In doing so it increases greenhouse gas emissions, as well as placing additional pressure on aging infrastructure and the subsequent negative effects on human health and well-being. Some of the projections show that temperatures are expected to rise above 1.5 degrees by 2050 (6th IPCC Report, March 2022). This ultimately calls for a new approach to urban sustainability ensuring that urban areas undergoing developmental change will need to have an innovative approach to create opportunities that will foster lifestyles that are in harmony with the environment. One which incorporates urban greening techniques (Register, 2006).

The concept of green infrastructure has its roots in the 19th Century parks movement, with significant elements being traced to the work of Frederick Law Olmsted, Lewis Mumford and Patrick Geddes in urban planning, ecological planning, and the landscape architecture profession (Eisenman, 2016). Olmstead is famous for designing many well-known urban parks, such as Central Park and Prospect Park in New York City. Olmstead designed, using his own term, to 'civilize' the city, by building parks that simulated nature (Sutton, 2015:11). Working in the late 1800s Olmsted was seen as somewhat of a 'visionary'. He predicted the rate of urbanization and how it would affect the role that nature, and in addition, what the future constructed reality of green infrastructure would entail. Currently, green infrastructure has begun to emerge as a subject of significant interest in city and regional planning and has witnessed other contemporary built environment thinkers such as Pickett *et al*. (2004), Kellert (2005), Benedict and McMahon, (2006), Tzoulas *et al*. (2007), Wise (2013) and Beatley (2011), advocating for green infrastructure in 21st Century cities, highlighting the role of nature in urban infrastructural design whether humanly constructed or natural (Wilson, 1989:9). There are several definitions available for green infrastructure; however, a commonality in all is that of a natural life-support system for cities. One that promotes strategically planned networks of green spaces and water systems that both conserve natural ecosystem values and functions as well as delivering multiple environmental, economic and social values and benefits to urban settlement inhabitants and wildlife (Artmann *et al.,* 2017). Green infrastructure offers improvements, such as a reduction in the UHI effect (which is a result of replacing the natural landscape with hard, non-porous surfaces found in most cities). Green infrastructure, in the form of vegetation, cools the environment actively by evaporation and transpiration (evapotranspiration) and passively by shading surfaces that otherwise would have absorbed short-wave radiation. During the night the high sky view factor of open fields allows heat to escape fast through long-wave radiation (Givoni, 1998: 244).

Green infrastructure should therefore be thought of as a contemporary area of urban planning research and implementation. Some of the major types of green infrastructure identified in the literature are, rain gardens or bio-retention basins; porous or pervious pavements and green parking areas, vegetated or bio-swales, storm water planters, green roofs and rooftop gardens. By taking simple, practical interventions and looking at cities ecosystems one can investigate the many functions of green roofs as contributing factors to creating urban resilience. Green roofs are an example of green infrastructure and therefore contribute to the resilience and sustainability of urban spaces which can be used as mitigative installations against UHI. According to Roberts and O'Donoghue cited in du Toit *et al*. (2018) in Durban, South Africa, the municipality specifically identified the urban heat island, stormwater runoff, water conservation and sea level rise as some of the challenges facing them due to climate change. In Durban it was difficult to implement climate adaptation plans and interventions such as green infrastructure as there was a lack of data on the local impacts of climate change so there was a need to provide data to help support possible approaches to help alleviate the pressures of climate change in an urban context. Cilliers (2019: 4) states that for green roofs to become more of an urban reality adequate policies and legislative frameworks would be required in the respective province of jurisdiction. However, green infrastructure is still very limited in planning practices in South Africa. Therefore, the GRPP projects data from 2010-2017 would prove valuable in supporting future policies and green infrastructure frameworks.

Since cities hold a major percentage of the earth's population, they need to be reshaped to form part of a sustainable solution to environmental degradation, resource exhaustion and human-induced climate change. The role of urban greening in contemporary urban environments is becoming increasingly more relevant and is currently being written into broad policy plans by several international cities. Urban greening is a planned effort made by city inhabitants and municipalities to improve the quality of life for visitors, commuters, residents and workers through enhancing spaces within the city environment. This is not a new philosophy, authors such as Nicholson- Lord (2003) and Kahn (2006), as well as others who offer insights into urban growth, the environment and the greening of cities. These plans aim to identify needs, opportunities, and strategies for both enhancing existing, as well as creating greener opportunities, for more environmentally sustainable and liveable urban environments. Owing to these concerns, the question to ask is whether we are nearer to embracing more appropriate ecologically friendly sustainable growth advantages within South African cities? With strategic and creative planning solutions from both municipal governments, corporate stakeholders and citizens, the urban environmental question offers a vision of a healthier and more sustainable urban space. To do this city spaces need to be re-conceptualized and restructured. We need to examine how existing empty spaces can become spaces that could help alleviate the UHI effect. One way of redesigning the city is through sustainable city programmes which incorporate urban greening techniques, and its increased relevance to future urban form as a three-dimensional construct of green roofs.

In the current research on urban greening in South Africa, there are several gaps regarding green roofs. From two independent studies done by Cilliers (2019), it was found that among planning professionals in South Africa, there was a lack of know-how and knowledge relating to green infrastructure and in turn limited implementations, as well as the uneven distribution of green infrastructure projects in practice. This can be expected as, until 2023 there is no existing published quantitative data of the benefits of local green roofs in curbing the heat island effect, as well as other technicalities and installation processes. This article will provide data on how green roofs in a sub-tropical climate for UHI adaption from a South African context – where the understanding, knowledge and benefits that green roofs can play are not documented. According to Labuschagne and Zulch (2016), there is a lack of knowledge amongst the professional team members in the construction industry regarding the types of green roof construction. Sadly, professional members of the construction industry as well as built environment professionals and the public have little to no understanding of the overall advantages that local green roofs can play as climate change adaption tools. Urban greening and the practice of green roofs as a specialised form of urban greening offers many substantial advantages (Kohler *et al.,* 2002 and Mentens *et al*., 2005). The greening of cities can provide space, not only for ecological functioning, but also provide opportunities for green infrastructure. Both offer benefits for humans in various ways such as curbing the UHI and may help to provide food and other resources for urban populations (a function normally displaced to agricultural regions).

Green roofs offer opportunities to revisit longstanding themes on urban greening within the built environment. Previous literature and research has demonstrated the advantages of green roofs in several cities but none yet in South Africa. Installation of green roofs in South African cities is in its infancy when compared to other cities in the world like Stuttgart, Toronto, Singapore, Linz, Chicago, Montréal, Tokyo and several others (McDonough, 2005). There is also significant international research into green roof technologies and green roof construction, design, maintenance and planting regimes. Much of this is, however, applicable to northern contexts. Dunnet and Kingsbury (2004), and McDonough (2005) offer direction into western green roof construction, design, maintenance, and planting but there is no mention of green roofs in the sub-tropics such as those with conditions found in Durban, KwaZulu Natal. One of the rationales for promoting green roofs is in support of the view that they help reduce the UHI effect and direct heat to the building's rooftop. This in turn will result in decreased energy usage and greenhouse gas emissions (promoting green infrastructure and urban sustainability). Planning responses require urban adaptations that are equally supportive where energy efficiency and climate change are related. For example, improved building shading decreases the need for air-conditioning while also reducing the

UHI effect in cities (KZNCOGTA, 2020: 11). In so doing, green roofs offer pragmatic examples of urban sustainability through an urban greening and how the changing role of technology and science has directed the growth of modern-day green roofs through the evolution of numerous materials and techniques in the application of green roofing. Science, even mainstream applied science, is certainly part of the problem, but it can also offer solutions towards developing innovative sustainable cities through installations such as green roofs for green infrastructure. Various statistical tests were performed to analyse whether values are different between the various green case study sites. The Green Roof Pilot Project (GRPP) investigated the temperature variations between green roofs and a control site.

Case Study

The GRPP is in eThekwini Municipality CBD within KwaZulu-Natal, on South Africa's east coast (see Figure 1 below). It boasts a rich ecological heritage and is in the middle of the Maputaland-Pondoland-Albany Region, an area recognised by Conservation International as a biodiversity hotspot. The GRPP case studies are located at the eThekwini Municipality City Engineers Building – K. E. Masinga Avenue, Durban, Kwazulu-Natal (see Figure 1, 2 and 3 below). It was installed in February 2009. This site has eight green roofs totalling +/- 400m2 with one control (Blank roof +/- 50m2). It provided critical empirical evidence with selected statistical data of the ability of green roofs to decrease the UHI effect in Durban's CBD located in the eThekwini Municipality, KwaZulu-Natal.

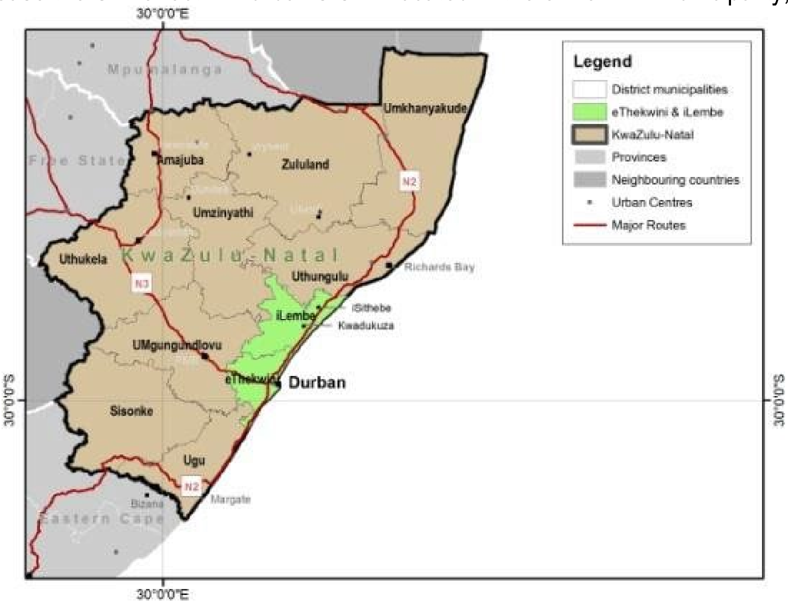

Figure 1: Location map of Durban, KwaZulu-Natal South Africa

Figure 2: Aerial location of GRPP within the CBD of Durban - 290 01'04.29"S / 31001'25.95"E
Source: Google earth 2021

The roof consists of two flat slabs on either side of a raised arched roof (see Figure 3 below). The portions of the roof have easy access, and the roof was assessed by a structural engineer and found to be suitable for the installations of a green roof in terms of its loading capacity. The loading capacity was set at 100 to 150kg square metres. The area occupied by the green roof project is +/- 405 square metres.

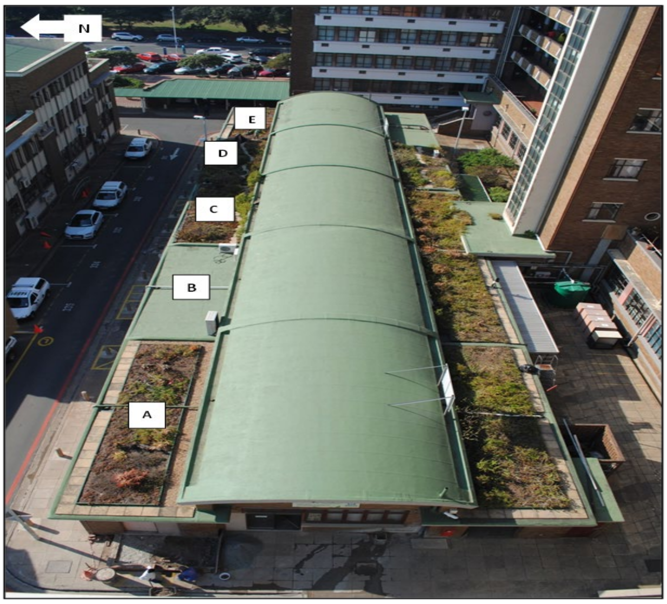

Figure 3: Case study areas GRPP.
Source: Author 2017

The GRPP used various instruments, probes that were calibrated to log data at hourly intervals with the intended goal of measuring temperature variances of the UHI from April 2010 to February 2017. The data was then captured by computer programs namely EXCEL and SPSS to verify variables and their consistency, and to present the data into summary graphs and charts.

Methodology

The ability of rooftop greening to mitigate against the UHI effect by consistently reducing the temperature of the surface of buildings was measured, effecting the transfer of heat through the thermal mass of the existing building. This theoretically should lead to a decrease in the need for air conditioners and hence energy expenditure. The research used an applied research design, which investigates practical problems to find solutions that can be applied in practice. In so doing, a quantitative primary data approach was used to evaluate whether green roofs located in Durban CBD could be a useful climate change mitigation tool against the increasing UHI effect.

This was measured using data loggers with six sensors attached (All - Part numbers MCS 154). M.C. Systems data logger and sensors. The temperature probes were placed in various areas on the GRPP (see Table 1 below and Figure 3 above). The data loggers were programmed to record the data on temperature at one hourly intervals throughout the day on the GRPP. Statistical packages were important to this research, as it was important to find out whether there were statically significant differences between a blank flat roof and a roof with plants with respect to various indicators. In some instances, data was being logged every hour for seven years, making the understanding of the large amounts of data difficult without statistical techniques and software packages.

Table 1: Location and rationale of temperature probes in case study site

No. of Probes	Placement Location	Rationale
1	Under section B - the roof membrane of the control site (blank roof)	Measure the temperature of the membrane. To determine how hot flat roofs get during the day.

1	Under section C	Measure the temperature of the roof under a 50mm average depth green roof application
1	On top of section C	Measure the temperature of the roof on top of the growing medium
1	Under section D	Measure the temperature of the roof under a 90mm average depth green roof application
1	Between section D and E	Stevenson Screen - record ambient air temperature above the green roof
1	Under section E	Measure the temperature of the roof under a 30mm average depth green roof application

Statistics were used to discover patterns leading to summaries of sections of data, which would in turn allow for the isolation of key events concerning temperature variations. The statistical conclusions showing significant differences were shown between a blank flat roof as opposed to a roof that had plants on top. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure. A Bonferroni correction for multiple comparisons was made with statistical significance accepted at the $p < .0083$ level.

This *post hoc* analysis revealed statistically significant differences between all group comparisons. As a result of the data not being normally distributed (Kolmogorov-Smirnov test, $P < 0.05$) and due to the presence of outliers (it was decided that although outliers and extremes were used in the analysis, they have not been represented in the box plots to avoid cluttering and to facilitate the interpretation of trends). The average temperatures of various test sites were compared using the Kruskal-Wallis H test (also known as the one-way ANOVA on ranks) (Vargha and Delaney, 1998). It showed that there was a significant difference between the median temperatures of the different treatment groups (Kruskal-Wallis: $H5,213568 = 4639.269$; $P < 0.005$) and in so doing confirming that the various green roof interventions had indeed presented differing temperature data.

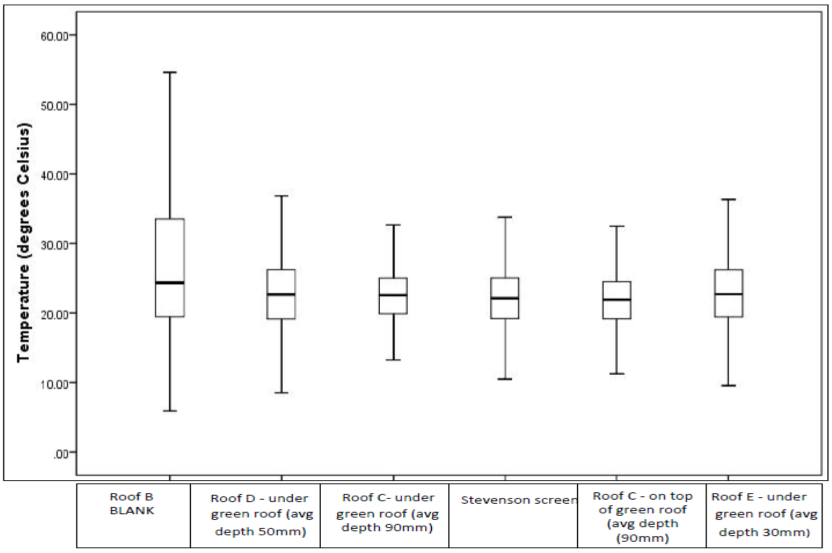

Figure 4: Temperature box-and-whisker plots showing the mean, first and third quartiles.

Figure 4 above shows how the mean, first and third quartiles of results was used to illustrate where the data was not normally distributed.

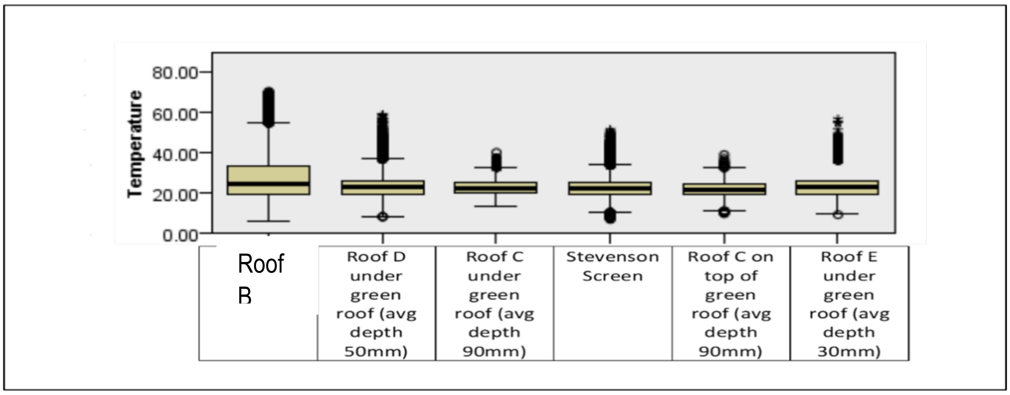

Figure 5: Independent – samples Kruskal- Wallis test

Results and Discussion

As global heating intensifies, UHIs are expected to as well, placing green roofs as one of the key interventions to help alleviate this. Extensive green roof adoption has been documented in Toronto and New York to be very effective in mitigating the UHI effect (Getter and Rowe, 2006 and Alexandria and Jones, 2007: 486). In Toronto, a conventional roof can reach 70˚C in the afternoon, while a neighbouring green roof will reach only 25˚C (Getter, 2006: 1272). Onmura *et al*. (2001) conducted a field measurement on a planted roof in Japan. The surface temperature decreases from around 60 to 30˚C on certain days.

In warmer climates, green roofs play a part in reducing the indoor temperature as the planted rooftop layer provides shade and protection from solar radiation (Niu *et al.,* 2010 and Ouldboukhitine *et al*., 2011). In some cases, the average difference between green roofs and conventional rooftops for only the summer months are +/- 10˚C. The GRPP over a seven-year study period (January 2010 to February 2017) showed a 9.2˚C difference between the conventional roof and the combined average of the green roof case studies during the summer months. This may seem minimal however, when analysing the data from (Figure 8: Page 14) there are significant monthly differences between the blank roof +/-70˚C and the green roofs with best performing green roof C showing +/- 28˚C which is a +/- 40˚C difference. Wong *et al*. (2003) found that in Singapore green roofs over a typical day recorded a 10% difference to that of a control roof. A study in Madrid showed similar results with the green roof reducing the heat transferred in an eight-story building by six percent during certain days in the hot summer months (Saiz *et al*., 2006).

Extensive green roofs found in subtropical climates have great potential to help minimise heat (Simmons *et al*. 2008). Energy provided by the sun is the major input of energy to the system. The process works as follows: the energy from the sun radiates onto the green roof plants. The plants then intercept and reflect some of this radiation, with some of the radiation that does make it to the growing mediums layer being partially reflected. Some of the absorbed energy at the surface is converted to latent heat or evaporative cooling. This happens through evapo-transpiration from the soil layer and green roof plants (Del Barrio, 1998 and Theodosiou, 2003). According to Sailor, (2010) the energy that is not taken away from the surface is conducted into the growing media and then partially absorbed and stored in the soil. Only then does some of it make its way into the building, reducing the amount of heat absorbed directly by the building in question. Although there are variations with regards to green roof research results, studies have shown that green roofs are able to reduce the energy required for building cooling on the floor directly below the roof by upwards of 50% (Peck and Richie, 2009). There is still significant scope for further research regarding temperature reductions using green roofs to provide more concrete evidence. More control roofs and green roofs need to be tested across the Durban CBD area.

From the data recorded during the period from January 2010 to February 2017 that green roofs contributed to the thermal benefits of both buildings and their surrounding environments the following figures depict:

- Average daily temperatures recorded over a 7-year period (Figure 6)
- Average temperature variances during the summer months (Figure 7)
- Hottest days recorded over a 4-year period (Figure 8)

These all substantiate the role that green roofs in Durban can play in controlling UHI effects and the other environmental consequences caused by extreme temperatures experienced in city forms. The following will highlight some of the more important differences, with regards to local temperature variances and the potential effects it has on the UHI effect.

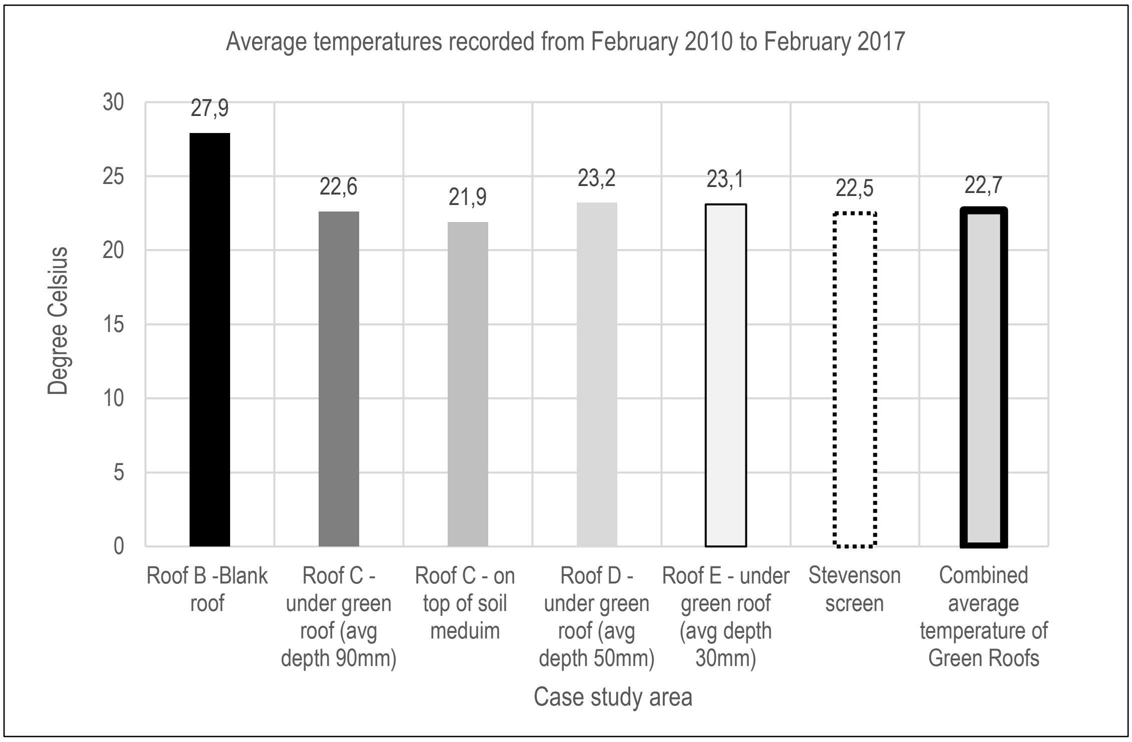

Figure 6: Average Temperatures recorded from February 2010 – February 2017

Figure 6 above shows the difference between the blank roof and the individual green roof case studies as well as the combined green roof temperature averages recorded from February 2010 to February 2017. There is an average difference of 5.2 degree Celsius between the control roof and the combined average of the green roof case studies. Green roofs can reduce heat moving through the roof, which can decrease the demand on the building's existing cooling system.

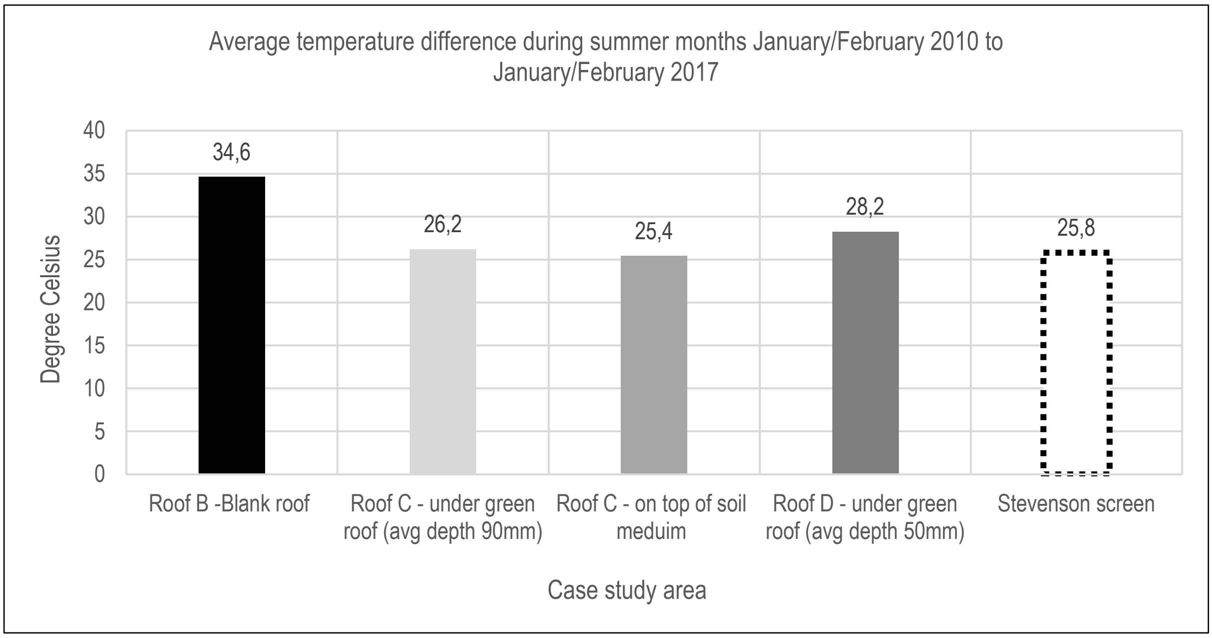

Figure 7: Average temperature difference between blank roof, the green roofs and Stevenson screen (ambient air temperature) during summer months

Figure 7 above demonstrates the effect of green roofs in the cooling of buildings in summer. It shows the average temperatures recorded on the blank roof; the three green roof sections and the Stevenson screen for the summer months, January and February, between 2010 and 2017. The average differences are varied depending on the green roof in question. The green roof that performed the best (9.2-degree Celsius difference) is the one where the thermo-probe was placed on top of the soil but significantly covered by vegetation. This is expected as the foliage would allow cool wind through. Furthermore, the succulent flora offers significant shade from the direct sun. The other green roofs had the thermo-couplings buried under the growing medium and they showed a difference of 8.4 degree Celsius and 6.4 degree Celsius respectively.

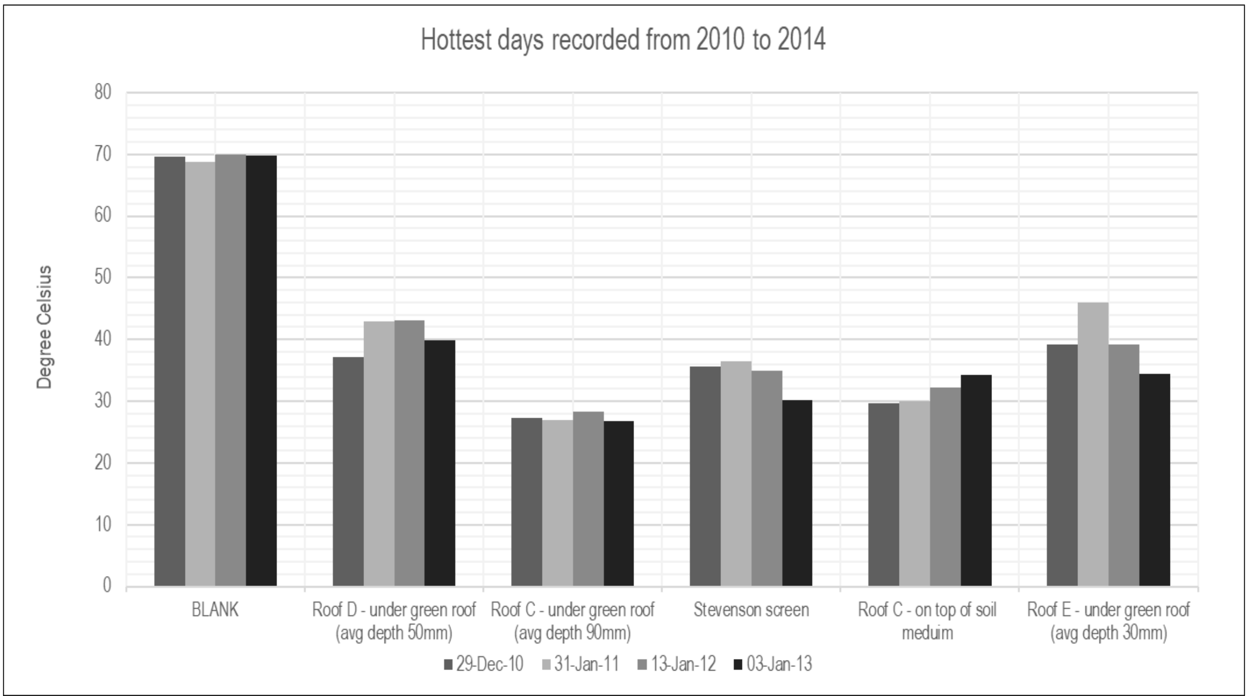

Figure 8: Hottest days recorded from 2010 to 2014

Figure 8 above shows the hottest days recorded between 2010 to 2014, the surface temperature of a green roof is cooler than an adjacent control roof over the midday period. What this research has shown is that within local contexts, similar scenarios to the one measured in New York are recorded with the blank roof recording temperatures of up to 70 degrees Celsius on the hottest days. Deeper green roofs were able to minimise temperatures by +/- 30 degree Celsius throughout all study areas with the shallow green roofs performing slightly less well in this regard.

Conclusion

The dated data presented can provide a valuable source for climate change mitigation techniques as well as offering a tried course of action that could support further investigation. Considering that it is challenging to integrate green infrastructure into spatial planning and, according to Cilliers and Cilliers, (2016) in city contexts it is more complex because land use decision-making has to address the demand for housing and other services. However, through green infrastructure such as green roofs this could become a viable option as it provides green spaces on both existing buildings rooftops as well as new builds. In addition, such efforts can speed the recognition of the value of a body of research from a given area and more quickly allow for its useful application. Rooftop greening offers quick, practical and effective urban management intercessions that both minimise the burdens placed on existing urban infrastructure as well as promoting a culture of urban renaissance and built form identity that is complementary, reparatory and compensatory to nature. These innovative projects need to be scaled up to offer a more macro advantageous position that will provide key decision-makers with guidance for future urban policy directives and additional appropriate urban design retrofications as well as new builds. With strategic and creative planning solutions from both municipal governments and citizens, the urban environmental question offers a vision of a healthier and more sustainable urban space. However, to do this, city spaces need to be re-conceptualised, restructured and examined to identify how existing empty spaces such as rooftops, can become useful resources.

Empirical data gained through case study observations indicate that one of the primary benefits for using green roofs as green infrastructure is their ability to provide immediate urban ecosystem services through temperature controls. International literature suggests that when green roofs are installed *en masse* in an urban area, the benefits are more readily felt. The data here also helps support the hypothesis that green roofs reduce the heat island effect and the direct heat flowing to the building's rooftop. In so doing it has used local experiments in the form of case studies and other data to support and investigate international claims that green roofs offer several improvements to urban areas. It was found that in a local context green roofs can reduce the UHI effect.

Under Local Government regulations there are specific areas where the municipality may be able to encourage development of green roofs. In Section 1.11 of the Land Use Management Schemes, green roof materials could be stipulated in all new builds that fall within the Durban Scheme. According to Dubbeld (Senior planner at the eThekwini Municipality 2015), within local land use management policies there is no land use specifically dedicated to green roofs. There are opportunities for green roof inclusion in several clauses in the land use management scheme, some of which addresses special consent. Green roofs could fit here. Despite the national, provincial and local legislative frameworks not offering much in terms of the promotion of urban greening and green roofs, there are some existing opportunities that do promote certain aspects of environmental planning and urban greening. The Integrated Development Plan features an eight-point plan which represents some of the direct links that green roofs and rooftop gardens could have in either alleviating or supporting the key performance areas. The Durban Metropolitan Open Space System (D'MOSS) and the efforts of the private sector Green Building Council of South Africa (GBCSA) must be applauded for their initiatives to support environmentally sustainable urban developments that promote urban sustainability and environmental protection.

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