

Designing Out the Urban Heat Island Effect

Karen Munro and Dr David Grierson
University of Strathclyde Glasgow



Figure 1. Pollution in city centre of Los Angeles (Photo from US Environmental Protection Agency)

RESEARCH

As the global population reaches an all time high and shows no sign of slowing, and the urban population outnumbers the rural population for the first time in human history, the social, economic and environmental issues faced by those living in urban centres become increasingly relevant. The urban heat island effect is a phenomenon witnessed in cities worldwide which sees the ambient air temperatures in cities be significantly higher when compared to temperatures in the rural surroundings. A number of characteristics of cities contribute to the creation of an urban heat island: the removal of vegetation to construct buildings and roads; the ability of materials such as concrete, asphalt, steel and brick to absorb, store and release heat; the energy used by a building's services including heating, air conditioning and ventilation; vehicular movement through a city; and general lack of green spaces. Essentially, urban heat islands are caused by the land use change from natural environment to built environment.

Urban heat islands are described by their intensity; the difference in temperature between the rural and the urban areas. Urban heat island intensities can be anywhere from 2°C to over 10°C and have been linked to a city's size and population. Since the effect was first recognised in 1810, urban heat island research has moved from establishing existence of the effect, to understanding its causes, and onto understanding its side effects. Research has proven that the weather in and around a city is affected by urban heat, with the effect being linked with increased rainfall, dangerous wind speeds, increased flooding, altered growing seasons, and even hurricanes and tornadoes. Urban heat islands also have a detrimental effect on people's health; they are thought to significantly increase the risk of fatalities during heat waves, as well as increasing levels of pollution thus reducing the quality of the air in the city. (Figure 1)

With the urban heat island effect well and truly established, its causes and side effects understood, research has moved to the mitigation of urban heat – how can cities be cooled?

It is at this stage that architecture's role becomes undisputable. The creation of the built environment is the main cause of the urban heat island effect, and so much of a city's identity and culture is reflected in and defined by its architecture – the sleek corporate skyscrapers of Manhattan, Gaudi's fairytale forms in Barcelona. Arguably, the ability to design out the urban heat island effect, and indeed the responsibility to do so, lies with architects and planners; they have a responsibility to the urban environment and the people living in it to understand the impact of their designs on people's health and lives.

Project Description

The project focussed on the urban heat island in Glasgow, which has twice been explored, with the first study being published in 1977 and the second in 2011. Both studies identified the presence of an urban heat island in Glasgow's city centre, and both concluded that the Merchant City area towards the east of the city centre was a notable hotspot. The endurance of the Merchant City as a point of interest in two Glasgow urban heat island studies carried out nearly 35 years apart produced an ideal setting for the research.

With the urban heat island in Glasgow established, the project began to address the role Glasgow architecture plays in creating the effect, and the possible opportunities those working in the profession have to help mitigate the effect. Numerous possible research routes were identified, from exploring the effect of building geometry to the effect of proximity to vegetation. The route selected was to study cladding material choice. Basic lab experiments were designed in order to establish how five cladding materials identified as being common to Glasgow reacted when exposed to prolonged heat, thus aiming to better understand the effect of each material on Glasgow's urban heat island.



Figure 2 - Ingram Street Cladding Materials

The lab experiments hoped to provide information which could allow architects, designers and planners to begin to comprehend how their cladding material choice could be affecting not just their building's appearance and internal air quality, but the external air quality of the immediate area and the entire city.

The selection of materials to be involved in the experiments was based on those materials present along Ingram Street, one of the Merchant City's main streets. In addition to being located in the centre of the well established urban heat island hotspot, Ingram Street is home to numerous architectural styles, construction types, building functions and cladding types and was therefore considered to be representative of Glasgow's architecture on a broader scale, allowing the opportunity for any results to be applied, in a general sense, across the whole city.

Experiment Equipment

A building cladding material study (Figure 2) was carried out in Ingram Street, and from this and knowledge and observation of Glasgow's architecture as a whole, five materials were selected to be used in the experiments. The materials are among the most common cladding materials in Glasgow and were therefore the most beneficial to study: red sandstone, blonde sandstone, concrete, red brick and toughened, structural glass.

A frame was constructed to hold the materials and heat lamp. The frame was fully adjustable; the height, width, distance to heat lamp could all be altered as well as the heat lamp's height, allowing the heat to always be aimed exactly in the centre of each material. The heat source for the experiment came from a 75W infrared heat lamp, encased in a heat resistant lamp fitting. The lamp was fixed precisely in the centre of the frame horizontally, and was adjusted vertically as required.

Experiment Methodology

The experimental process was as follows:

1. Three thermometers (T1, T2 and T3) were calibrated to ensure maximum accuracy. All were switched on and allowed to settle at room temperature, with the experiment only beginning when all thermometers registered the same ambient air temperature.
2. While the thermometers were calibrating, the frame was prepared. The material to be tested was fixed to the frame. When in place the heat lamp was adjusted to ensure it was exactly 30cm away from the front face of the material. The lamp was then adjusted vertically to ensure it was aimed at the centre of the material. (Figure 3)
3. Once the thermometers were calibrated, they were fixed into place. T1 was used to monitor the ambient air temperature to ensure it remained as constant as possible, and was positioned at the other side of the room from the heat source so as to be unaffected by it. T2 was used to measure the surface temperature of the material and was fixed to the front face using tape. Finally, T3 was used to monitor the alterations in the air temperature immediately in front of the material, and was placed 5cm from the front face. (Figure 4)
4. The starting temperatures of all three thermometers were recorded before the heat lamp was switched on. Readings were then taken from each thermometer every 20 minutes for the following three hours while the material was exposed to the heat. (Figure 5)
5. After three hours, the heat lamp was switched off. Readings continued to be taken every 20 minutes for a further three hours to monitor each temperature as the material cooled.
6. The material was removed from the frame, and the thermometers allowed to return to room temperature before the experiment was repeated with the next material.



Figure 3 - Experiment Setup



Figure 4 - Thermometers T2 and T3 in place

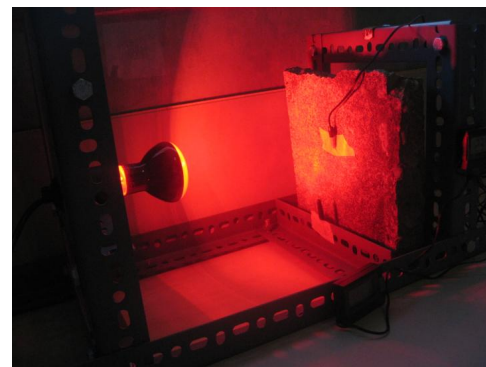


Figure 5 - During experiment

Temperatures (°C)

Time (Mins)	Concrete			Red Brick			Red Sandstone			Blonde Sandstone			Glass		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
0	19.5	19.6	19.4	21.1	20.9	20.9	20.8	20.5	20.6	21.6	21.4	21.7	20.7	20.7	20.7
20	19.9	36.8	31.2	21.2	37.8	35.9	20.8	37.3	34.3	21.6	40.7	35.6	20.7	35.3	30.7
40	20.0	40.1	32.2	21.2	38.5	35.9	20.9	40.6	35.4	21.6	44.4	36.7	20.8	36.0	31.0
60	20.2	42.5	33.0	21.2	40.2	36.7	20.9	42.2	35.9	21.6	46.4	37.5	20.8	36.3	31.3
80	20.5	44.6	33.8	21.3	40.9	37.0	21.0	43.5	36.4	21.6	46.4	37.5	20.9	36.6	32.3
100	20.6	45.9	34.1	21.3	41.6	37.4	21.0	44.3	36.5	21.7	46.5	37.5	21.0	36.7	32.3
120	20.7	47.1	34.4	21.4	42.0	37.8	21.1	44.9	36.7	22.0	46.5	37.9	21.0	36.9	32.2
140	20.8	47.9	34.9	21.4	42.4	38.1	21.1	45.6	36.8	21.9	46.9	38.3	21.1	37.0	32.3
160	21.0	48.5	35.2	21.4	42.5	38.2	21.2	45.6	36.8	21.9	47.1	38.1	21.1	37.1	32.3
180	21.1	49.3	35.6	21.4	42.5	38.3	21.2	46.2	36.8	21.8	47.2	38.3	21.2	37.2	32.4
20	21.1	33.1	24.5	21.4	28.6	24.1	21.2	32.0	25.7	21.7	31.8	25.8	21.2	23.1	23.1
40	21.2	30.5	23.7	21.4	26.2	23.0	21.2	27.8	24.1	21.7	27.2	24.0	21.2	22.1	22.1
60	21.3	28.5	23.2	21.4	25.0	22.5	21.2	25.9	23.3	21.7	25.0	23.0	21.3	21.6	21.7
80	21.3	27.1	23.0	21.4	24.0	22.1	21.2	24.3	22.6	21.6	23.7	22.4	21.3	21.3	21.4
100	21.5	25.7	22.7	21.4	23.4	21.9	21.2	23.1	22.1	21.5	22.7	21.9	21.3	21.2	21.2
120	21.5	25.0	22.5	21.4	23.0	21.8	21.2	22.5	21.8	21.5	22.2	21.6	21.3	21.1	21.1
140	21.5	24.4	22.4	21.4	22.3	21.5	21.2	22.0	21.6	21.5	21.9	21.5	21.2	21.0	21.0
160	21.5	23.8	22.2	21.4	22.2	21.5	21.3	21.7	21.4	21.5	21.7	21.3	21.3	21.0	21.0
180	21.5	23.3	22.0	21.4	21.8	21.3	21.3	21.6	21.3	21.4	21.5	21.2	21.2	20.9	20.9

Table 1 - Temperature Readings Results

Results

The readings from T1, T2 and T3 were recorded every 20 minutes during the heating and cooling periods and can be seen in Table 1. Concrete recorded the highest surface temperature by the end of the heating period, at 49.3°C. The near surface air temperature was relatively low at 35.6°C.

Red brick had one of the lowest surface temperatures recorded at 42.5°C but the highest near surface air temperature 38.3°C. Both the red sandstone's surface temperature and near surface air temperature fell in the middle of the temperature extremities recorded for concrete and toughened glass; the surface temperature peaked at 46.2°C while the air temperature reached 36.8°C after 120 minutes and remained there until the end of the heating period.

The blonde sandstone very quickly recorded high surface temperatures, reaching over 46°C in the first hour before levelling and only increasing by another 0.8°C by the end of the heating period. The near surface air temperature rose much more steadily and peaked at 38.3°C, the joint highest recorded in the experiments.

Finally, the toughened glass registered very little increase in either surface temperature or near surface air temperature, with both rising by less than 2°C and falling almost immediately after the heat lamp was switched off.

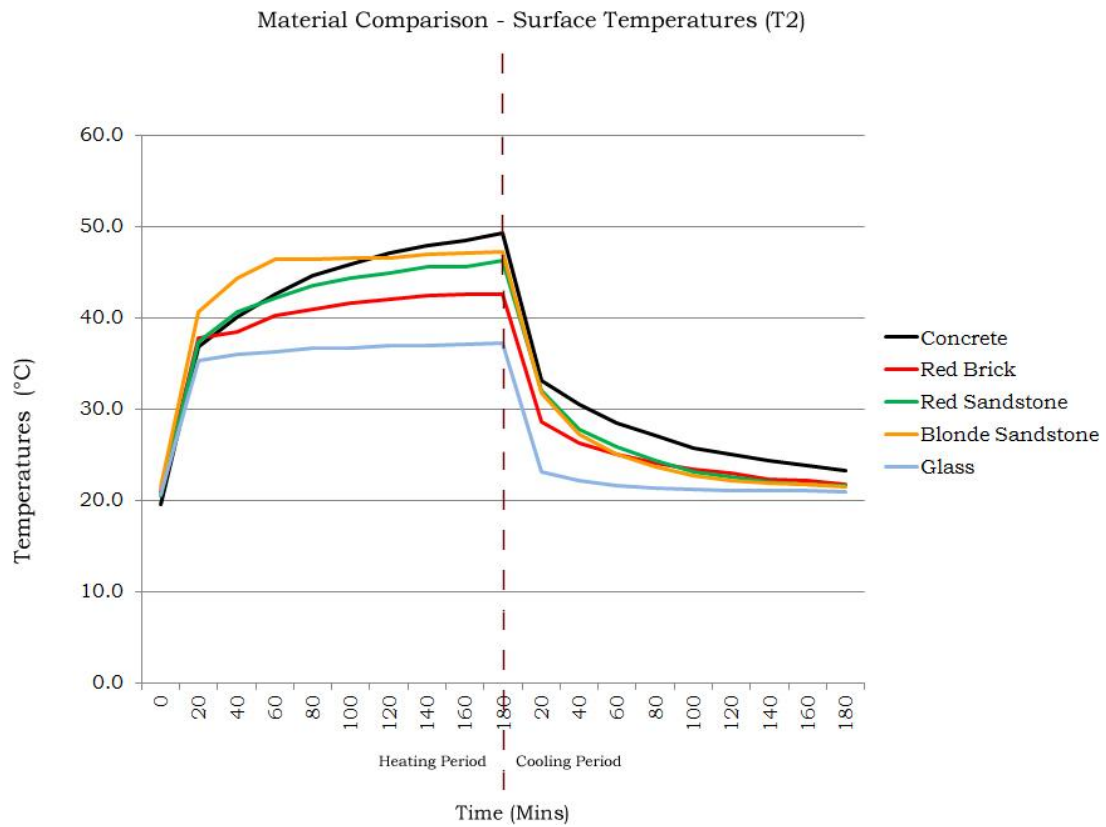


Figure 6 - All Materials Surface Temperature T2 Results

Discussion

Figure 6 compares the surface temperature (T2) results for each material during both the heating and cooling period, while Figure 7 shows the near surface air temperatures (T3). The concrete behaved as would be expected of a material of such mass, absorbing and storing heat during the heating period thus explaining the high surface temperature yet low near surface air temperature.

During the cooling period the heat stored was released hence the near surface air temperatures during cooling remaining high and not returning to ambient air temperature. Both the surface temperature and the near surface air temperature were still rising steadily at the end of the heating period, thus suggesting the concrete would have continued to heat up had the heat lamp not been switched off.

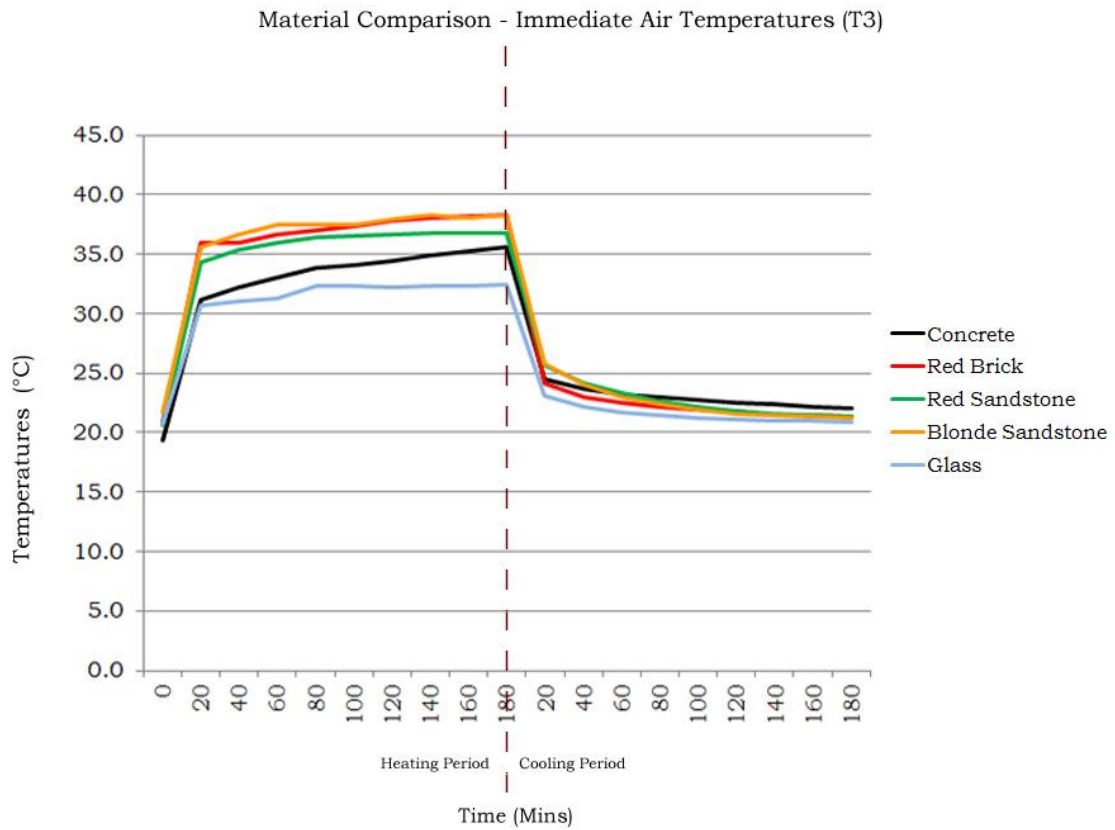


Figure 7 - All Materials Air Temperature T3 Results

The red brick results proved surprising: instead of absorbing heat, as it was thought it would due to its relatively dark colour and mass, it actually recorded low surface temperatures and high near surface air temperatures, thus suggesting the red brick was actually reflecting a significant amount of heat.

The red sandstone was expected to reach higher temperatures than the blonde sandstone as the latter was a lighter colour and therefore more like to reflect heat; in reality the blonde sandstone reached high surface temperatures very quickly, suggesting it was in fact absorbing heat instead of reflecting it. Contrastingly, the surface temperature of the red sandstone remained cooler.



Figure 8 - Ingram Street Predicted Microclimate

The blonde sandstone recorded both high surface temperatures and high near surface air temperatures, with an interesting trend: the surface temperature rises very quickly before levelling out, where the near surface air temperature experienced a sort of plateau in the initial stages of the heating period before rising again towards the end. This was taken to suggest that the blonde sandstone reached a sort of saturation point of heat absorption before beginning to reflect excess heat, explaining the near surface air temperature's increase towards the end.

The toughened glass was barely influenced by the heat lamp, heating up a very small amount before cooling very quickly – in many ways the ideal material to combat urban heat. However the material would not work as a mass cladding material in Glasgow's climate as it would allow too much heat in during the warmer months, and would let too much heat out during the winter.

Implications on Glasgow's urban heat island

The results of the experiments support the urban heat island research completed in Glasgow to date.

Ingram Street was chosen as the focus for the experiments due to its location in the Merchant City, an area which had shown up in both the 1977 and 2011 urban heat island studies to be a significantly warm area of the city. The building cladding material study carried out showed a majority of the buildings along the street were blonde sandstone, with a significant cluster of red brick buildings and very few buildings clad in glass or red sandstone. With the results of the experiments proving blonde sandstone and red brick produce the highest air temperatures, it could be said fairly confidently that this research and these experiments begin to explain why this particular area of the city centre consistently features in urban heat island studies as a hotspot. The Predicted Microclimate diagram (Figure 8) represents the temperatures along Ingram Street as suggested by the results of the experiments, with red hotspots positioned at the buildings which are clad in the two materials which recorded the highest near surface air temperatures, blonde sandstone and red brick. The diagram and adjacent photographs show how the majority of buildings on Ingram Street are clad in these materials, while only four buildings are clad in the materials which recorded the lowest air temperatures, concrete and glass.

Future Research

The experiments carried out were just the first step in addressing the role of architecture in creating and mitigating the urban heat island effect and the results provide numerous potential future research routes, not just in Glasgow, but in cities worldwide. For example, some of the unexpected experiment results could be further explored such as the blonde sandstone becoming hotter than the red, or the surprisingly low temperature of the red brick. Other types of glass and brick could be tested, or the experiment extended to include more materials thus building up a full understanding of Glasgow's cladding materials. In addition to the questions raised by this particular set of experiments, research routes into other architecture related factors with the potential to influence urban heat islands could be explored. For instance, does a curved facade absorb and retain heat any differently to a flat facade? How do modern buildings compare to older buildings in terms of absorbing, retaining and releasing heat?

As the world grows increasingly urban, the urban heat island effect will only become more prevalent, and the ability - and indeed the responsibility - for architecture to significantly contribute to its mitigation will grow. As the natural environment continues to make way for the built environment throughout the world, the decisions architects, designers and planners make regarding these new roads, buildings and cities will hugely affect the quality of life for the people living there, from the air they breathe to the energy bills they pay to the weather they experience. Knowledge is the key: only through knowledge of the urban heat island effect, understanding of its causes and side effects, and awareness of how it can be addressed can any real difference be made and it is for this reason that architecture must begin to understand, accept and address its role in these mitigation efforts, through continued research and education