RETROFITTING HOUSING WITH LIGHTWEIGHT GREEN ROOF TECHNOLOGY IN SYDNEY - AUSTRALIA AND RIO DE JANEIRO - BRAZIL.

Sara J Wilkinson[1] & Renato Castiglia Feitosa[2]

[1] School of Built Environment, Faculty of Design Architecture and Building UTS, Australia, sara.wilkinson@uts.edu.au
[2] Post-Doctoral Fellow at the University of Sydney, Researcher at Oswaldo Cruz Foundation (Fiocruz) – Department of Sanitation and Environmental Health of National School of Public Health, rentcf@yahoo.com.br

Abstract

The built environment contributes around half of all greenhouse gas emissions and 87% of residential buildings the UK will have in 2050 are already built (Kelly, 2009), there is a need to adopt sustainable retrofit for existing residential buildings. Furthermore these statistics are broadly similar across many countries. The question is; what are viable solutions? One answer may be to retrofit with green roofs as there are environmental, economic and social benefits. Environmental benefits include potential reductions in operational carbon emissions, reductions in the urban heat island, increases in bio-diversity, housing temperature attenuation and reductions in stormwater run-off. Economically, benefits are reduced roof maintenance costs and lower running costs. The social gain is the creation of spaces where people have greater access to nature. However there are barriers to the adoption of retrofitted green roofs; which include perceptions of structural adequacy, risk of water damage, high installation and maintenance cost, as well as access and security issues.

In some locations the intent will be to reduce cooling loads, whereas others will desire thermal insulation, or will seek reduction in stormwater run-off. The ability to meet the demands will depend on budget and physical characteristics. Many Australian and Brazilian residential buildings have profiled metal sheet roofing which is a lightweight material with poor thermal performance During summer periods Sydney as well as Rio de Janeiro temperatures can reach 45 degrees Celsius and rainfall patterns are variable and changing. This research reports on an experiment on two small scale profiled metal sheet roofs in both cities which aimed to assess thermal performance. One roof was planted to compare performance to an unplanted roof. The findings are that considerable variation in temperature were found in both countries indicating that green roof retrofit could lower cooling energy demand considerably.

Keywords: Green roof retrofit, Sydney, thermal performance, residential buildings, housing, case studies.

Introduction

There is a consensus amongst climate scientists that global weather patterns are changing with some regions getting hotter and drier whilst others will become wetter (BOM, 2014). One of the highest contributors to human induced climate change is the built environment, which adds around half of all greenhouse gas emissions into the atmosphere. Within the built environment the biggest land use type contributing to green-house gas emission is the residential sector (Maslin et al., 2007). Whilst efforts are being made globally to improve sustainability in buildings through operational and embodied energy efficient design, it remains the case that most of the stock that will exist by 2050 is already built. In the UK it is estimated that 87% of residential buildings the UK will have in 2050 are already built (Kelly, 2008). Furthermore many cities are experiencing rapid urban expansion and or densification which contribute to the phenomena known as the urban heat island effect whereby city centres are sometimes up to five degrees warmer than outer suburbs (Lamond et al, 2014). In addition, within some cities urban heat canyons are created whereby heat is trapped between buildings which during excessively hot days can contribute to negative human health impacts and even fatalities (Oke, 2006; Harlan et al., 2005). In the recent past, high temperatures have been observed worldwide. The city of Rio de Janeiro experienced historical records of high temperatures on February 2014 (Climatempo, 2014). In a four to five day period of plus 45 degree days in January 2014 in Melbourne Australia more than twice the average rate of mortality was experienced. These deaths were attributed to the excessive heat conditions which were exacerbated in the CBD (ABC, 2014); furthermore with predicted climate change impacts and an ageing population these statistics look likely to increase. On this basis the focus for climate change mitigation is through the adaptation and sustainable retrofit for existing buildings. Furthermore these statistics are broadly similar across many countries. The question is; *what are viable solutions in terms of retrofitting our existing residential buildings?*

If the aim is to reduce building related green-house gas emissions; for some regions the goal will be to keep buildings cool and therefore reduce cooling loads, whilst for other areas the problem will one of retaining heat and reducing heat loss through leaky buildings. Whereas in other regions the problem will be one of accommodating increased frequency of intense rainfall (Lamond et al., 2014). One answer, which may suit a number of regions to some degree, may be to retrofit buildings with green roofs as there are environmental, economic and social benefits.

The environmental benefits include potential reductions in operational carbon emissions, reductions in the urban heat island, increases in bio-diversity, housing temperature attenuation and reductions in stormwater run-off (Castleton, 2010. Wilkinson and Reed 2009, City of Sydney 2012). Air quality is improved as plants remove carbon dioxide and harmful pollutants from the atmosphere. In addition green roofs provide a habitat for insects and birds and reptiles to shelter and find food sources and water (Williams et al, 2010).

Thermally the mass of the green roof improves the insulating qualities of the building by reducing heat transmission through the roof. Much heat loss occurs through the roof as heat rises and then escapes through inadequately insulated and leaky roof structures. Some authors have evaluated the role of green roofs cooling and warming potential in energy savings, and the potential for retrofit, based either on modelling or experimental data. It is a common consensus that, in non-insulated buildings (common feature in Rio de Janeiro and Sydney), the addition of green roofs can improve the insulation properties and reduce annual energy consumption. According to Castleton (2010) over the past 10 years, several studies have shown that green roofs can offer benefits in winter heating reduction as well as summer cooling. Nichaou et al. (2001) showed an annual energy saving potential of green roofs on non-insulated buildings for heating and for cooling, of 45-46% and 22-45%, respectively. Wong et al. (2003) found for a non-insulated case covered by an extensive green roof of turf, an annual energy saving of 10.5% when compared with a non-greened exposed roof. However, it is important to emphasize that the aforementioned energy saving is applied to adjacent environments to the rooftops. Alcazar and Bass (2005) state that due to the tall nature of the buildings, roofs comprise around 16% of the total building envelope, and the largest reductions in energy consumption were seen in rooms directly below the green roof. There was no energy savings for more than three floors down.

Where stormwater or pluvial flooding is an issue green roofs can reduce the run off rate and also filter or cleanse the water passing through the roof covering (Lamond et al, 2014). There are numerous environmental benefits from the installation of green roofs in urban settlements which are suitable whether the problem is one of excess stormwater or a need to enhance thermal performance. It is the case that the specification of white roofs, roofs that are painted white or reflective colours is the most cost effective means of reducing heating load in buildings however the bio-diversity and air quality benefits are absent with this option (Hes et al., 2012). Thus the decision to retrofit a green roof has multiple variables and should not be evaluated on one variable alone but the multiple benefits that are delivered (Wilkinson et al., 2012).

Economically, the benefits to occupiers and owners are reduced roof maintenance costs and lower running costs (Castleton, 2010 Porsche and Köhler, 2003). There are erroneous perceptions however, among the practitioner community that green roofs lead to higher maintenance costs (Wilkinson et al., 2012) which is resulting in less specification of green roof technology in buildings. Whether the aim is heat retention or reducing the cooling load green roofs can deliver lower operating costs (Porsche and Köhler, 2003. Castleton, 2010).

The third aspect, the social gain is the creation of spaces where people have greater access to nature. The bio-philia effect describes the phenomenon whereby humans experience positive feelings as a result of the connection to the natural environment (Kellert and Wilson 1993). Unfortunately for many, living in cities; access to the natural environment is limited and diminishing (City of Sydney, 2012). In Sydney, for example, it is estimated that there are less than 22 metres squared per resident and that around 15.5% of the city is covered by urban canopy (City of Sydney 2012). The city wishes to increase this level of urban greenery for the health and well-being of the community (City of Sydney 2012). There are initiatives which seek to increase the amount of urban greenery in Sydney by 20% before 2020 (202020 Vision, 2014) and the specification of green roofs would be a way of contributing to the delivery of this target. On the contrary, the amount of green spaces in Rio de Janeiro has decreased significantly, mostly due to the lack of space and population growth. Furthermore no plans have been adopted yet to deal with this problem.

However there are barriers to the adoption of retrofitted green roofs; which include perceptions of structural adequacy, risk of water damage, high installation and maintenance cost, as well as access and security issues.

In some locations the intent will be to reduce cooling loads, whereas others will desire thermal insulation, or will seek reduction in stormwater run-off. The ability to meet the demands will depend on budget and physical characteristics. Although the technology to design and retrofit green roofs exists, the uptake and the demand have not been high. Overall, the gains have not been deemed sufficient and in both cities, the existing numbers of residential green roofs confirm this observation. Many Australian and Brazilian residential buildings have profiled metal sheet roofing which is a lightweight material with poor thermal performance; heat transfer is very high. Many buildings have little or no insulation to offset the high heat gains. During summer periods Sydney, as well as Rio de Janeiro, temperatures can reach 45 degrees Celsius and rainfall patterns are variable and changing; affected by La Nina and Il Nino weather cycles. This research reports on an experiment on two small scale profiled metal sheet roofs in both cities to assess thermal performance. In each city, one roof was left as a control whilst the second roof was planted with succulent plants in trays. Data was collected using thermal data loggers over a summer and autumn season. The paper discusses the findings and the potential for retrofitting residential stock with lightweight trays planted with succulents.

In 2014 the City of Sydney adopted the first green roofs and walls policy for Australia, which sets out a commitment to increase the number of high quality green roofs and walls in the City (City of Sydney, 2014). The policy includes a 3-year implementation plan to ensure the policy is understood, properly adopted and integrated. There are 59 green roofs in Sydney currently which serve a variety of purposes including enhancing thermal performance (City of Sydney 2014).

Research Methodology

The methodology adopted is predicated on the development of simple technologies to mitigate the problems created by increasing urban densification which exacerbates the urban heat island which in turn leads to uncomfortably high internal housing temperatures. There are many technologies and approaches available to execute this research; but in this case the researchers aimed to use adaptive techniques that minimised initial costs and maintenance costs; in other words technologies which would be affordable and easy to implement. For this reason, this project used lightweight removable modules of vegetation (rectangular containers) of low thickness. This modular system enables planting, cultivation and maintenance off site to be undertaken.

The researchers sought to evaluate the performance of a green roof retrofit system which could be widely used in metropolitan areas. At this point in time there is a dearth of empirical evidence on the performance of green roofs in Australia, with most data coming from the US or Europe where climatic conditions are very different. Similar conditions exist for South America in terms of empirical data on green roof performance. Previous studies have shown significant variations based on temperatures, evaporation rates and wind conditions which affect the performance of green roofs.

Two sets of experiments were performed in Australia (Sydney) and in Brazil (Rio de Janeiro). The Australian site is located at the University of Technology, Sydney in Ultimo Sydney and the Brazilian location is on the roof of an existing building at the Oswaldo Cruz Foundation (Fiocruz).

Succulent plants were preferred due their higher drought resistance qualities and a lower risk of fire. Furthermore these species can develop easily in shallow soils, and thus, structural reinforcement of existing roofs is unnecessary. Additionally, due to the modular characteristics of the planting containers, the modules can be applied directly onto the roof covering be it profiled metal sheeting or tiles.

Rectangular plastic containers were selected according to the availability at the different sites (Rio de Janeiro – 400 x 500 mm and Sydney – 190 x 330 mm) where the experiments were performed, as shown in
Figure **1**.

Figure 1 – Rectangular plastic containers used in the temperature experiments. Left hand side - Brazilian module, provided by Cidade Jardim Institute; right hand side - Australian module.

It is important to highlight that both containers have a water storage system which meets two main objectives. Firstly it provides water to the soil through evaporation, enhancing the plants survival even during extended period of no rain. Secondly, it can attenuate temperature fluctuation due to the water layer between the soil and the roof.

The soil is separated from the drainage system by a permeable fabric (Geotextile) which allows the passage of water but prevents the soil from leaking into the water chamber. For the plant species used in this research a soil with good drainage and low organic load is required. A composition of two parts of sand to one part of loam is employed.

The evaluation of the green roofs cooling potential is performed by the comparison between two housing prototypes with vegetated and non-vegetated roofs. Due to financial limitations it was not possible to use full scale housing for the experiment. Therefore small scale structures are used to demonstrate the thermal performance of a non-green, traditional roof and a green roof. The experimental set-up comprises covering the roof of the one of the prototypes with planted soil containers. Different types of housing prototypes are considered in this research. As shown in
Figure **2**, the Rio de Janeiro tests were carried out using small brick houses covered with metal sheeting, whereas in Sydney, metallic sheds were employed. In Australian housing profiled metal sheet roofs are typically specified and for this reason the metal sheds were selected.

A simultaneous comparison between the records of temperature inside the vegetated and non-vegetated structures was made use of data loggers that allows a continuous temperature records during long periods of time. The temperature measurements were carried out using Extech TH10 Temperature USB Data logger, using a time sampling of 30 minutes. The Rio de Janeiro tests were performed over 194 days, from October 17th 2012 to April 29th 2013, whereas Sydney trial tests comprised a 97 day period from December 11th 2013 to March 18th 2014.

The data loggers were positioned in different heights inside each of the prototypes, according to the experimental site. In Rio de Janeiro and Sydney they were placed 250 and 50 mm respectively, below the top of the structure. All the temperature differences observed are attributed only to the influence of heat incidence on the structures, given that the perimeter conditions between the vegetated and un-vegetated prototypes are identical.

Figure 2 – Housing thermal experiments. Left hand side – Rio de Janeiro; Right hand side – Sydney.

Results and discussion

The results with regards to the green roof cooling potential for the two experimental sites (Rio de Janeiro and Sydney) are depicted in figures 3 to 5 below. Besides some basic differences in the structures (that is blockwork in Rio de Janeiro and metal sheeting in Sydney), the tendency in temperature attenuation is evident. From the measurements performed in Rio de Janeiro and in Sydney it was observed that green roofs are able to attenuate daily variations of temperature.

Rio de Janeiro results

Figure **3** presents a comparison between the non-green and green roofs internal temperatures, during the 194 day data collection period, which comprises the whole Brazilian Summer period, and also part of Spring and Autumn. Some of this work was partially reported in Feitosa (2012).

During the period of investigation the non-green roof presented maximum, minimum and average temperatures equal to 41.1ºC, 20.1ºC and 28.8ºC respectively. Correspondingly the values observed in the green roof case were 39.3ºC, 20.3ºC and 27.7ºC.

Based on daily variations of temperature, the maximum values observed during daytime for non-green and green roofs varied from 23.9ºC to 41.4ºC and 23.2 to 39.3ºC, respectively. The minimum values which occurred during the night time, varied from 20.1ºC to 31.8ºC for the non-green roof and 20.3ºC to 31.8ºC for the green roof. It is important to highlight that the green roof cooling potential is not directly related to the differences observed between those limits presented, due to the existing time lag between the non-green and green roof temperature peaks.

Comparing the simultaneous temperature differences between green and non-green roofs it was observed that these values vary from -1.5ºC to 5.6ºC. The temperature differences were dependent on the temperature background. That is to say that previous temperature register are able to influence present ones, considering that green roofs tend to attenuate thermal exchanges. If for example a warm day increases the inner temperature, this internal heat will influence the following temperature register. Positive values mean higher non-green roof temperature, whereas negative values depict the opposite. The lowest positive temperature differences between non-green and green roofs (≤2ºC) were observed when the internal non-green roof temperatures were below 30ºC. The highest positive temperature differences (≥5ºC) were registered at the end of the summer period, when during the previous night-time period the green roofs temperature were cooler than the non-green roof. However, higher green roof nocturne temperatures contribute to weaker following day-time temperature differences (<5ºC). The delay observed between the temperature peaks of non-green and green roofs results in slightly warmer green roof temperatures (negative differences) during the night-time and early morning periods, which contributes to weaken the temperature differences in the following day.

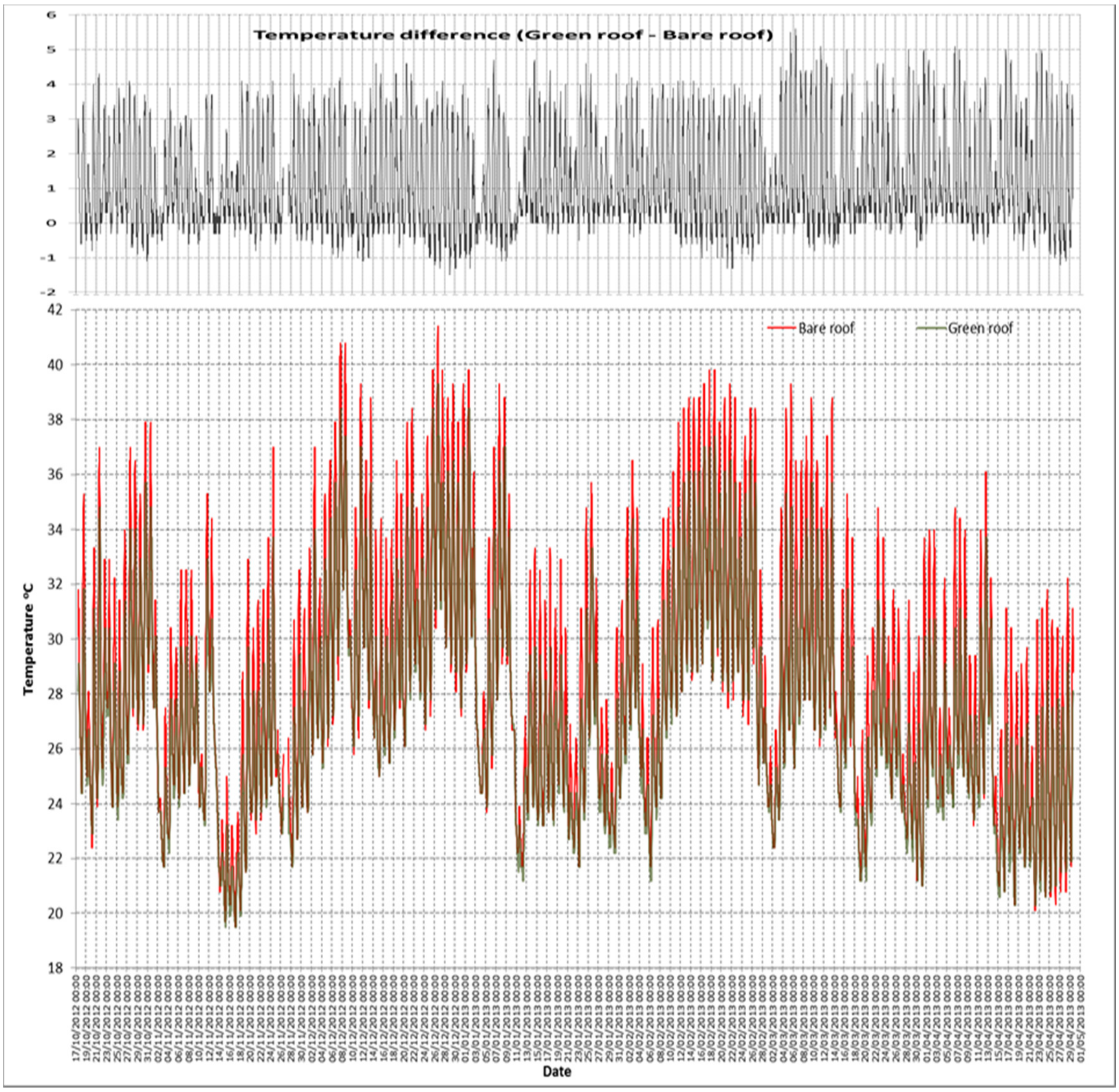

Figure 3 – Comparison between non-green (bare) and green roofs inner temperature. Experiments performed in Rio de Janeiro, Brazil.

Sydney results

Despite of the shorter period, when compared to Rio de Janeiro experiments, it was also observed that a significant green roof cooling potential occurs. However, according to the characteristics of the site where the experiments were undertaken, it can be observed a particular pattern in temperature registers. As shown in
Figure **4**, it is observed a sudden reduction in temperature for non-green and green roofs occurs around 3pm due to the shadows caused by adjacent buildings. From this same figure it can be seen that a slower response to temperature variation for green roofs, which is consistent with their insulating properties.

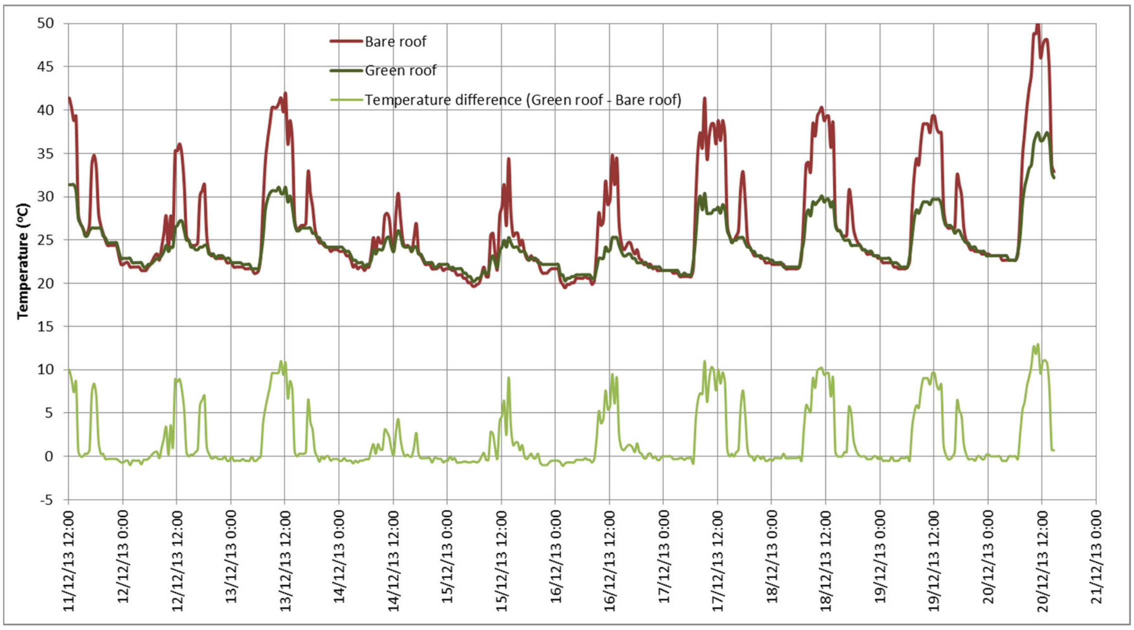

Figure 4 – Influence of shadows caused by nearby buildings in temperature

Figure **5** presents a comparison between non-green and green roof inner temperatures, over 97 days, during the summer period. The Sydney non-green roofs presented maximum, minimal and average temperatures equal to 50.3ºC, 17.2ºC and 25.2ºC, respectively. Correspondingly, the values observed in green roof case were 37.4ºC, 17.6ºC and 23.9ºC. The Sydney experiments showed a similar profile to the observed experiments in Rio de Janeiro, where the highest positive differences also occurred around noon in the warmest days.

The temperature differences between green and non-green roofs varied from -1.6ºC to 14.8ºC. The lowest positive temperature differences between the non-green and green roofs (≤4ºC) were observed for the non-green roofs inner temperature under 30ºC. The highest positive differences (≥10ºC) occurred basically to non-green roof temperature peaks higher than 42ºC. Negative differences were evident practically along all night time periods, corroborating additionally the green roof efficiency in attenuate high and relatively low temperatures.

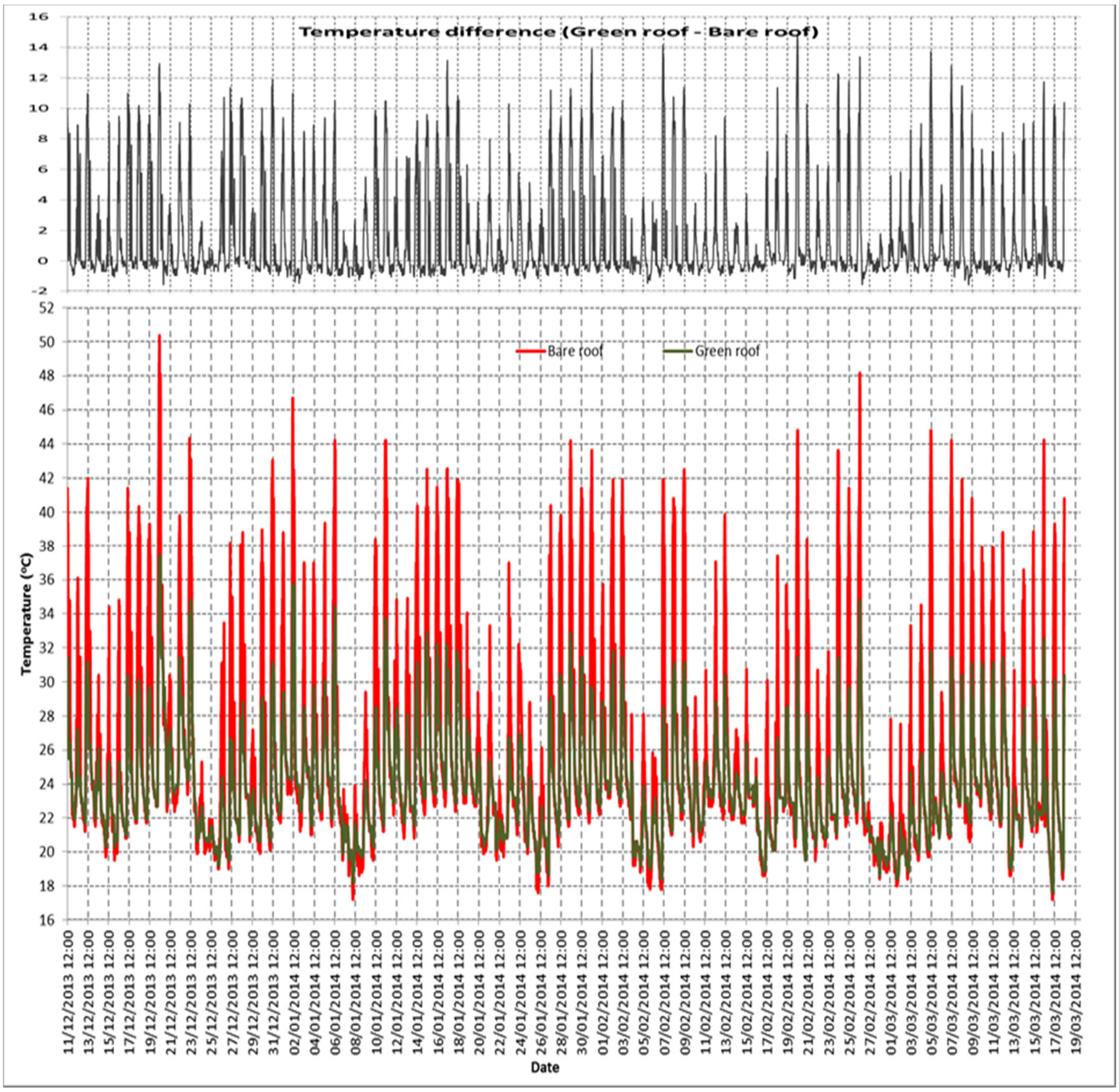

Figure 5 – Comparison between non-green and green roofs inner temperature. Experiments performed in Sydney, Australia.

Evaluation of Rio de Janeiro and Sydney results

This work does not solely intend to perform a comparison between Sydney and Rio de Janeiro experiments, but it aims to evaluate the green roofs potential to attenuate housing temperature under different aspects.

The following table depicts for Sydney and Rio de Janeiro sites, non-green and green roofs maximum, minimum and average temperatures, as well as, their higher and lower differences.

It was observed a green roof cooling potential in Sydney greater than the observed potential in Rio de Janeiro, which was most likely due to the existing differences in both experiments. This may be attributed basically to positioning of the temperature data loggers. In Sydney they are located about 50 mm below the roof, whereas in Rio de

Janeiro they are 250 mm below the roof. To evaluate this influence, a new pair of data loggers has been purchased to be placed in both Sydney sheds, in order to provide a future temperate comparison in a lower position.

Table 1 – Experimental temperature comparison between Sydney and Rio de Janeiro.

Temperatures (ºC)	Rio de Janeiro			Sydney		
	Bare roof	Green roof	Simultaneous temperature difference	Bare roof	Green roof	Simultaneous temperature difference
Maximum	41.4	39.3	5.6	50.3	37.4	14.8
Minimum	20.1	20.3	-1.5	17.2	17.6	-1.6
Average	28.8	27.7	-	25.2	23.9	-

(Source: Authors).

It is believed that the new temperature measurements in a lower position in both sheds will provide temperature differences closer to the observed in Rio de Janeiro. Additionally, it is also important to consider that, besides the positioning of the data loggers, the differences observed between Sydney and Rio de Janeiro may lie on the setup characteristics of both experiments sites, such as:

- Neighbourhood shading condition existing in Sydney and non-existing in Rio de Janeiro
- Different roof side conditions, which comprises brick walls in Rio de Janeiro and metal sheeting in Sydney.

Besides, the differences adopted in both methodologies showed the green roofs' relevance in temperature attenuation.

Another aspect to consider is related to the water existence and/or its levels in the storage systems. Due to the high specific heat, water is supposed to provide inertia against temperature fluctuations. However, in the studies performed so far, these water levels were not monitored, and its influence remains unknown in the present work. This evaluation is intended to be object of further research to be carried out in Rio de Janeiro.

Additionally, it should be pointed that only temperature, and not solar radiation levels, was collected in the two studies presented. Thus, it is posited that the temperature attenuation provided by the green roofs must be directly related to high solar radiation levels and that during cloudy days this effect tends to be less pronounced.

Conclusions

Both experimental setups in Rio de Janeiro and Sydney showed the potential for green roofs as a means of cooling buildings, reducing carbon emissions and helping towards zero carbon targets. However, the experiments carried out in Sydney presented a potentially better green roof performance in housing temperature attenuation, which may be partly attributed to the closer positioning of the data loggers in relation to the roof. Additionally, the water levels in the water retention systems may have a relevant role with regards tothe heat exchange through the roof, which can support the role of the water layer as part of the green roofs insulation properties. To evaluate this issue further research is necessary.

Even though there are no registers of low temperatures (that is <16ºC) in this dataset, the negative differences observed (green roofs temperature higher than non-green roof) may indicate the potential for green roofs to attenuate extremes of temperature, due to their insulation properties. It is probable that different substrates would provide different results and this should be investigated,

The temperature differences showed a relationship to the temperature background. The delay between temperature peaks of non-green and green roofs results in slightly warmer green roof temperatures (negative differences) during the night-time and in the early morning periods, which contribute to weaken the temperature differences during the following day.

Considerable differences of temperature between city centre and suburban urban areas have been reported in the literature. Green roofs promote thermal comfort improvement, attenuating heat exchanges between the internal and external environments of buildings. Additionally, as these results show; it is expected that attenuation of the urban heat island effect in large cities can be achieved, if green roofs are adopted for new build and retrofitted for existing buildings on a large scale. The research has demonstrated that roof structures planted with succulent plants are viable and could provide a low cost, drought tolerant, lightweight option to reduce heat gain and heat loss through roof structures in some regions of NSW and Australia.

However, as far as thermal effect is concerned, the adoption of green roofs in urban centres is a partial solution, due to the contribution of the building facades in the overall heating. Thus, a combination of green walls and green roofs could be an optimum solution to this problem. Furthermore, with regard to energy saving issues, considering that buildings comprise the most part of big cities, the use of green roofs would only bring effect to top floors, which reinforce the combination of these systems (green roof and green walls) in the urban environments.

Further experiments with structures which more closely emulate typical Australian housing specification in terms of wall construction would be very useful. One of the limitations of the research is that the walls of the shed are profile metal sheeting which is not typically specified in housing. In the Rio de Janeiro experiments, brick walls comprise a common type of solution adopted in the majority of housing. However, additional procedures, such as green walls, should be evaluated in order to mitigate the existing thermal exchanges through the walls.

This research is ongoing and data is being collected for a full calendar year. Through this data it may be possible to estimate the level of economic savings and greenhouse gas emission reductions that may be achieved through green roof retrofit with succulent plants in New South Wales. Further iterations will see insulation introduced to the structures in Sydney to determine and compare the thermal performance of the structures. Data is also to be collected on the nature and extent of the attraction of bio-diversity to the Sydney roofs to determine the likely impact of an increase in green roof provision over time. In the Rio de Janeiro case, it is intended to evaluate the role of water in the green roof retention system, in the prototype covered with the vegetated system. Additionally, a future project to be submitted for approval, would be for the evaluation of the effect in energy savings before and after the adoption of green roof and green walls system in an existing house. It is possible that the widespread retrofit of green roofs may, with reductions to cooling demand, help towards zero carbon goals in the built environment.

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