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Sustainability

Urban Heat Islands

BlueScope Steel Ltd. (BlueScope Steel) has made a commitment to continually improve the company's environmental footprint and the sustainability of its products and services.

This is the second in a series of technical bulletins relating to sustainability issues that directly or indirectly impact the steel value chain. In writing these bulletins BlueScope Steel wishes to inform and educate the market, based on the latest available and verifiable information.

The term *urban heat island* (UHI) is used to refer to the fact that cities and urban areas are often significantly warmer than the rural or undeveloped areas that surround them. This technical bulletin details why UHIs form; the consequences of UHI formation; and what can be done to mitigate these effects.

Urban forestry and *cool roofs* are two of the most effective ways to reduce the intensity of UHIs: light coloured COLORBOND® steel can be used to create cool roofs because it has high solar reflectance and thermal emittance.

Other sustainability technical bulletins in this series related to urban heat islands and cool roofs include:

3. Voluntary Green Buildings Ratings Tools in Australia;
5. Mandatory Sustainability Requirements for Residential Buildings in Australia;
7. Sustainable Building Solutions: Thermal Mass;
8. Steel in Sustainable Buildings; and
9. Extreme Weather Events.

Other BlueScope Steel technical bulletins related to cool roofs include:

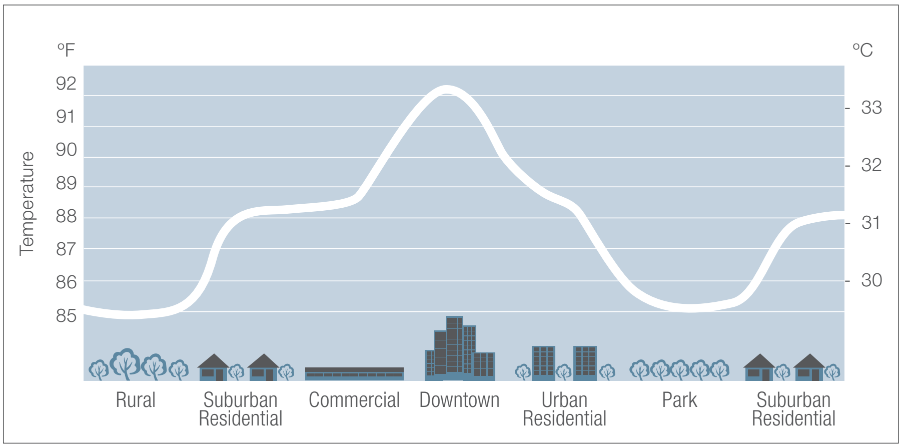
28. Building Materials, Thermal Efficiency & Reflectivity.

1. Formation of Urban Heat Islands

Urban heat islands are not a new phenomenon. In 1833 Luke Howard – a chemist and amateur meteorologist – presented evidence that the air and surface temperatures in London were often higher than in the surrounding countryside: this is now considered to be the first documented case of an *urban heat island* (UHI). Today, many cities and suburbs record air temperatures warmer than the surrounding natural land-cover (*Figure 1, following page*): the United States Environmental Protection Agency (EPA) reports that on average US cities are up to 5.6°C warmer than the surrounding countryside[1].

Urban heat islands form when vegetation is replaced with non-reflective, high mass, water resistant, impervious surfaces that absorb a high percentage of incoming solar radiation. There are three main drivers of heat island formation: *heating as a result of human activities; reduced evapotranspiration* due to decreased vegetation cover; and increased absorption and retention of heat due to decreased *surface reflectivity*.

Figure 1: Urban Heat Island Profile (adapted from Reference 1).



The formation of heat islands is not necessarily uniform across the city, or over time: heat islands can evolve around a single building, across a small section of the city or over the entire city region. Some researchers have also reported that local and regional climate, and the topographic features of cities, affects the strength and persistence of heat islands.

1.1 Surface Reflectivity: Increased Absorption of Heat

All surfaces reflect a proportion of the energy that arrives from the sun (*solar radiation*). The more reflective a surface is, the less solar energy it absorbs and the cooler it is. Conversely, the less reflective a surface is, the more solar energy it absorbs and the higher its surface temperature will be. Compared to natural land-cover, urban environments often have lower surface reflectivity, absorb more of the available incoming solar radiation and are consequently warmer. This is the beginning of the formation of a UHI.

The solar radiation absorbed by the surface of the Earth is predominantly re-radiated to the atmosphere – and eventually to space – as longwave radiation (*Figure 2*). Energy also leaves the surface by thermal convection and conduction (sensible heat), and when water is evaporated (latent heat). The amount of energy re-radiated from a surface is dependent on the temperature of that surface: the hotter the surface, the more energy it will emit. Because cities are comparatively warmer, they can emit more longwave radiation than the surrounding countryside.

Because of its longer wavelength, re-radiated energy can be absorbed by clouds, and particles in the atmosphere such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20) and water vapour (H_2O_v) – *greenhouse gases* (GHGs). These particles emit the energy back to the atmosphere and to the surface of the Earth (*Figure 2*) – emitted longwave radiation acts to heat both the atmosphere and the surface further.

The increase in atmospheric GHG concentrations that have occurred due to human activities – particularly since the industrial revolution – have resulted in an overall warming of the atmosphere (the *anthropogenic greenhouse effect*). Because activities in urban environments are often major generators of GHGs (such as the CO_2 produced by vehicle use and industrial processes), outgoing longwave radiation from cities is more likely to be absorbed and re-radiated in the atmosphere above cities than longwave radiation emitted from the surface in a less polluted environment. The net result again, is more potential heating of both the city and atmosphere above it.

1.2 Reduced Evapotranspiration

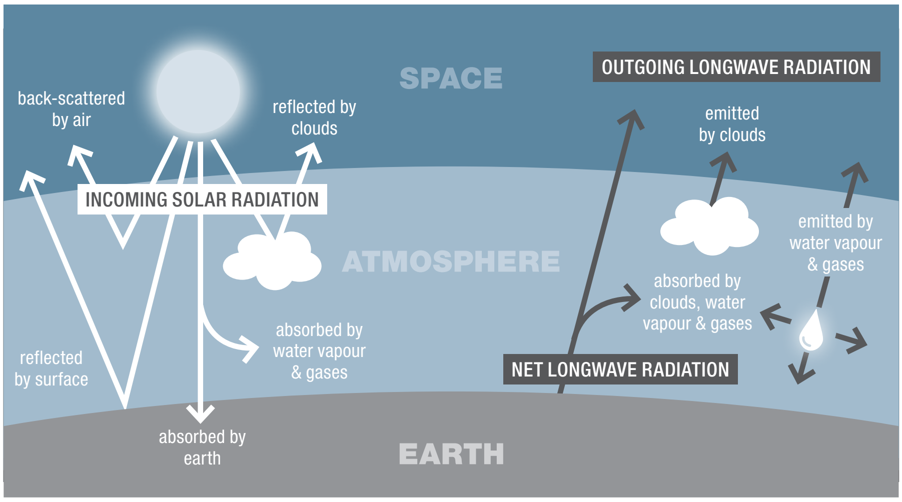
Evapotranspiration rates are also altered when vegetation is removed and replaced with an urban environment. Evapotranspiration is the sum of *evaporation* and *transpiration*: essentially the sum of water entering the atmosphere from the surface of the earth. Evaporation accounts for the movement of water to the air from sources such as the soil, forest canopy interception and bodies of water, such as lakes and oceans. Transpiration accounts for the movement of water within a plant, and the subsequent loss of water vapour through the leaves. Evapotranspiration acts to cool the surface because of the loss of latent heat – the energy used during phase change from liquid to gas. Evapotranspiration is generally decreased when vegetation is replaced with a cityscape – there are less transpiring plants, fewer opportunities for interception and runoff is increased because of the expansion of impervious surfaces. The reduction in evapotranspiration therefore contributes to the formation of a UHI.

1.3 Anthropogenic Heating: Heating as a Result of Human Activities

The third factor that causes UHIs is the increase in near-surface temperatures that is a result of human activities, for example, the heat produced from industrial processes, electricity generation and building and traffic heat loss.

The combination of heating at the surface and in the lower atmosphere can create an inversion layer which stops heat and other pollutants dispersing, this enhances the heat island effect and is a cause of smog (ozone) formation at the surface.

Figure 2: The Earth's Radiation Balance (adapted from Reference 2).



2. Consequences of Urban Heat Islands

In low- and mid-latitude cities such as Sydney, New York and London, increased local temperatures often lead to increases in energy demand for air-conditioning, particularly in the summer. This in turn places a strain on power delivery systems, and may result in the need for additional power generation sources. If power is generated using fossil fuels, then GHG and particulate emissions are also increased. Thermal comfort is also reduced inside buildings without air-conditioning and outside: there is evidence that heat-stress mortality and illness are higher in cities during the summer months than at other times of the year.

High pollution levels – particularly under inversion conditions – can also adversely affect human health. Infants, the elderly and those with respiratory or cardiac complaints are particularly vulnerable. High concentrations of pollutants can also affect the buildings themselves: deposition of acids (such as sulphur and nitrous dioxides) from the atmosphere, and soiling (black carbon deposition), have a corrosive effect on limestone, sandstone and marble structures. Acid deposition can also adversely affect the water quality of nearby lakes and rivers, and the animal and plants that live in them. The health of forested ecosystems can also be negatively affected: trees are weakened through leaf damage, nutrient limitation and the uptake of toxins from the soil.

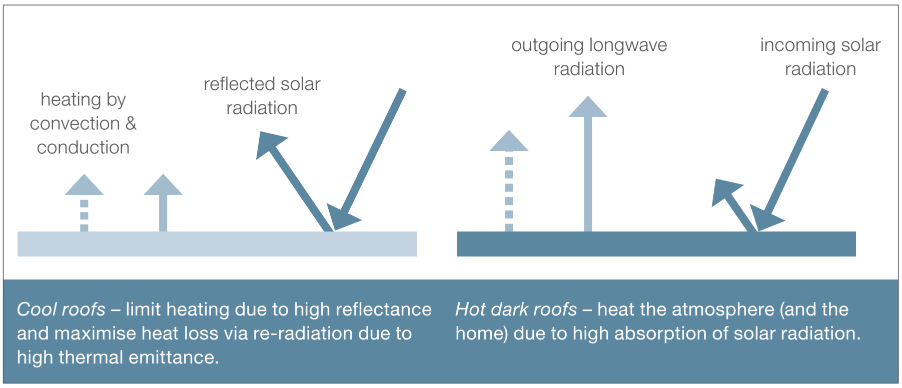
3. Mitigation of Urban Heat Islands

Increasing surface reflectivity (to reduce the amount of solar energy absorbed and converted to heat), and evapotranspiration (to cool the surface through latent heat loss), are two of the key strategies for reducing the intensity and longevity of UHIs.

Potential evapotranspiration can be increased by extending vegetated areas and reducing the amount of impervious surfaces. *Urban forestry* has been found to produce the greatest reduction in surface temperature per unit area, because of the increase in evapotranspiration and the additional shading of buildings and pavements[3]. Urban forestry includes *street-to-trees* i.e. curbside planting, and *grass-to-trees* i.e. open space planting. *Living roofs* i.e. *roof-to-grass*, also effectively increase evapotranspiration, particularly in areas with limited space at street-level. Green roofs do not, however, have as great an impact on energy demand because they afford no additional shading to buildings.

Replacing dark surfaces and roofs with *light surfaces* and *cool roofs* increases the reflectivity of the city. This is a very effective UHI mitigation strategy because more surface area can be transformed in this way than can be revegetated. For example, it is estimated that 64% of the surface area of New York City could be redeveloped to incorporate highly reflective surfaces, whereas only 17% of the city's surface could be planted[3].

Figure 3: Cool roofs v traditional dark roofs.



Cool roofs – limit heating due to high reflectance and maximise heat loss via re-radiation due to high thermal emittance.

Hot dark roofs – heat the atmosphere (and the home) due to high absorption of solar radiation.

3.1 Cool Roofs

Cool roofs can help reduce the intensity of UHIs, as well as maintain thermal comfort and minimise energy demand in buildings. Cool roofs have *high solar reflectivity*, and preferably, *high thermal emittance*. High solar reflectivity means that less energy is absorbed into the roof initially, thereby reducing the amount of energy that can be converted to heat and re-radiated as longwave radiation (*Figure 3*). This reduces the heat that can move from the roof to the atmosphere by convection and conduction – the surface temperature of a light-coloured cool roof can be up to 39°C less than a traditional dark coloured roof[1] – and limits the amount of longwave radiation that can interact with GHGs and heat the atmosphere.

High thermal emittance means that any energy that is absorbed into the roof is re-radiated from the building quickly (again increasing thermal comfort and minimising energy demand).

There are also financial benefits for building owners. Limiting the quantity of absorbed solar energy and reducing daily temperature fluctuations – which cause repeated contraction and expansion – can extend the life of the roof.

High solar reflectance and glare are not the same phenomenon, and in the case of cool roofs, high solar reflectance does not necessarily translate to increased potential for glare. While solar reflectance is important for thermal comfort, and can affect the local radiation balance, it is not always a good indicator of the visual attributes of the surface. The high solar reflectance required to create a cool roof is usually achieved by increasing reflectivity in the infrared part of the spectrum, which is not visible to the human eye, as well as using lighter colours (which may be perceived as brighter). A surface with high near infrared reflectance will have higher solar reflectance than a surface of identical colour (and glare potential) with low near infrared reflectance.

Glare is a function of a number of additional surface characteristics, as well as the position of the sun in the sky and observers on the ground. This means that where potential glare is observed it is a function of both season and time of day.

Because of surface roughness, most opaque surfaces in the built environment reflect both diffuse (reflection in all directions) and specular (reflection as per a mirror) light. Diffuse reflection is less likely to be perceived as glare by an observer. Therefore, consideration of the conditions under which specular reflection is likely to occur and be perceived to be a nuisance (based on time of day/year) is an important step in the design process to mitigate glare. Roof pitch, building orientation and configuration, and placement of fencing and vegetation can all play a role in reducing the potential for nuisance glare from a building[4].

3.1.1 BlueScope Steel Cool Roofs

In terms of energy efficiency, the Building Code of Australia (BCA) classifies roofs based on solar absorptance – the inverse of reflectance – expressed as a ratio between 0 and 1. Solar absorptance values are based on as-new/unweathered product. A value of 0 indicates that a roof absorbs none of the incoming solar radiation, whereas a value of 1 would mean that a roof absorbs 100% of the incoming radiation. For residential buildings (Class 1 and 10 buildings), three classes have been established: solar absorptance of less than 0.4; solar absorptance of between 0.4-0.6; and solar absorptance of more than 0.6 (referred to herein as *very light*, *light* and *dark* respectively). For commercial buildings (Classes 2-9), the BCA categorises very light as solar absorptance of less than 0.5; light as between 0.5 and 0.6; and dark as more than 0.6. BlueScope Steel produces a range of roof products with low solar absorptance (high reflectance). 16 products have a solar absorptance of less than (or equal to) 0.6 (*Table 1* and *2*): there are 9 products from the standard COLORBOND® steel range (which incorporates Thermatech® solar reflectance technology); five products from the COLORBOND® Metallic steel range; COLORBOND® Coolmax® steel; and ZINCALUME® steel.

Table 1: BlueScope Steel products in BCA low solar absorptance – light colour – categories for residential (Class 1 and 10) buildings.

PRODUCT	VERY LIGHT Solar Absorptance ≤0.4	LIGHT Solar Absorptance ≤0.6
Standard COLORBOND® steel	Classic Cream™	Paperbark®
	Surfmist®	Evening Haze®
		Shale Grey™
		Sandbank®
		Dune®
		Windspray®
		Pale Eucalypt®
COLORBOND® Metallic steel		Citi®
		Axis®
		Conservatory®
		Skybridge®
		Cortex®
COLORBOND® Coolmax® steel	Whitehaven™	
Metallic coated steel	ZINCALUME® steel	

Table 2: BlueScope Steel products in BCA low solar absorptance – light colour – categories for commercial (Class 2-9) buildings.

PRODUCT	VERY LIGHT Solar Absorptance ≤0.5	LIGHT Solar Absorptance ≤0.6
Standard COLORBOND® steel	Classic Cream™	Windspray®
	Surfmist®	Pale Eucalypt®
	Paperbark®	
	Evening Haze®	
	Shale Grey™	
	Sandbank®	
	Dune®	
COLORBOND® Metallic steel	Citi®	Axis®
		Conservatory®
		Skybridge®
		Cortex®
COLORBOND® Coolmax® steel	Whitehaven™	
Metallic coated steel	ZINCALUME® steel	

Typically, painted steel has higher thermal emittance than unpainted steel. So a light coloured roof made of COLORBOND® steel is not only likely to reduce the amount of solar radiation absorbed, but is also very effective at re-radiating heat. This means that the building may be cooler across the day, and cool down faster when the sun isn't shining, which helps reduce energy demand.

Overall a light coloured painted steel roof, on a building surrounded by trees – to provide shade and water movement to the atmosphere – is one of the best design scenarios to reduce the intensity and impact of UHIs.

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