Assessment of International Urban Heat Island Research

Review and Critical Analysis of International UHI Studies

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Navigant Consulting, Inc
8000 Towers Crescent Drive, Suite 350
Vienna, VA. 22182

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Marc Lafrance.

Program Manager – Urban Heat Islands

EE-2J / Forrestal Building

U.S. Department of Energy

1000 Independence Avenue SW

Washington D.C. 20585-0121

Email: Marc.Lafrance@ee.doe.gov

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List of Acronyms and Abbreviations

A/C.....Air Conditioner
ACEEE..... American Council for an Energy Efficiency Economy
AHS .....American Housing Survey
ASHRAE.....American Society of Heating, Refrigerating & Air-Conditioning Engineers
BEM ..... Building Energy Analysis Model
BT .....DOE Building Technologies Program
C .....Celsius
CAM_x ..... Comprehensive Air Quality Model with Extensions
CFD .....Computational Flow Diagram
CM .....Urban Canopy Model
CO .....Carbon Monoxide
CO_2 .....Carbon Dioxide
CRRC .....Cool Roofs Rating Council
DCS .....District Cooling System
DOE .....Department of Energy
EPA ..... Environment Protection Agency
EU .....European Union
g/kg ..... Grams per kilogram
GA .....Genetic Algorithms
GCM ..... General Circulation Model
GHG..... Green House Gas
GIS ..... Geographic Information System
GLA .....Greater London Authority
GPS .....Global Positioning System
Gt..... Gigatonne
GW .....Giga Watt
GWh..... Gigawatt Hours
IECC.....International Energy Conservation Code
K .....Kelvin
L/day..... Liters per day
LANDSAT..... Data from earth observing satellite program
LBNL .....Lawrence Berkeley National Laboratory
LEED..... Leadership in Energy and Environmental Design
LES.....Large-eddy Simulation
LUMPS .....Local Scale Urban Meteorological Parameterization Scheme
MS^{-1} .....Meters per second
MJ .....Mega Joule
MM5 ..... Mesoscale Meteorological Model

uMM5 .....Meso-urban Meteorological Simulations
MRT .....Mean Radiation Temperature
NO_2 ..... Nitrogen Dioxide
NO_x ..... Nitrogen Oxide
O_3.....Ozone
PM..... Particulate Matter
PPB..... Part Per Billion
SET ..... Standard Effective Temperature
SMUD ..... Sacramento Municipal Utility District
SO_2 .....Sulphur Dioxide
SRP.....Solar Reflective Paint
SVF..... Sky View Factor
SVR .....Sky View Ratio
TAPM .....Air Pollution Model
UAM-V ..... Urban Air Shed Model
UHI ..... Urban Heat Island
UHII..... Urban Heat Island Intensity
UN.....United Nations
USDA..... United States Development Agency
USGBC..... United States Green Buildings Council
Wm^{-2} ..... Watts per square meter

Useful Conversions

1 Gt	= 1 billion tonnes
1 GWh	= 1 billion watt hours
1 MJ	= 1 million joules
1 TWh	= 1 billion (109) kWh
1000 TWh electricity	= 3.412 quads delivered electricity
1 quad delivered electricity	= 3.211 quads primary energy

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) has funded this project with the overall objective to support the Secretary's initiative on cool roofs through a review of international literature on urban heat islands (UHI) and the identification of a panel of scientific experts to develop a research priority plan founded on the findings from this research study. The study is desk based and is composed of two principal tasks.

The first was to collect, review and critically analyze the international UHI literature published in the past two decades with the scope of identifying the potential to save energy and CO_2 through implementation of UHI countermeasures; summarize the documented understanding of the opportunity for scale-up national and international UHI mitigation efforts; review of the UHI countermeasures in various climates examining where the value of the energy savings justify the implementation of mitigation efforts or if incentive schemes are required; assessing the urban planning issues and how they affect the deployment of UHI countermeasures; and finally developing a set of recommendations on the next steps required to support the development and deployment of the UHI mitigation efforts. The second task was to identify the most prominent scientific leaders in the UHI field to serve on an international scientific panel that will develop a research priority plan to validate the CO_2 mitigation potential of cool roofs as well as debate the recommendations emerging from this study.

The research conducted has reviewed a total of two-hundred and thirty-eight papers across the entire UHI value chain with the greatest interest (descending order) from the following continents: North America, Asia, Europe, Australia, and Africa. The predominant focus was in warm, arid and equatorial climate types with a majority of the seminal studies relating to UHI emanating from the Lawrence Berkley National Laboratory, UHI Group.

The UHI phenomenon itself was well documented and universally interpreted by all research groups. It is apparent that the focus of climate on the global scale has shifted from the global to local scale with most of the research groups and studies addressing the urban climate. The research conducted to identify the UHI causal factors and measuring the impact of UHI clearly demonstrates that the impacts have greater implications than simply temperature increases. The research in this field was found to be comprehensive in identifying the causal factors; however, their collective interaction upon the urban heat island as a system appears to be less well understood.

The studies that used modeling and simulation were found to be a useful method for modeling individual buildings/cities experiencing the UHI phenomena and in evaluating UHI mitigation countermeasures. Much of the focus appeared to be on the micro (single building) to macro (city scales) with great emphasis on the micro-scale phenomena, it was however, noted that such models were often highly constrained to effectively break free from the micro scales, and in certain cases under developed to cope with the macro/global scale required to produce accurate mass UHI countermeasure assessments. It was demonstrated that the modeling and simulation of mitigation scenarios is an important step in regulatory planning as it acts as a low cost, low risk test of the effectiveness of the mitigation technology.

The mitigation technologies were found to possess great capabilities in addressing many of the UHI impacts and in generating significant financial savings as-well-as various environmental benefits which also often translated into financial savings. The studies however, indicated the requirement for more data, refined models and most importantly the need for empirical testing in the form of mass implementation programs. Furthermore, the mitigation studies demonstrated the need for collaboration within and across nations to promote, advance and deploy technologies and strategies to address global warming – evident was the fact that significant synergies between global warming mitigation strategies (at the global scales) and the UHI strategies (at the micro/local scales) exist.

It was clear that both the negative radiative forcing and direct/indirect effect principles examined by the literature demonstrate that the UHI countermeasures have significant potential to mitigate global warming impacts. The simple estimates developed back claims made in the literature indicating that the negative radiative forcing effect has a greater mitigation potential than the direct/indirect effect methods. Although both methods demonstrate significant mitigating potential there is still the need for continual research efforts to realize these potential benefits but that greater emphasis should be placed on exploring the sizable benefits that can be achieved through the mass implementation of the high albedo surfaces that induce the negative radiative forcing effect.

The evidence assessed regarding the potential for energy savings and mitigation efforts from countermeasures to urban heat islands presents a mixed picture. There are clearly cost effective energy and CO_2 savings to be delivered in many circumstances, however, still much uncertainty remains about the overall magnitude of those savings and about how feasible it is to access them through public policy initiatives. The recommendations made in this report reflect this pattern and are divided into research based and policy/programmatic recommendations.

Despite existing uncertainties about the overall magnitude of savings that can be accessed through public policy driven UHI countermeasures the latter are still justified in many cases because the uncertainties are not so great as to require the delay in measures within urban areas that clearly stand to derive significant benefits from commencing ameliorative actions. Furthermore, the apparent potential scale of mitigation impacts from countermeasures targeting negative radiative forcing are so large that they justify a significant policy and research effort to clarify the phenomena and respond with policy efforts if the mitigation scales are validated.

1 INTRODUCTION

This investigation seeks to provide an assessment of all international urban heat island (UHI) research and identify the leading global researchers that will convene to discuss the emerging issues and develop a research priority plan that will help validate the CO_2 mitigation potential of the key mitigating technologies. This study examines and identifies the salient findings across all the UHI literature collected concerning UHI mitigation potentials and related techno-economic factors. It seeks to identify not only the current status across the entire UHI value chain but also to identify gaps in relevant research conducted to date thus helping identify a set of recommended priority areas for policy and research. Due to the nature of the research and the significance of the geographical location and climate type each source is examined for its regional significance and transferability of findings. For each study, we also summarize key data, including the author, publication date, journal, areas of research addressed and the key outcomes.

The structure of the report, in alignment with the objectives of the investigation, is as follows:

Chapter 2, Evidence of Urban Heat Islands: reviews the key papers which examine the fundamental causal factors to the observed urban heat island phenomena and how the literature measures the magnitude of the UHI impacts.

Chapter 3, Quantitative Modeling and Simulation of Urban Heat Islands: This section provides an insight into the modeling and simulation tools which are used to evaluate the urban heat island phenomena and mitigation technologies/strategies. The models are classified by what they simulate: temperature; air quality; energy consumption; and mitigation strategies (surface albedo, green roofs and urban green areas, and urban form & planning).

Chapter 4, Mitigation of Urban Heat Islands: This section provides a review of the literature gathered on the urban heat island mitigation technologies and strategies and summarizes the salient points from these studies. The studies reviewed have been collected from across the globe and seek to highlight the mitigation potentials of the technologies, their current status and the related techno-economic factors applying to both existing and newly built urban environments. The papers are categorized and reviewed as follows: Energy/Peak Power/CO_2; Economic Assessment; Policy/Strategic Assessment; Technologies; Implementation Issues; Urban Design/Planning; and Environmental Assessment - for each of these sections the underlying principles, a summary and the salient points from the literature review follow. In the case of the key mitigation technologies it provides an overview of the current status of the policy and a critique focused on identifying the limitations and research gaps in the existing studies.

Chapter 5, Critical Review of Urban Heat Island Countermeasures: This section provides a critical analysis of the studies and the opportunities for scale-up efforts leading from local to national and national to international efforts. This analysis examines the two principal methods in which the UHI countermeasures mitigate global warming impacts; provides a critical review of the policy actions for each of the key mitigating technologies, highlighting the current status across the globe, barriers to scale-up, the reach and level of implementation of these policies and

a forward path; provides an economic review/analysis to identify the climates where energy savings alone justify the mitigation efforts and where incentive schemes may be required to justify their implementation; a high level analysis of the barriers and catalysts that may hinder the mass adoption of urban heat island strategies and technologies; and concludes by examining the urban planning issues and how they affect the deployment of the urban heat island countermeasures.

Chapter 6, Recommended Priority Areas: This section puts forward proposals for the key priorities for policymakers who have the potential to put in place policy portfolios influencing UHI countermeasures at the national, local and international level. It also provides a set of research recommendations for the direct/indirect mitigation methods and those that address mitigation through negative radiative forcing.

Chapter 7, Global Scientific Panel: This section proposes a high level scientific panel that will be equipped to discuss the identified emerging issues and develop the research priority plan that will help validate the CO_2 mitigation potential of cool roofs and pavements.

Chapter 8, Conclusion: Highlights the key findings and recommendations evolving from this investigation.

Bibliography: Lists, categorizes and identifies all the studies collected and reviewed in the assessment of international urban heat island research.

2 EVIDENCE OF URBAN HEAT ISLANDS

There are two types of urban heat islands, surface and atmospheric, UHI are a combination of a number of factors, some controllable and some uncontrollable. They are generally measured by air and surface temperatures, which can vary from city to rural area by up to 5°C.

The factors that contribute to the creation of an UHI are: Population size and density - studies have shown that as population increases annual temperatures in the city increase exponentially; thermal properties of building materials - buildings are commonly made from materials that conduct solar radiation during the day; radiative building materials - the heat conducted diurnally is released at night thus raising temperatures; Geometric effects of urban design - urban canyons are created by narrow streets and tall buildings, they decrease wind speeds and increase reflective surfaces which traps heat, which due to the decreased wind speeds cannot be dissipated; anthropogenic factors - waste heat from vehicles and buildings; altered land surface cover - the land that was once porous vegetation is replaced with non-porous materials thus restricting evaporative cooling and water run-off on the surface.

This section seeks to review the key papers which examine the fundamental causal factors to the observed urban heat island phenomena and their relative magnitude. The table to follow summarizes these classes of causal factors, the origin of the papers and the climate types considered.

2.1 Causal Factors

Causal Factors	Number of References	Continent Considered	Climate Types Considered	List of references
Population size/density	5	North America, Asia	Snow[1], Warm temperate	114, 119, 118, 116, 007
Land/Building Material Thermal and Radiative Properties	9	Asia, Europe, Australia, North America	Warm temperate	139, 078, 001, 098, 043, 116, 127, 023, 014
Anthropogenic Heat Sources (cars, air conditioning, industrial processes, power plants, etc.)	6	North America, Asia, Europe, Australia	Warm temperate	124, 125, 126, 038, 092, 137
Geometric Effects of Urban Design and Sky View Factor (SVF)	7	Asia, Europe	Warm temperate	118, 120, 122, 123, 116, 078, 121

There are 14 papers that discuss the causal factors of Urban Heat Islands (UHI). Of these papers the regional studies took place over five continents; Asia, Africa, North America, Europe and Australia and four climate types, warm temperate, arid, snow and equatorial.

[1] We use the Köppen Climate Classification system to identify climate type in this paper. Köppen's main climate types are: A: Equatorial, B: Arid, C: Warm Temperate, D: Snow, and E: Polar.

2.1.1 *Population Size/Density*

Population is a good indicator to express the character and features of a city [116]. The United Nation's (UN) World Urbanization Prospects: 2007 Revision Population Database measured the urban to rural population spread to be 30% in 1950, 49% in 2005 and predicts a rise to 55.6% in 2010 [151]. With more than half of the world's population living in cities, the impact on the environment will be significant.

The earth's surface has changed significantly due to urbanization and industrialization which in turn has created urban climates, Yamashita [116], due to the increase in population; vegetative surfaces have been replaced with manmade impervious surfaces in the form of high density residential and commercial areas. The modifications to the earth's surface caused by an increase in population indirectly affect the radiation, heat and water balance of an area. Population density, has a direct effect on heat generation in that the more people there are, the more energy they consume and that consumption leads to heat emittance [007].

A number of studies have considered the relationship between population and heat island intensity and concluded that a direct correlation can be identified [114]. The studies look at a route that covers 10 settlements of varying sizes, measured by population, and temperature recordings were made along the route. Oke's, study [114] concluded that there was a correlation between the intensity of an urban heat island and the size of the city.

A study by Brian Stone [119] said that residential areas with low density housing with higher spatial distribution contribute more to the production of an urban heat island effect.

Sailor [124], in his study of anthropogenic heat flux in six US cities found that results were substantially lower for those cities with lower population density. Atlanta and Salt Lake City had maxima winter values of less than 15 Wm^{-2} compared to Chicago, San Francisco and Philadelphia's maxima values of between 65-75 Wm^{-2}.

Limitations; Oke's model assumes similarities between settlements and does not take into account geographical variations in latitude and unique settlements like airports that can have their own unique UHI.

Intensive urbanization on small areas of land limits the progression of further urbanization because there simply will not be any land left to build on, so the results, if population continued to be monitored would become less significant [114]. Another factor influencing further comparisons is that a convergent thermal breeze circulation is created in large UHIs which creates a cooling effect.

Another theory is that because there are so many other variables involved in the increased heat content of an area, population alone should not increase the heat contents of an area [007].

2.1.2 *Land/Building Material Thermal & Radiative Properties*

Another effect of urbanization is that land surface cover changes as buildings are constructed and replace vegetation. This affects the surface energy balance of the land. Common building materials affect UHI in the following manners, through their solar reflectance, thermal emissivity

and heat capacity [078]. Solar reflectance or albedo is generally low in urban materials so they reflect less and absorb more energy thus increasing temperatures at surface level. Thermal emittance describes the process of how materials release heat back into the atmosphere, generally more common buildings materials have high emittance values meaning they release heat quickly and stay cooler. Heat capacity, common building materials such as tar, asphalt, brick and concrete [001] store solar energy during the day and release it at night, so UHI intensity is often reported to be stronger at nighttime [098, 078, 014, 139].

In a study by Asaeda surface level heat flux was measured for a number of different materials, the study found that asphalt had much higher levels of heat capacity and thermal emissivity than concrete and soil. Asphalt emitted an additional 150 Wm^{-2} in infrared radiation and 200 Wm^{-2} in sensible transport to the results for bare soil [127].

There is an inverse relationship between latent heat flux and increased vegetation cover. Offerle et al studied turbulent heat flux in Lodz, Poland by measuring turbulent fluxes, radiative flux, temperature and humidity, water vapor flux, carbon dioxide and net radiation. They also found that sensible heat flux was positively related to impermeable land cover and building density. Offerle's work could be applied to other cities, but vegetation type should be considered as some species are non-transpiring [043].

The roughness of the building material is often commented upon in papers and experts agree that roughness of building materials means they are more thermally conductive, one study also showed that the correlation between roughness and air temperatures was stronger during the night than the day time [116].

Alonso et al studied the UHI of Salamanca, Spain, as part of their study they considered the intensity of a nocturnal heat island in relation to the surface material. They used a grid system around the temperature apparatus based on the size of the city and categorized the surface into percentages of asphalt, buildings, water and green areas. They found that maxima temperatures were recorded over areas with a higher percentage of urbanization/building cover, the opposite was found for areas with a higher percentage of green cover [023].

2.1.3 Anthropogenic Heat Sources

Anthropogenic heat is described as heat that is generated from stationary or mobile sources in an area, in most studies this relates to air conditioning, industrial processes, power plants, buildings, vehicles and people [007]. Anthropogenic heat is usually measured in Wm-2 and many papers have been produced on this study. Five papers were examined and were undertaken in North America, Asia, Europe and Australia, all studies were in warm temperate climates, however, the results of the studies differ. Generally values are higher in the winter season in colder climates as heating loads are heavier.

Sailor splits his findings into three components, building sector, transportation sector and metabolism based on population density, profiles were developed to take into account the

workday effect and weekends. Studies were undertaken in six large US cities. He found summertime maxima up to 60 Wm-2 and winter maxima up to 75 Wm-2. Limitations in this study were that using Census as a tool for obtaining population figures does not take into account those that travel in for work from outside the study area, therefore daytime figures for population will often be larger [124].

Offerle looked at the surface energy balance of a European City for a two year period, they estimated anthropogenic heat through residual readings from net heat storage. Results were maximas of 32 Wm-2 from October to March and -3 Wm-2 from June to August. Negative value indicates the underestimation of turbulent fluxes [125].

Simmonds analyses data from the daily values of maximum and minimum temperatures, rainfall and some pollution data over a 134 year period. They found that the only variations to have taken place were in the winters of the most recent period 1964-1990 where maximum and minimum temperatures were greater on weekdays compared to weekends, rainfall was also found to be greater on weekdays [126].

Ichinose et al studied energy consumption in central Tokyo over variable land, he used energy use statistics, land use data and numerical modeling. He found that heat flux exceeded 400 Wm-2 in daytime, and the maximum value was 1590 Wm-2 in winter of which 51% was from hot water supplies. In winter, office energy demand peaked at 9am and reduced throughout the day, hotels had a larger demand at nighttime and demand in the residential sector had two peaks, at 8am and 9pm. In the summer daytime space cooling demand was constant but peaked at nighttime in the residential sector at around 9pm. Ichinose concluded that the near surface temperature in Tokyo could be reduced by a maximum of 0.5°C if the energy demand for hot water was reduced by 50% and space cooling by 100% [038].

A Chinese city with a dense population produces 37.87 x 10 Mega Joule daily [137].

2.1.4 *Geometric Effects of Urban Design and Sky View Factor*

Urban geometry refers to the dimensions and spacing of buildings in a city [078]. Tall buildings and narrow streets create urban canyons which affect wind speeds, energy absorption and heat emissivity. Also densely arranged buildings allow only low winds thus heat and air pollutants aren't as easily dispersed [157].

Oke discusses urban geometry and its effects on solar radiation and identifies two factors, albedo and solar access. Building materials with a low albedo will absorb solar radiation and store heat, solar access means building interiors that are sunlit benefit pedestrians on comfort and psychological levels [121].

Sky view factor is defined as the ratio of the area occupying the sky view to the whole sky area [118]. There are a number of ways it can be measured: scale model, analytical method – estimation by graphics, computer analysis of photography using a fisheye lens, evaluation of GPS

signals and computer evaluation of a 3D database [120]. Dense buildings patterns lock heat into the area without winds to dissipate it.

Yamashita took controlled sky view factor (SVF) readings from a number of locations and recorded the air temperature also, he found that in all cities as SVF decreased air temperatures rose, he also mapped SVF against heat island intensity for day and night time temperatures, this showed that the daytime temperatures showed stronger correlation to minimum SVF. Because of these studies sky view is considered a causal element of an urban heat island [118].

Blankenstein and Kuttler studied urban geometry and its effects on air temperature and downward long-wave radiation and found that the interrelation between SFV and long-wave radiation was very strong but was weak with air temperature, they concluded that air temperature was influenced by many other factors and thus was very challenging to predict using SVF alone [122].

Jusuf's analysis on a green Singapore estate when studying SVF and its affect on air temperature found there was a strong correlation in day time temperatures but a weak correlation in night time temperatures [123].

Yamashita discusses Sky View Ratio (SVR) as the ratio of wall height to street width to calculate urban canyons, he believes SVR is a better measure of air temperature in the urban canyon as it takes into account the heat flows from all directions [116].

2.2 Measured Impacts

Measured Impacts	Number of References	Continent Considered	Climate Types Considered	List of references
Temperature Increase	13	Asia, South America, Europe	Equatorial, Arid, Warm temperate	078, 047, 145, 137, 138, 022, 143, 144, 146, 147, 096, 148, 157
Air Quality	9	North America, Africa, Asia	Equatorial, Arid, Warm temperate	078, 157, 141, 136, 140, 039, 139, 135, 014
Energy Use	11	Asia, North America, Europe	Equatorial, Arid, Warm temperate, Snow, Polar	078, 155, 153, 154, 150, 149, 080, 112, 152, 151, 157
Peak Power	4	North America	Warm temperate, Snow	168, 169, 170, 171
CO_2 Emissions	10	North America, Asia, Europe	Arid, Warm temperate, Snow	167, 163, 165, 166, 162, 159, 158, 164, 132, 133
Health Impacts	6	Europe, North America,	Arid, Warm temperate	078, 117, 129, 133, 132, 131, 174
Economic Impacts	5	North America	Warm temperate	173, 172, 175, 080

Some UHI impacts are positive such as increased growing seasons for plants, but most are negative. Increased air temperatures can cause or exacerbate poor air and water quality, impaired health and psychological conditions, increased energy consumption and negative impacts on the economy such as agricultural losses, impacts to tourism and financial losses due to increased extreme weather events [078].

The following papers review the literature found in this area, the papers are categorized into impacts on: temperature; air quality; energy use; peak power; CO_2 emissions; health; and the economy.

2.2.1 *Temperature Increase*

The urban heat island effect is quantified by rises in air and surface temperatures in urban areas compared to the surrounding rural areas. Increased temperatures make city living more uncomfortable and when nighttime temperatures rise it can affect or even inhibit sleep. High temperatures in extreme circumstances such as heat waves can cause death. Rising temperatures boost energy consumption due to the demand for cooling appliances such as air conditioning units and fans [078]. Temperature increases are also linked to increased rainfall and the production of photochemical oxidants [047]. Urban heat islands follow a similar temperature pattern from city to city, with a few exceptions. Starting from rural areas temperatures start to rise at the edge of the city and continue to rise until they reach their peak over the city centre, where buildings are most dense. Pockets of cooler air are often found over parks or woodland [157].

Air and surface temperatures in urban areas are affected by many different variables, topography, the features of an area, the climate type of the region and temporary conditions like weather patterns and breezes. Breezes can negate the urban heat island effect by the mixing of cooler winds with the warmer city winds thus creating an overall cooling effect [157].

There are 11 papers addressing air temperature changes in urban climates. Of those 11 studies three are from China, three from Japan, one from Singapore, one from Hong Kong, two from the USA and one from the UK.

Studies in Tokyo have recorded the total number of hours where air temperature was more than 30°C in a typical summer has doubled in the last 20 years [148].

The papers measured urban growth on surface temperature [145, 137, 147] and land use on surface temperature [138, 144, 096].

For the impact of urban growth on surface temperature various research methods were used: remote sensing, Landsat, GIS modeling and data from weather stations. In a study in China results showed uneven growth, an increase of 13.01 Kelvin. The study found that the spatial pattern of radiant temperatures correlated with urban expansion [145]. This particular study however failed to take into consideration the land surface type/ roughness and emissivity which can have a significant impact on temperature readings.

The second report recognized that changes in urban land use has an impact on urban heat island intensity (UHII) and subsequently increases temperatures in urban areas up to 4.7°C compared to rural areas. It also made a strong correlation between urban development and air temperature [137].

A study in the USA compared temperature readings from 1219 weather stations across the country over a period of 83 years. The results were that urban effects on climate were detectable even in small towns. A mean annual temperature increase was recorded at 0.1°C compared to rural stations with smaller populations. The study found that urbanization decreases daily maxima in all seasons except winter and the temperature range in all seasons also decreased. An increase was identified in the diurnal minima and daily means in all seasons. The results of this study are objectionable as 85% of the stations used were in areas where population was less than 25,000 inhabitants [147].

In the studies on land use and surface temperatures the following research methods were used: Landsat Thematic Mapper images, topographical maps, vegetation maps, aerial photographs, satellite images and climatic data. Results showed that changes in land use and land cover widens the temperature difference between urban and rural areas. Vegetative cover eased temperatures in urban areas but warmed land in colder weather. Of all the land use types studied urban and built-up areas showed the highest average temperatures [138].

Some limitations to the use of temperature records in cities is that some cities don't keep records at all, records are generally only for the last 100 years, temperature recording devices are not best placed and are sometimes in rural areas outside of the city, devices are moved from location to location so constant and consistent measurements are unavailable and finally some cities do not record summertime temperatures [157].

2.2.2 *Air Quality*

Cities are often associated with poor air quality and air pollution which result in problems such as acid rain and smog, a combination of nitrous oxides and suspended particles emitted by vehicles and factories. As energy demand in urban areas rise, emissions rise exponentially, which means air pollutants such as carbon dioxide CO_2, sulphur dioxide SO_2, nitrogen oxide NO_x, carbon monoxide CO and particulate matter PM are released into the atmosphere causing the aforementioned problems to humans.

The higher temperatures found in UHIs, as discussed in 1.2.1.1, speeds up the chemical reaction that leads to pollutants such as ozone formation. Ozone is a result of nitrogen oxide reacting with volatile organic compounds in sunlight and at surface level, is a harmful pollutant [078]. It was calculated that for every 1°F rise in temperature polluted days may increase by 10% [157]. It is however, not just air temperature that affects air pollution, other contributing factors include the air's dew point, air pressure, cloud cover and wind speed [157].

Six papers were studied on air pollution in urban areas, of these papers one reported results from China, one from France, two from Taiwan, one from Tanzania and one from Japan. The papers looked at the association between urban land surface cover, climatic parameters/urban heat islands and air pollution [136, 139, 140, 135, 014]. One paper also studied pollutants and their

correlation with vehicles and traffic flow [141]. The methods used were: statistical analysis, simulation and modeling, GIS and correlation analysis and real data.

Results showed that there was a positive correlation between air pollutants and urban density [139] and increased temperatures over urban areas [136, 140]. Turbulent flux was identified as the key driver in the spatial distribution of air pollutants such as ozone and NO_x [039]. One study found that air pollution generally and more specifically types of pollutant are influenced by many variable land uses e.g., water bodies, dense urban structures, and green parks. The street canyon effect was particularly evident by raised pollutant concentrations. The paper acknowledged that there are numerous variables affecting pollutant concentrations which makes studies like this complex, errors were also acknowledged when converting data between GIS vector and GIS raster data formats [136].

Lai studied air quality and its association with urban heat islands using statistical analysis and simulations, he found that certain weather patterns deteriorate air quality and generate heat islands. He found that high UHI intensity correlated with increased concentrations of air pollutants that gathered at night and affected the air quality the following day [014, 135].

When considering a specific case study with sea breeze conditions, Yoshikado found that high concentrations of air pollutants were found in the convergence zone over the urban area caused by the mixing of the land air temperatures and sea air temperatures [135].

In terms of vehicle emissions and the study of traffic in an urban canyon, studies showed that pollutants followed the traffic flow rate. The introduction of outside air reduces pollutant concentrations as do increased wind speeds. In an urban canyon pollutants were up to 16% higher on the leeward side compared to the windward side, pollutants are up to 107% higher when wind speeds are low, between 2 and 4 ms^{-1} [141].

2.2.3 *Energy Use*

The United Nations predicts that by 2010 more than half of the world's population will be living in cities [151]. This increased urbanization, will have a significant impact on energy use in urban areas, some negative - increased temperatures raise demand for cooling in the summer, and some positive - raised temperatures decrease the demand for heating in the winter [157].

In 2008 world energy consumption, which includes coal (the majority share at 3303.7 million tonnes), oil, natural gas, nuclear and hydro power, grew by 1.4%, the Asia-Pacific region accounted for 87% of this growth [152].

Ten papers were studied on energy consumption in cities and countries, of those studied, two were from China, one from Canada, one from Greece, one from Brazil, two from the USA and three were global orientated studies. The papers looked at energy consumption in various cities, influencing factors like the impact of urban climate, including heat islands and changing air temperature. They used various methods to reach their conclusions: statistical analysis, household questionnaires, statistical modeling, climatic measurements and GIS.

In a study in China, researchers found the residential electricity consumption in the largest case study city was 1.6 times higher than the national average. In terms of coal and gas, again consumption in the largest city was considerably higher than the rest [155].

Another study in China acknowledged each case study city's characteristics and the influencing factors of energy use, these were: city locale, housing type, space cooler and water heater distribution, household characteristics and indoor thermal environment [153]. These variables affected a city's energy consumption differently from city to city, one having a dramatic effect on one city and no or little affect in another.

However, a study in Quebec, Canada on the impact of urban density on energy use found that cities with the largest densities consumed less gasoline and electricity per capita. They found that policy factors affected energy consumption such as services offered by a city, street lighting and building requirements. Factors that weren't included in their study were variables such as energy price, time series analysis, standard of living, geographic situation and economic activities [154].

An increase in urban population by 1% causes an increase in energy consumption by 2.2% [150].

In US cities with populations over 100,000 a 1°F increase in daily maximum temperatures means that peak energy demand rises by 1.5-2%. Air conditioning use accounts for up to 10% of urban peak electrical demand [157]. Based on the calculations of electricity demand and temperature increases across the US in 1992, heat islands alone were estimated at costing $1 million an hour or over $1 billion a year in electricity costs [157].

Since 1920 Los Angeles' temperature has increased by 2.5°C which represents a 1500 MW increase in energy demand.

Rising temperatures increase the demand for cooling in the use of air-conditioning units and fans. In the USA a sixth of all electricity generated was used to air condition buildings. This equates to 80 million metric tonnes of carbon emissions and approximately $40 billion a year in energy bills. Of these figures roughly 50% occur in cities that have been classed urban heat islands [080, figures from 2001]. In the last 40 years air conditioning use has risen by 10% [080].

Another study in the USA has shown that the temperature increases relating to UHI account for 5-10% of urban peak electricity demand for air conditioning use [112]. Peaks are generally on hot, summer weekday afternoons [078].

A study in Brazil looked at a residential area of a medium sized city and mapped its energy consumption against its thermal environment. The study used air temperature data, rural temperature data, electrical energy consumption of the houses and the income levels of the residents. Then GIS tools produced maps for analysis. In the results when comparing thermal maps to energy consumption those areas showing larger UHI intensity showed increased levels of energy consumption, up to 20% more than other areas regardless of income level. However, when maximum air temperature levels were compared to energy consumption no such correlation existed [149].

In Athens, heat island intensity often reaches 10°c. In Athens the increase in energy use as a result of this temperature increase was studied, the building's cooling load nearly doubled, peak electricity load nearly tripled for higher set point temperatures; however, heating loads were reduced by up to 50% compared to suburban buildings [150].

2.2.4 *Peak Power*

Peak power describes the point at which demand for electricity is at its highest and more power is required from the grid to satisfy demand. Due to the increases in temperature associated with UHIs, demand for cooling has increased in residential and commercial buildings. Cooling makes up a signification proportion of energy consumption and peak power demand [171]. In extreme weather scenarios like heat waves, peak load capacity is often exceeded [172].

Few papers exist that look primarily at an urban heat island's effect on peak power specifically. Many talk about peak power in terms of energy savings relating to mitigation technologies and the Lawrence Berkeley National Laboratory in California lead the research in this area.

Four papers, three focusing on the US and one on Canada discuss the energy impacts of heat island reduction strategies and radiant cooling systems and three discuss peak power in detail.

In the study undertaken in Toronto, an increase in summer temperatures have been recorded as the city expands so much so that most new buildings are now equipped with air conditioning units. As a result of the change in energy demand the utility company serving Toronto has changed from a winter peaking to a summer peaking utility [168].

Studies on residential buildings in the USA using DOE-2.1E simulations found that by implementing mitigation technologies shade trees and high albedo surfaces will reduce peak power demand by up to 42% [169, 170].

In a study of an office building in the USA using RADCOOL and DOE-2 simulations, by implementing a radiant cooling system which uses water as the heat transfer medium rather than an all-air system which uses air, savings average 27% of the peak power demand [171].

2.2.5 *CO_2 Emissions*

Carbon Dioxide (CO_2) is considered to be the primary component for global warming and an important greenhouse gas [157]. CO_2 is emitted as a result of the burning of fossil fuels and deforestation as trees sequester CO_2 as part of their life cycle and when they die release it back into the atmosphere. According to UN Habitat, the world's cities emit almost 80% of global CO_2. Anthropogenic emissions of CO_2 from fossil fuel combustion and deforestation are reported to have quadrupled in global terms over the last 150 years [157].

Cities with populations over 100,000 use approximately one billion kilowatt hours per year and each kilowatt hour of electricity creates half a pound of carbon in the form of CO_2. [157].

Ten papers study CO_2 concentrations in cities, of those ten seven are in the USA, one in Mexico, one in the UK and one compares concentrations of a city in Kuwait to one in the US.

The majority of the studies were undertaken on, or made significant reference to, the "CO_2 dome" of Phoenix, Arizona. The "CO_2 dome" is characterized by high-level CO_2 concentrations over the most urbanized areas and suburban areas of the city, due to its topography and heavily vehicular

use. In a two week intense study of the "CO_2 dome" its existence was confirmed and identified as being 75% stronger than the surrounding rural area [162].

Other papers discussing CO_2 emissions concluded that:

In Kuwait atmospheric CO_2 concentrations were highest in February and lowest in September. Higher on weekdays than weekends. Higher after sun set, when conditions were more stable and lower in late afternoon, several hours after unstable conditions [167].

A paper from the UK measured CO_2 and SO_2 concentrations along a transect between a city and rural area. They found that in winter CO_2 and SO_2 increased towards the city at day and nighttime. CO_2 was lower in the afternoon, but SO_2 was higher. In summer concentrations increased for both but larger increases were observed on rural sites. There were uniform concentrations over rural areas and small differences between rural and urban areas [163].

In a residential study of CO_2 concentrations in Phoenix, Arizona, [165] daily maximum concentrations occurred at nighttime but varied according to season and the air temperature. They peaked on winter evenings and just before sunrise in the summer. Daily minimum concentrations occurred during the afternoon. The urban mean cold season max was 67.4% higher than the rural areas surrounding and 32.6% for the residential mean cold season maximum. CO_2 was also recorded as being in higher concentration on weekdays. Variables were identified as air temperature inversions and solar induced convection which dilutes the pollutant levels.

Another study on CO_2 concentrations found that urban areas had 16% higher concentrations compared to rural, the study was undertaken over a number of years, and concentrations had actually dropped in the more recent years compared to rural areas. Again, concentrations were highest in the early morning and lowest in the early afternoon [158].

A study looking at emissions in cities across the US found that CO_2 emissions were higher in suburban areas and during the month of July [159]. In a study in Mexico City, CO_2 fluxes were at their highest during the morning and lowest at night and fluxes correlated with traffic flow [164].

A study looking at the sources of CO_2 emissions found that 80% were humans and vehicles compared to natural sources like soil CO_2 efflux (the release of CO_2 from the soil) [166].

2.2.6 *Health Impacts*

Health conditions such as respiratory illness, heat cramps, exhaustion, non-fatal heat stroke and heat related mortality are all associated with urban heat islands and elevated levels of heat compared to rural areas. Phenomenon such as heat waves put vulnerable groups such as young children, adults with health conditions and the elderly more at risk from heat related illness. Homes particularly at risk are those with dark roofs, on upper floors with windows on two sides and of brick construction may experience extreme heat during heat waves [078].

Many infectious diseases are linked to changes in climate and land use. Sensitive diseases are transmitted either indirectly or are vector-borne diseases meaning they require a host, generally an insect or rodent. Animals, disease carrying or otherwise, are hugely affected by changes in

temperature and climate, thus changing a diseases geography, seasonality and infection frequency [129].

There are many papers looking at mortality rates during heat-waves, the elderly appear to be the highest risk group [078, 089, 117, 129, 130].

A study undertaken after a heat wave in the summer of 2003 in Italy analyzed death records for that period and compared them to the same period for the previous year in the 21 Italian regional capitals. The results confirmed that there had been an increase in mortality by 3,134 and 92% of those deaths were aged over 75 years old, which was more than a 20% increase. The highest increases occurred in the over 75's in the northwestern cities which typically experience cooler weather. This study was asked to be undertaken at relatively short notice and so the data may not have been complete and due to time constraints only compared to one year prior to the event [117].

A heat wave in France in the summer of 2003 recorded 14,802 excess deaths compared to the same period in the three years prior. Again the age group with the largest increase was the over 75s [130].

A study of the July 2006 heat-wave in California, as well as air temperature, weather and ozone levels were accounted for, results showed a daily mortality rate increase of 9% per 10°F, this is 3 times greater than for full summer non heat-wave seasons [131]. Heat waves are often associated with high levels of air pollution [130].

When examining heat-wave related deaths it is important to consider other indirect causes, where there is perhaps not such a defined cause of death. Studies suggest that often mortality rates in heat waves are often underestimated [131].

Temperature increases have also been linked, although somewhat controversially, to violent crime, heat can make humans more aggressive and irritable, one study in the USA found that for every 1°F increase in temperature violent crimes (murders and assaults) increased by 4.58/100,000 [174].

2.2.7 *Economic Impacts*

Many papers discuss the impacts of urban heat islands on human health, air quality and green house gases and energy consumption but few discuss the impacts to the economy.

We know from previous sections that rising temperatures increase the demand for cooling in the use of air-conditioning units and fans. In the US a sixth of all electricity generated was used to air condition buildings, this equates to approximately $40 billion a year in energy bills of which about half occurs in cities that have been classed urban heat islands [080, figures from 2001].

Extreme weather events such as heat waves can have devastating effects upon the economy. In Europe, in 2003 the heat wave caused 35,000 deaths and agricultural losses of $15bn across three countries. The losses incurred by extreme weather events are rising, according to the Stern Review: Economics of Climate Change. In 2005, globally annual damage/losses were reported to be as much as $184 billion from windstorms alone [175].

The frequency of these events results in rising insurance premiums. Data from the insurance industry shows that the losses incurred by weather related catastrophes increased by 2% a year since the 1970s [172].

In Phoenix, Arizona the urban heat island effect is reported to have increased average daily temperatures by 3.1°c and nighttime minimum temperatures by 5°c. They have reported impacts on plants experiencing heat stress, Phoenix's crop of cotton on the city fringes has reduced in quality and quantity and they have reported increasing quantities of arthropods (agricultural pests and carriers of vector borne disease). Dairy cows also experience heat stress which has a negative effect on their milk production, up to 16% less in farms with the closest proximity to urban areas compared to rural [173].

Another industry which may come under threat is the tourism industry, as tourists will be less attracted to areas associated with extreme heat [056].

3 QUANTITATIVE MODELING & SIMULATION OF UHI

Modeling and simulation are used in every part of science and act as a substitute to what is actually being studied. Models have many different functions and can be scaled-up and scaled-down, they can consist of a series of equations or computer code and can vary in terms of their complexity, design, and type. They are very useful as a way of predicting outcomes which is why they are so important in the UHI arena, models in this section are used to describe the impact of UHI on temperature, air quality etc or they are used to describe a UHI mitigation strategy's impact on temperature, air quality etc.

For the non scientific community models are often regarded as being overly complicated and difficult to interpret or translate and often, and particularly in terms of UHI studies, modeling studies and their results are not always adopted by the likes of planners for this reason. Models also come under scrutiny relating to their accuracy and representation of reality, so it is important to understand that models can only be as accurate as the current understanding of the scientific area they are used in.

This section provides an insight into the modeling and simulation tools which are used to evaluate the urban heat island phenomena and mitigation technologies/strategies. The models are classified by what they simulate: temperature; air quality; energy consumption; and mitigation strategies (surface albedo, green roofs and urban green areas, and urban form & planning).

The table below summarizes the literature reviewed by: model description; origin of the study; and climate types considered.

Model design/Methodology	Number of References	Continent Considered	Climate Types Considered	List of references
To estimate UHI impacts:				
Temperatures	3	Asia, North America	Arid, Warm temperate	065, 049, 142
Air quality & CO_2 emissions	7	North America, Asia, Europe	Arid, Warm temperate	013, 141, 139, 014, 049, 051, 050
Energy/Power Demand	5	Asia, North America	Warm temperate, Snow, Polar	062, 154, 031, 022, 033
To estimate UHI mitigation options:				
Surface Albedo	4	North America	Arid	079, 064, 142, 015
Green Roofs and Urban Green Areas	5	North America, Asia	Arid, Snow	013, 041, 109, 063, 055

Urban form/planning	3	North America, Australia, Asia	Arid, Warm temperate	056, 054, 085, 224

The more typical models used in this area of research are described below. Some overlap exists in terms of the scales of the models.

Meteorological/Atmospheric Models (Primarily concerned with weather processes)

Mesoscale Meteorological Model (MM5) - A MM5 is a numerical model and is commonly used to record temperature trends [031]. It is widely used in conjunction with photochemical models and for specifically simulating the potential impacts of urban surface modification strategies [049]. This model is used for resolutions of 40-2km.

Meso-urban Meteorological Simulations (uMM5) – A uMM5 is based on the urbanised MM5 which includes a soil model based on the ISBA force-restore model. This model achieves finer resolutions at can accurately identify phenomena at sub-grid level and within the canopy layer [049]. This model is used for resolutions of 1km-100m.

Urban Canopy Model (CM) – A CM is a type of MM but modeled at a smaller scale, for example building scale. A CM is a one-dimensional model which can compute the temporal variations of air temperature, humidity and wind velocity in the urban canopy layer [031].

Large-eddy simulation (LES) – LES is used to simulate turbulent flows. This model is used for resolutions of 1km – 50m.

Micrometeorological models – Models weather conditions on a small scale, this model is used for resolutions of 500m - 5m.

Computational Fluid Dynamic (CFD) – CFD simulates the dynamics of things that flow, typically used to simulate air flow and climate. This model is used for resolutions of 5m to centimeters (or finer if needed).

Photochemical Models (Primarily concerned with pollutant concentrations)

Comprehensive Air Quality Model with Extensions (CAMx) – CAMx is a Eularian, 3-dimensional grid, that allows simulation and assessment of "one atmosphere", such as ozone or particulate matter [049].

Urban Air Shed Model (UAM-V) - The UAM-V Model is a three-dimensional, multi-scale photochemical grid model that calculates concentrations of pollutants by simulating the physical and chemical processes in the atmosphere [217].

The following papers use a number of models to estimate the UHI impact on temperatures; air quality & CO2 emissions; and energy use and peak power demand. The types of models used have been described in more detail in the following paragraphs.

3.1.1 *Temperatures*

As temperatures are used to quantify the existence of an urban heat island they regularly appear as a dataset for models and many simulations have temperatures as their outputs. Few look at temperature specifically, rather the affects of albedo, buildings, reforestation on temperature. Temperatures are modeled using meteorological models such as MM and CM.

A modeling study in Japan used a CM and a MM to calculate temperature variations in a city as a result of the presence of buildings in the area. The data input for the MM in this study was from a Grid Point Value Meso Scale Model, a weather prediction model used by Japan's Meteorological Agency. The CM's components were wind velocity, potential temperature, humidity, anthropogenic sensible and latent heat, surface heat budget for the walls of the building and radiation/reflection from surfaces which is modeled only once because the modeling is so complex [065].

3.1.2 *Air quality & CO_2 emissions*

Seven studies focus on air quality specifically, of these seven studies two studies are from Asia, four from North America and one from Europe. Some studies look at the urban heat island's effect on air quality [014, 139, 141] and some on mitigation strategies affect on air quality [013, 051, 050, 049]. The air pollutants focused on were Nitrogen Dioxide (NO_2) Carbon Dioxide (CO_2) Carbon Monoxide (CO) Nitrogen Oxide (NO_x) and Ozone (O_3).

The meteorology models commonly used were MM, photochemical models were typically Urban Air Shed Models for ozone, the Air Pollution Model (TAPM) for air pollution generally, and Biogenic Emissions Inventory Systems (BEIS-2) for biogenic emissions.

Haider Taha, originally at Lawrence Berkeley National Laboratory (LBNL) and now at Altostratus, is a leader in the field of meteorological and air quality-modeling and has written many papers on the modeling of urban heat islands. In Taha's 2008 paper he discusses the heat island's impact on air quality using uMM5 and CAMx models with particular reference to ozone. The study also models albedo increase and its impact on air temperature. In this study Taha considers the meso-urban modeling of heat island mitigation superior to the mesoscale as it produces impacts on air quality etc on a larger scale, and captures phenomena that a mesoscale model would not have identified for example cool islands [049].

Another study by LBNL looked at the air quality benefits of implementing mitigation measures including increased albedo urban reforestation - using meteorological and photochemical simulations. The outputs of the meteorological models were used as inputs for the photochemical and urban air-shed models were used as inputs to the photochemical model [050].

In Taichung, Taiwan the air pollution model TAPM was used to study the relationship between the weather patterns associated with UHI and air quality. The model was fed with real meteorological and air pollutant data. TAPM simulated the convergence phenomenon and was used to compensate for the lack of vertical field data such as wind speed and direction. TAPM's air pollution section is us made up of four modules: Eulerian Grid Module; Lagrangian Particle Module; Plume Rise Module and Building Wake Module. TAPM can predict hourly pollutant concentrations for up to one year, sea breezes and terrain induced flow [014].

3.1.3 Energy Use and Peak Power Demand

Five studies look at energy consumption and peak power demand, of those five studies four are from North America and two from Asia. Only two of these studies look at the heat island's effect on energy demand specifically [054, 062], the others look at heat island mitigation strategies on energy demand [022, 031, 033].

The models used were predominantly building simulation models (often called Building Energy Analysis Models or BEMs), particularly DOE-2.1E. A program called RADCOOL, another building simulation, was used in one study but proved to be limited in scope. Where other influential factors were simulated MMs and CMs were used.

A statistical model was developed for Quebec, Canada to decipher whether there was a relationship between annual energy consumption per capita and a number of variables: average inhabitant age; annual degree-days below 18°C; urban density; share of homes heated by electricity; and the standardized land wealth per inhabitant. Electricity consumption data was supplied by Hydro Quebec and population related data by Statistics Canada. They concluded that population density was not the only factor that affected energy use, standard of living, city geography and economic activities should also be factored in [154].

A simulation was developed in Japan to study the effects of the city's mitigation activities and their affect on the energy demands of city buildings. The simulation uses three main models: a MM model, a CM model and a BEM. The MM model was selected to simulate the relationship between the outside environment and the building. The difficultly in using a MM in this study is that they do not take into account the variables that affect buildings such as radiance and drag force, so a CM was used. The CM was selected because these models can simulate the physical influences of the urban canopies on the surface boundary layer over cities and the BEM simulates the cooling load in the buildings and the amount of cooling energy/demand. The results of the MM were input into the CM to simulate initial and upper boundary layer conditions. Waste heat from the BEM simulation was released into the CM atmosphere linking the two simulations [031].

Another study in Japan simulated air temperature and building energy consumption and their relationship with an urban climate. This simulation used combining a one dimensional meteorological canopy and building energy use model [022].

An hourly building energy simulation model was presented in this paper for a case study in Toronto, Canada. The model set out to calculate annual energy savings and peak-power avoidance after heat island mitigation measures were implemented. The model types used were: the DOE-2.1E which simulates a building's energy use for the year, the input data was actual data from the Toronto Weather for the Year Energy Consumption and to capture the temperature changes from the reduction strategies a PSU/NCAR MM5 mesoscale meteorological model was used. Nine building prototypes were modeled, the focus was on residential properties as that building type was considered to benefit most from these countermeasures. The following methodology was used to assess the potential effects: defined building characteristics; simulated energy use using the DOE-2.1E model and calculated savings for each reduction strategy; estimated total roof area using existing data sources; and calculated metropolitan wide effects of the strategies [033].

The following papers use models to estimate the effectiveness of UHI mitigation technologies; the technologies under review are increased surface albedo; green roofs and urban green areas; and urban form/planning. The types of models used are described in more detail below.

3.1.4 Surface Albedo

The Lawrence Berkeley National Laboratory (LBNL) have published numerous papers on the modification of albedo surfaces to promote energy savings, reductions in urban temperatures and the improvement of air quality. Four papers look at modeling for albedo specifically, all of which are from LBNL and focus on the California region [015, 142, 064, 079]. Many papers look at a number of mitigation options, predominantly albedo and shade trees, and attempt to evaluate the most effective strategies using modeling and simulations. Of the 12 modeling studies that look at more than one mitigation strategy, nine were for studies in North America and three in Asia. Of the 12 studies, six focused on air quality as an output [028, 050, 104, 048, 012, 058] three on energy use [022, 028, 168] six on temperature and urban climate [022, 050, 059, 092, 084, 058] and one on health impacts [089]. Please note that some studies looked at more than one output.

A sample of the models used in this section were:

Energy simulation models of buildings were run to calculate the impacts of cool surfaces, these simulations were fed with actual surface temperature and reflectivity data used in conjunction with the as-built drawings of the buildings. A cost benefit analysis was then conducted on the simulation results [015].

For a global study of albedo modification and the potential global cooling and CO_2 reductions that could be achieved, a General Circulation Model (GCM) simulation was carried out. A GCM simulation is used to estimate the changes in the average globe temperature by changing the

albedo of all the land surfaces. However, GCMs are considered too course as they are performed over such a large scale. New GCMs are being developed that can run at smaller scales [142].

A study on the impacts of large scale albedo changes on air quality was run by the LBNL using CSUMM and UAM models. CSUMM is a hydrostatic, primitive-equation, three dimensional Eulerian model used to simulate meteorological conditions, its domain is about 10km high, to a soil depth of 50cm. The UAM is a three dimensional, Eluerian photochemical model, it can simulate the advection, diffusion, transformation, emission and deposition of pollutants [064].

Another LBNL modeling study sought to calculate power consumption reductions as a result of albedo changes Three numerical models were used URBMET, WTHCHANGE and DOE-2.1C. URBMET is a one dimensional model used to calculate ground surface energy and moisture budgets. WTHCHANGE is a lumped-sum model developed to simulate evapotranspiration from vegetation canopies and DOE-2.1C is a building energy simulation model [079].

A simulation in Japan was produced that modeled UHI countermeasures by using an evaluation model. The model was made up of two sub-models, a canopy model (CM) and a building energy model (BEM). This model the shows how the external environment impacts on the energy demand of the building by its use of air conditioning and how the waste heat from the air conditioning enters back into the external environment of the building. The CM calculates all weather components on the buildings, the buildings density is considered for every altitude in the vertical direction. The BEM assumes that the building is a single box to compute its heat budget, the sensible and latent heat loads are also considered. The simulation period was for one year. Air temperatures, humidity and wind velocity were based on real data from the Japan Meteorological Agency. Urban district data came from LANDSAT and GIS data and data on building from various sources and previous papers. Traffic flow was calculated using census data. The counter measures modeled were photocatalytic coatings as the humidification technology and solar-reflective paint as the albedo-increase technology, energy efficiency technologies were also modeled [022].

3.1.5 Green Roofs and Urban Green Areas

A number of studies as mentioned in the previous section covered more than one mitigation measure as part of their model, this included urban reforestation, green roofs and urban planting. Of the studies that focused solely on urban green areas, five were identified, four from studies in North America and one from Asia. One study from Israel looked at urban trees as part of the design of an urban street, while the others focused on the air quality benefits of urban trees. A selection of the studies and types of modeling used can be found below.

A model to calculate how much air pollution could be reduced by the introduction of urban trees and shrubs was carried out by the US Development Agency (USDA) Forest Service. The input data was from hourly meteorological and pollution studies in a number of cities across the US, the inputs were made up from further calculations and weather data [013].

This paper applied a model to calculate the amount of carbon that could be saved by the existing vegetation in two residential areas in the Chicago, US. The simulation programs used were Shadow Pattern Simulator (SPS) and MICROPAS. SPS creates data relating to the shading patterns from trees on entire building surfaces, the software uses sun-tree-building geometry to compute the surface shading coefficients and can calculate for a monthly, daily or hourly time period. The SPS data is produced in a MICROPAS friendly format so that this program can go on to estimate the building's energy use based on its thermal characteristics, residential lifestyle and any weather data relevant. MICROPAS can also compute on an hour by hour basis. MICROPAS receives its climate data (temperature, radiation and wind speeds) from a local weather file by ENERCOMP which is loaded into the program [041].

3.1.6 Urban form/planning

The studies found in this area are scare, some acknowledge the importance of urban design in cities but there are few papers devoted to testing and simulation. Four papers that specifically consider this area are discussed below. The papers cover three continents; Australia, Asia and North America.

The paragraphs below lay out the types of models used in these studies:

The study in Japan considers the best design method in an urban area, buildings and trees, to achieve the optimum outdoor environment using simulations and genetic algorithms (GAs). The optimum outdoor thermal environment in this study is specifically focused on human comfort levels. GAs are coupled with simulations of convection, radiation and conduction to achieve the brief. In the first part of the study the optimum design method is considered, the second part of the paper looks at human comfort levels using Standard Effective Temperature (SET), and how meteorological conditions effect these levels such as wind speed, air temperature, humidity and mean radiation temperature (MRT). The third part of the study considers the optimum results for part 1 and 2 and checks they are compatible. In terms of the coupled simulation of the outdoor thermal environment, the composites (spatial distribution of air, wind velocity, air temperature, humidity and MRT) are calculated as follows: MRT uses the Monte Carlo Method; radiation analysis using Gebhart's absorption factor and conduction analysis is used to calculate ground and wall surface temperatures; and CFD simulation is fed with surface temperature data. GAs are simulations used to mimic humans and as such are considered living organisms, the fitness of the human simulation is calculated using genetic operations and the model with the highest fitness is considered to be the optimum model. After all the simulation components are tested on the human simulation the optimum design method can be selected based on the human simulation's design parameter. The final stage of this study is to test the optimum design system on an arrangement of buildings and trees to test for pleasant outdoor thermal design [085].

This study looks at urban design as a way of mitigating the urban heat island in Phoenix Arizona along with water. The heat island in Phoenix has been studied intensively, as Phoenix experiences daily summer minimum temperatures over 32°c, making it an ideal study/testing area for mitigation strategies. Obvious mitigation measures such as urban reforestation and green

areas are dependent on irrigation and abundant water supplies, Phoenix is described as a desert city with limited water supplies so a trade-off is created. A model called Local-Scale Urban Meteorological Parameterization Scheme (LUMPS) is used to model heat fluxes in urban areas as a measure of the effectiveness of various heat island mitigation strategies. A number of scenarios were modeled; industrial, residential with irrigated landscaping and residential with native desert landscaping. An urban energy balance model was used to simulate temperature and evaporation under the different mitigation strategies in the different locations. LUMPS uses net radiation, surface cover, morphometry and standard weather observations to calculate hourly energy budget components, measured in Wm^{-2}, of latent heat, sensible heat, heat storage and net radiation. The outputs of LUMPS, latent heat flux, were converted to figures that represent water loss and sensible heat flux to calculate nighttime temperature cooling rates. LUMPS was also used to test three urban-design scenarios; a dense compact city, a more highly vegetated city, and a desert city with less vegetation and unmanageable soil. LUMPS is a useful model as the data required for input is fairly simple, however a GIS tool would allow more of a city-wide approach [056].

In a study in South East Queensland, Australia, computer simulation of urban heat islands test the indoor thermal performance of residential dwellings to help future proof the for climate change. The methodology has three stages; 1. To identify a typical housing model based on common passive house design techniques and energy rating programs; 2. Successful mitigation strategies are applied to the residential developments; and 3. Meteorological conditions associated with UHI are simulated and applied to the housing developments. The simulation software used to test the impact of temperature of the houses is an industry software called DEROB-LTH, this software allows an accurate representation of the building and can provide accurate analysis on a room by room basis. The software is fed by actual climatic data. Mitigation was kept separate from the simulation so the strategies were not tested thoroughly [054].

A GIS based model is being developed to predict air temperature trends as a result of different urban planning approaches. The model will enable planners to test their designs for their potential impact on urban climate. Data for the model are based on long term field measurements between 2005–2008. The model can factor pavement area, building areas, wall surface area, green plot ratio, sky view factor and surface albedo. Another model developed to assist planners is STEVE (Screening Tool for Estate Environment Evaluation), it is an estate based (fixed point within an estate) planning tool that can calculate minimum, average and maximum current and future temperatures based on a planning proposal. STEVE is a web based application making it more accessible to planners. STEVE was developed as a result of a gap identified between development of climate based models and their use by non-scientific community such as planners, due to the models being overly complex and difficult to use. A limitation for the first model was that anthropogenic heat influence was not considered, and for STEVE the modelers identified some user issues with pre-set values for the 'fixed point' and master plan maps being difficult to alter within the current program version [224].

3.2 Simulations of UHI

3.2.1 Introduction

A simulation is the execution of a model, so when considering simulations the focus is more on the outputs or results of the study rather than the methodology of the model. Most of the urban heat island papers we have looked at contain an element of simulation, generally coupled with real data to validate the simulation results. Simulation is very useful in the study of meteorological conditions as a number of conditions can be tested and variables changed as and when the designer wishes. The modeling and simulation of mitigation scenarios is an important step in regulatory planning as it acts as a low cost, low risk test of the effectiveness of the mitigation technologies.

Similarly to the modeling section 3.1, we have arranged the simulations by what they describe. The table below summarizes the literature reviewed by: simulation description; origin of the study; and climate types considered.

Simulations of UHI	Number of References	Continent Considered	Climate Types Considered	List of references
Simulations of Temperature Impacts	4	North America, Asia	Arid, Warm temperate	016, 024, 049, 065
Simulations of Air Quality & CO_2 Impacts	9	North America, Europe, Asia	Arid, Warm temperate, Snow	012, 014, 028, 041, 049, 050, 063, 139, 141, 233
Simulations of Energy Use & Peak Power Impacts	2	Asia, North America	Warm temperate, Snow	031, 033
Simulations of mitigation impacts	13	Asia, North America	Arid, Warm temperate, Snow	013, 022, 041, 048, 051, 054, 055, 058, 089, 092, 104, 109, 142, 233

The key findings of a number of papers simulating the impact of the UHI on temperature; air quality; and energy consumption and the effectiveness of UHI mitigation strategies on temperature; air quality; and energy consumption and can be found in the following paragraphs.

3.2.2 Simulations of Temperature Impacts

Temperature trends are one of many outputs of a simulation testing UHI mitigation strategies so a limited number of studies solely focus on the UHI and its impact on urban temperatures. Four studies were identified, one from North America and three from Asia. Descriptions of the types of models used can be found below.

A study in Japan looks at ways of controlling the night temperature during summer seasons using countermeasures. Before countermeasures can be identified, a model is developed to predict urban temperatures. The model used was a one dimensional model of the surface

boundary layer. The model calculates the upper boundary conditions, temperature, wind velocity and water vapor pressure. Test sites are modeled under two scenarios, built areas, pavement and structures and green areas. Results showed that the greatest causes of the nighttime temperature increases was the release of heat from soil, the study proposed that the green surface balance of the city was modified in order to control temperatures at night [024].

In Japan four simulations were carried out on the effects of building drag and heat storage in the urban canopy on city temperatures. The simulations were: 1. a realistic study; 2. sensible heat flux and radiation only; 3. drag effect of building on wind only; 4. no buildings presented. Each simulation was carried out for an urban and a suburban case study and the simulation results were tested again actually temperature readings for validation. The results showed that in comparison with scenario 4, the contribution of heat flux from buildings was 49% in the urban area and 20% in the suburban; wind reduction due to building drag for urban and suburban were 41% and 59% respectively and the effect of interaction between 2 and 3 was +10% for urban and +20% in the suburban area [065].

Haider Taha, LBNL, discusses the heat island's impact on air quality using uMM5 and CAMx models with particular reference to ozone. The study also models albedo increase and its impact on air temperature. Taha models the urban heat island in Sacramento California using a uMM5 model, the results of which show the UHI to start at around 1500 at 0 ~ 1°c higher than the surrounds, at 1800 temperatures reach 0 ~ 2-4°c, 2100 temperature peaks at 0 ~ 6°c and then they slowly decrease, there is no difference in the early morning hours and then temperatures decrease in comparison by 0 ~ 1-2°c between mid morning and midday [049].

3.2.3 Simulations of Air Quality & CO_2 Emissions Impacts

Air quality and CO_2 emissions are regularly simulated. Poor air quality is linked to many environmental and health problems. Much debate surrounds the topic of Greenhouse Gases and their effect on global climate change, at a smaller/city scale environmental problems such as acid rain and smog are effects of poor air quality. Poor air quality also exacerbates respiratory conditions in humans and as such, this area is of particular concern.

There are four papers simulating the impacts of urban heat islands on air quality specifically, one from Europe [139], one from North America [049], two from Asia [014, 141], and six that look at the impacts of mitigation strategies on air quality, all from North America [012, 028, 041, 050, 063, 233].

The primary air pollutants simulated were NO_2, CO_2, CO, NO_x and O_3. Meteorology Models commonly used were Mesoscale Meteorological Models (MM) and Photochemical models for the pollutant concentrations such as Urban Air Shed Models for ozone and Biogenic Emissions Inventory Systems (BEIS-2) for biogenic emissions.

The following paragraphs provide a review of the key findings of some of the simulations undertaken:

A study in France sought to find out through simulation what impact the Paris urban heat island had on the distribution or air pollutants. The simulation was carried out in an anticyclonic weather system. The simulations were conducted with the Meso-NH atmospheric model linked to a chemistry module. Meso-NH is a non-hydrostatic mesoscale atmospheric model allowing two-way nesting simulations. The model is initialized and forced at the lateral boundaries every 3 hours by a forecast model for dynamic parameters and a global chemical transport model for all chemical species. Two simulations were performed, one in an urban location using the town energy balance urban surface scheme, the other is performed without it representing a more rural location. The results of the simulation show that at night the UHI is very apparent and is advected by Paris' south-westerly winds. During the daytime the urban simulation's temperatures are still increased which has an impact on pollutant concentrations. In both simulations the turbulent flux is the primary driver for the spatial distribution of the ozone plume and NO_x concentrations [139].

The USDA Forest Service created a model to calculate how much air pollution could be reduced by the introduction of urban trees and shrubs. The model was fed with hourly meteorological and pollution concentration data and urban tree cover data over 55 cities across the US. The results of the simulation showed variation across the cities studied. The simulation calculated that urban trees in the US could remove 711,000 metric tonnes of urban air pollutants, O_3, PM_{10}, NO_2, SO_2, CO [013].

Taha discusses the heat island's impact on air quality, and a using uMM5 and CAMx models with particular reference to ozone. The study also models albedo increase and its impact on air temperature and air quality. The results of the CAMx simulation show that the model captures the higher downwind concentrations but not the downwind concentrations of the downtown area. Overall the model shows that the albedo increases of the mitigation strategy reduce levels of ozone, there are however, some signs of an increase, although only in short intervals. Decreases of around 5-10 parts per billion (ppb) are recorded and the average daily maximum 8 hours could be decreased by up to 13% [049].

3.2.4 Simulations of Energy Use & Peak Power Impacts

Only one paper discussed a simulation that was focused on energy consumption without the influence of mitigation technologies, this was undertaken in Tokyo, Japan [062]. Six studies were reviewed on energy consumption as a result of mitigation measures, four in North America [168, 033, 171, 012] and two in Asia [031, 022].

The models used were predominantly building simulation models (often called BEM), particularly DOE-2.1E. A program called RADCOOL, another building simulation, was used in one study but proved to be limited in scope. Where other influential factors were simulated MMs and CMs were used.

The following paragraphs provide an overview of some of the simulations undertaken and their results:

A simulation was developed in Japan to study the effects of the city's mitigation activities and their affect on the energy demands of city buildings. The results of the simulation showed that compared to real temperature readings of the area, the simulation could reasonably reproduce the conditions. The simulation and real readings for temperature sensitivity of the peak-time cooling electric power demand was 6.07%/°C and 5.66%/°C respectively. The simulation also calculated that if all waste heat from air conditioners was cut, near-ground air temperature would drop by 1°C and cooling energy consumption would reduce by 6% [031].

An hourly building energy simulation model was presented in this paper for a case study in Toronto, Canada. The model set out to calculate annual energy savings and peak-power avoidance after heat island mitigation measures were implemented. The results of the simulation were that as a result of the mitigation measures annual energy savings could be as much as $11m with the residential benefiting the most compared to offices and retail outlets. The most effective mitigation measures were: wind shielding from trees (37%), shade trees (30%), cool roofs (20%) and ambient cooling by trees and reflective surfaces (12%) [033].

3.2.5 Simulations of mitigation impacts

Thirteen papers were reviewed that simulate the effects of mitigation strategies on the urban environment, of those eleven papers, nine studies are based in North America, predominantly California, one in Asia, Israel and one in Australia, Queensland.

The split between technologies was 30% albedo, 30% green urban areas and 40% a mixture. The models used were a variety. CM, MM and urban air shed (UAM) models were the more common models. Other models used included DEROB-LTH, thermal performance of houses, meteorological models such as Mesoscale Community Compressible (MC2), Systems Application International Mesoscale Model, URBMET, GCM and GIS based models. Pollutant concentrations were simulated using photochemical models, BEIS-2, CAMx and UAM Models.

The following paragraphs provide an overview of some of the simulations undertaken and their results:

A simulation in Japan was produced that modeled UHI counter measures by using an evaluation model. The model was made up of two sub-models, a canopy model (CM) and a building energy model (BEM). The model was slightly different to other CM-BEM models in that it can calculate the year round environmental impacts rather than just for the summer period. This model shows how the external environment impacts on the energy demand of the building by its use of air conditioning and how the waste heat from the air conditioning enters back into the external environment of the building. The CM calculates all weather components on the buildings, the buildings density is considered for every altitude in the vertical direction. The BEM assumes that the building is a single box to compute its heat budget, the sensible and latent heat loads are also considered. The simulation period was for one year. Air temperatures, humidity and wind velocity were based on real data from the Japan Meteorological Agency. Urban district data came from LANDSAT and GIS data and data on building from various sources and previous papers.

Traffic flow was calculated using census data. The counter measures modeled were photocatalytic coatings as the humidification technology and solar-reflective paint as the albedo-increase technology, energy efficiency technologies were also modeled. The results were made in terms of energy savings. In the scenario where no mitigation measures were taken the annual energy consumption, which affects global warming, was 589 MJ/floor-m^2/y. Due to humidification annual energy consumption reduces 2.8% but increased by 0.1% due to albedo modification because of rising heating demand. With comprehensive counters measures energy savings up to 31.9% could be made. It appears that humidification is the better option although an increase in humidification could be uncomfortable to employees [022].

This paper applied a model to calculate the amount of carbon that could be saved by the existing vegetation in two residential areas in the Chicago, US. The simulation programs used were Shadow Pattern Simulator (SPS) and MICROPAS. The results of the simulation showed that where tree block cover was 33% carbon emissions decreased by up to 3.9% per year and up to 3.8% in the other simulation where tree cover was just 11%. Wind speed reduction meant carbon emissions decreased. When trees were located in the 'wrong' location shade, in the wintertime, actually caused heating bills to increase and therefore carbon emissions increased as a result [041].

In Taha's 2009 paper for the Second International Conference on Countermeasures to Urban Heat Islands he uses updated MM, uMM5 models in fine resolution photochemical models to determine the effects of vegetation and increased albedo surfaces on California's heat island with particular reference to temperature and ozone concentrations. The models showed that increasing albedo resulted in a decrease in ozone concentrations of between 16-26 ppb and up to 15-19 ppb for the increased tree canopy simulation in a 1-2 km^2 or slightly larger area. For the larger areas which are representative of California, results of 5-10 ppb for increased canopy and 5-14 ppb for albedo were simulated. For temperatures, the models showed that vegetated areas could result in a reduction of the peak daily temperature of up to 2°C and up to 3°C in high albedo scenarios. The models also found that there were little temperature changes at nighttime due to the mitigation measures. [233].

4 MITIGATION OF URBAN HEAT ISLANDS

4.1 Introduction

This section of the report provides a review of the literature gathered on the urban heat island mitigation technologies and strategies and summarizes the salient points from these studies. The studies reviewed have been collected from across the globe and seek to highlight the mitigation potentials of the technologies, their current status and the related techno-economic factors applying to both existing and newly built urban environments.

A vast majority of the papers have been written on mitigating the urban heat island through a range of countermeasures. The papers are categorized and then reviewed in the following sections: Energy/Peak Power/CO_2; Economic Assessment; Policy/Strategic Assessment; Technologies; Implementation Issues; Urban Design/Planning; and Environmental Assessment - for each of these sections the underlying principles, a summary and the salient points from the literature review follow. In the case of the technologies, the key mitigation technologies i.e. cool roofs, cool pavements and urban green areas and green roofs are examined in greater detail to provide an overview of the current status of the policy and a critique focused on identifying the limitations in the existing studies that lead to a research priority plan which is outlined in section 6.

Mitigation	Number of References	Continent Considered	Climate Types Considered	List of references
Energy/Peak Power/CO_2	20	North America, Asia	Equatorial, Arid, Warm temperate	009, 015, 021, 022, 027, 028, 031, 033, 034 035, 039, 041, 059, 066, 070, 079, 111, 112, 142, 171
Economic Assessment	8	North America (for city/ state/ national); and all continents for Global Estimates (not with rigor)	Equatorial, Arid, Warm temperate	025, 027, 028, 033, 035, 112, 142, 176
Policy/Strategic Assessment	24	North America, Europe & Asia	Equatorial, Arid, Warm temperate	025, 027, 034, 040, 045, 047, 060, 061, 066, 071, 073, 074, 076, 081, 093, 101, 108, 201, 210, 211, 212, 213, 214, 215
Technologies (Cool Roofs (including Photovoltaic roofs), Cool Pavements/Roads, etc., Green Roofs/Urban Green Areas, Vehicle Paints, Other (District cooling/ Water cooling))	83	North America, Europe, Asia	Equatorial, Arid, Warm temperate, Snow	002, 003, 006, 007, 010, 011, 013, 015, 020, 021, 025, 026, 027, 028, 029, 032, 033, 034, 035, 037, 039, 040, 041, 046, 047, 048, 053, 055, 058, 059, 060, 061, 063, 066, 067, 068, 069, 070, 071, 072, 074, 075, 077, 079, 080, 082, 083, 086, 087, 088, 092, 105, 109, 110, 111, 112, 122, 127, 128, 134, 142, 156, 177, 178, 179, 180,

				181, 192, 193, 194, 195, 196, 205, 206, 209, 222, 223, 226, 227, 228, 229, 236, 237
Implementation Issues	4	North America & Asia	Equatorial, Arid, Warm temperate	027, 047, 053, 060,
Urban Design/Planning	16	North America, Asia, Europe, Australia	Equatorial, Arid, Warm temperate	006, 007, 010, 045, 047, 054, 056, 101, 109, 112, 202, 203, 204, 225, 226, 232
Environmental Assessment	27	North America, Australia, Europe and Asia	Arid, Warm Temperate, Snow	003, 005, 012, 013, 014, 020, 024, 027, 038, 048, 049, 050, 051, 059, 061, 063, 064, 070, 080, 093, 104, 106, 108, 112, 115, 139, 141

4.2 Review for Energy/Peak Power/CO_2

4.2.1 Energy/Peak Power/CO_2 Principles

The characteristic elevated temperatures in the atmosphere and the lithosphere of urban areas compared to their rural surroundings has been well documented, see section 2. The urban heat islands generated are facilitated by the rapid industrialization and urbanization which often results in replacing open green spaces with tall built surfaces that trap the sun's solar radiation as well as the fact they themselves generate large amounts of internal heat from a range of anthropogenic activities. The local climatic conditions of cities experiencing the UHI phenomenon result in an increased energy demand as buildings seek to maintain optimal operating conditions (for thermal comfort of the occupants). This results in an increase in energy demand from power plants, leading to higher emission levels. As a result three key areas are examined in the UHI literature:

- Energy Use: this can be either positive or negative depending on the level of urbanization, geographical location, time of year, length of cooling vs. heating seasons, energy consumer habits, efficiency of cooling technology, etc;
- Peak Power: describes the point at which utilities providing the power to the grid experience the highest demand for the electrical power in order to satisfy demand. The increases in temperature associated with the urban heat islands in most circumstances exacerbates this peak demand due to the cooling requirements thus putting strain on the grid. Providers often have to draw in extra capacity peak load generators to avoid brown-outs or at worst blackouts;
- Carbon Dioxide: CO_2, one of the primary components for global warming is generated from the use fossil generators that power high energy using products such as air-conditioning units (used to maintain optimal temperatures in buildings), fossil fuels burned by cars in the urban environment and other power related devices are key contributors to the rising levels of CO_2. Furthermore, the rapid industrialization and urbanization result in less green space (trees and vegetation) implying that less carbon dioxide can be stored or sequestered therefore contributing to the increasing amounts of CO_2 which eventually only acts to exacerbate global warming and in turn the UHI effect.

This section reports the findings from UHI studies that address the above issues. Energy, peak power and CO_2 have been individually addressed for each of the UHI mitigation technologies and thus this section aims to report findings which address either combined mitigation technology effects at larger scales and examining the implications of the UHI phenomena upon energy use, peak power and CO_2 at a state, national or global scales.

4.2.2 Energy/Peak Power/CO_2 Summary of Literature and Findings

Over half of the studies examining the energy use, peak power and carbon dioxide emissions associated with UHI countermeasures originated from LBNL UHI Group and the main focal regions for all studies were in North America, Japan and Singapore.

These studies were founded primarily on numerical simulations (depending on the scaling they used different granularity of models that often made use of the DOE2/3 building energy analysis program) and not the outcomes of data collection from large scale implementation. It was found that temperature increases above a certain threshold would result in steady increase in peak urban electric demand. For case specific city studies and hypothetical scale-up scenarios (often in hot climates with collective countermeasure implementation) that energy consumption and peak power at the building, city and national scales can be decreased significantly both directly and indirectly. It was also found that the primary energy saving technologies could generate greater energy savings than UHI countermeasures and also have the potential to contribute to the mitigation of UHIs. The studies that examined the CO_2 reduction due to mass modification to existing cities with urban green areas, reflective roofs and pavements demonstrated that significant reductions in CO_2 levels were achievable. Results for energy use, peak power and CO_2 as a consequence of UHI mitigation measures were not easily transferable from one region/climate zone to another and in scaling up such estimates to a global scale it was evident that there is still significant research and refinement is required.

4.2.3 Energy/Peak Power/CO_2 Literature Review

There are twenty references which addressed the energy, peak power and CO_2 emissions as defined above in the literature reviewed. Of these studies 65% emanate from the Lawrence Berkeley National Laboratory Urban Heat Island Group [021, 027, 028, 033, 034, 035, 059, 066, 070, 079, 112, 142, 171] with a majority of studies focusing in North America and Japan but also Singapore.

Of these nine studies addressed energy use [009, 015, 021, 022, 027, 033, 066, 079, 171,], thirteen studies address peak power [021, 028, 031, 033, 034, 039, 059, 066, 070, 079, 111, 112, 171] and four address the CO_2 emissions [035, 041, 066, 142].

Nine studies addressed energy use were predominantly based on numerical simulations and were not results of large scale implementation and measurements [009, 015, 021, 022, 027, 033, 066, 079, 171]. A selection of studies that help highlight the key conclusions are reviewed here. A study produced by LBNL on Canada examines the heat island effect of the implementing UHI mitigation measures in mass in the form of shade trees strategically position such that they provide not just shading but also wind shielding and the use of cool roofs across the Greater Toronto Area – the annual energy savings of the building sector are calculated using an hourly building energy simulation model. The results show that annual energy savings of over $11m can result from the mass implementation of UHI strategies across the Greater Toronto Area – the potential annual electricity savings are estimated to be in the region of 150GWh. It demonstrated that the combined use of reflective roofs and strategic shade trees reduces the summer cooling energy use but also potentially incurs a penalty increase in the winter heating energy use, however the approach yields results that are highly sensitive to the prices of cooling and heating energy fuels (i.e. gas and electricity). It was evident that the research used to conduct this study was better suited for addressing the mass effects of shading as opposed to shading effects of trees; the DOE-2 model has been addressed in both this paper and others to underestimate the cooling-energy savings and potential of reflective roofs (by as much as a factor of two); the

method used to estimate the actual roof area for commercial buildings was based on population and residential roof area – thus further research in this area is required to generate more accurate results and estimates. The study made a valid point that from its findings the indirect savings potential appeared to be smaller than the total potential energy savings thus implying that mass implementation of cool roofs and shade trees that make both direct and indirect savings should be a higher priority than indirect saving methods (e.g. cool pavements – only indirect) [033].

Another study produced by LBNL looked at the use of 'cool communities' strategies which are the wide-scale use of planting shade trees and shifting roofs/pavements to lighter colors to examine the energy savings potential in the Los Angeles basin followed by a generalization of the findings and scaling up to the nationwide level in order to examine the potential savings of the nation by the year 2015. The method used accounts to some degree for the heating penalty in the winter and is based on estimating the physical input variables and calculating the impacts of the UHI measures on building use using meteorological models. Generalized to the entire US the results show that adopting the 'cool communities' strategies results in substantial energy use reduction (- energy savings) both directly and indirectly – estimated at 25GW avoidance with potential annual benefits of about US$5bn by 2015 [027]. Such findings in translating energy savings from the local scale to the national scale should be treated with great caution as the feeding physical parameters for each state that constitute the US vary significantly from one another – these estimate and numerical simulations provide a crude method of evaluation of the effects of mass UHI reduction measure implementation on the energy use of a region or nation.

Another LBNL study looked to identify mitigation measures that reduced the summer heat island effect in hot climates using mass albedo, evaporating surfaces, vegetative cover and increasing the urban thermal mass. The study correlates residential cooling energy and power consumption for the city of Sacramento, California with UHI intensity – this was performed using the DOE3 building energy analysis program in conjunction with micro-climate and planetary boundary layer models predicting the effects of albedo modifications on ambient conditions and micro-climates – simulations show significant energy reductions for Sacramento e.g. white washing the buildings yields 19% savings of electrical cooling energy and modifying the overall albedo in addition to the whitewashing yields 62% electrical cooling energy savings. As the study indicates there are still discrepancies between the simulation and reality and they do not consider the impact of other factors such as anthropogenic heat, assume that the albedo is the same for both rural and urban areas (lower albedo normally coupled with increased thermal storage capacity) and the model (URBMET) doesn't account for the moisture differences between rural residential areas [079]. All these factors combined would act to produce higher average temperatures and thus a lack of energy savings accuracy hence should be treated with great caution when moving out of the micro-scales.

A study originating from Japan evaluates the annual changes in energy consumption resulting from different combinations of mass UHI countermeasures (trees, vegetation, cool pavements/roofs translated as increases in humidification and albedo) and/or energy-saving measures using meteorological simulations for a typical office building district in Tokyo. It uses a UHI and energy-consumption simulation model that combines a 1D meteorological canopy model and building energy use models – expanded to evaluate the annual energy consumption. The results showed that reductions in energy consumption due to UHI countermeasures

(humidification and heat sink installation) set to reduce air temperatures during the summer were 2.8% and 1.1% respectively; with an increase of 0.1% due to albedo (heating vs. cooling demand penalty). Of the energy saving measures tested e.g. improved thermal insulation, high efficiency appliances and lighting, and high-efficiency a/c resulted in 8.1%, 15.6% and 11.6% reductions therefore the primary energy saving technologies are seen to significantly reduce energy consumption and may also contribute to the mitigation of the UHI [022]. Such methods do require further evaluation into the parameterization estimations as such models are sensitive to the input of physical characteristics and expanding such findings to the city, national and global scales won't necessarily translate without more detailed and sophisticated Modeling techniques. Moreover, it is important to evaluate the effects of energy saving techniques on mitigating the UHI effects.

Another study examines the UHI effects in two adjacent tropical cities Singapore and Kuala Lumpur. They highlight recent work for the implementation of more systematic data acquisition, the use of remote technology as well as the use of the surface energy balance Modeling. The results correlate well with findings in similar studies i.e. as temperatures rise so the a/c use increases and thus energy consumption increases. Using the DOE 2D building energy analysis program they anticipate the increase in building energy consumption due to a/c in the commercial sector is of the order of 33GWh per annum for the whole of Singapore [009]. More work is required to collect data for the inputs of the meteorological and physical input parameters as they have relied heavily on single sourced literature data which isn't always appropriate for the local context.

Thirteen studies address peak power [021, 028, 031, 033, 034, 039, 059, 066, 070, 079, 111, 112, 171] and as with energy use they were predominantly based on numerical simulations and were not results of large scale implementation and measurements.

One particular study conducted by LBNL and a UHI group from Japan present results from energy, meteorological and photochemical (air quality) modeling for the Los Angeles Basin as one of the largest urban regions in the world – they conduct simulations to evaluate the peak utility load savings for mitigating urban heat islands by implementing 'cool cities' strategies. They find that savings between 5-10% in peak utility load may be possible for the LA basin region of the US. This approach used in this study is claimed to have suitability across other regions of the world and is targeted to some degree to identify data sets needed to undertake similar analyses in various regions in Japan. It is important to keep in mind that such strategies may appear as feasible solutions to mitigate the UHI in one location but not another. As the study suggests in dry climates the increase in albedo and vegetation may be equally effective, whereas in humid climates the vegetation measure may not be optimal in humid climates as humid air does not facilitate the evapotranspiration [059]. In translating such results between regions it is important that numerical models and field measurements are tailored and collected respectively to the region under investigation.

A US study conducted at the city scale used computer simulations to test the effects of irradiance and wind reduction on energy performance of four US cities. The simulations were microcomputer-based building energy simulations that provided hourly estimations of building energy use founded on: building thermal characteristics; occupant behavior; and specific weather

data. It concluded that dense shade on all surfaces reduced peak cooling loads by 31-49% and therefore in hot climates high branching shade trees and low ground covers should be used to promote both shade and wind. This study however, makes several simplifying assumptions within both the simulation model (e.g. constant exterior film coefficients, reduced weather data) and in the input data [039]. Further research is required in isolating the contributing factors to the peak cooling load and in obtaining an understanding of the mass implementation and scale up issues associated with landscape design on the peak energy demand.

Two Japanese studies [031, 111] look to establish a comprehensive methodology for the assessment of UHI countermeasures while including the impact of these countermeasures upon urban energy demands. This study uses a composite numerical simulation system to express the city-block scale interactions between the outdoor weather and the cooling energy demands of the buildings during the summer. These studies make use of a mesoscale meteorological model which is fed by an urban canopy model and at the highest detail by a building energy analysis model. Using this system the study suggests that in large Asian tropical or subtropical cities where anthropogenic energy demand is concentrated, the UHI effects cause the increase in building demand to increase by an estimated sensitivity of 3%/degree K in Greater Tokyo, therefore about 1.6GW of additional demand is required as the regional air temperature increases by 1 degree K [031, 111]. This therefore examines the interaction between the urban thermal environment and cooling energy use and peak demand on a city scale using a multi-scale simulation. These outcomes have been verified to some degree by data from the field but such models vary from region/climate and are a composition of several complex and highly targeted models aren't applicable at larger scales without the loss of confidence in the results.

Similar such studies have evolved from the US by LBNL and have found and noted in three of their studies that the peak urban electric demand rises by 2-4% for each 1K rise in the daily maximum temperature above the threshold of 15-20°C. Therefore they conclude and quote that the additional A/C use caused by this urban temperature increase is responsible for 5-10% increase of urban peak electric demand [028, 070, 112].

The remaining studies that examine peak power take similar approaches to the ones described and consequently suffer from the same short-falls.

Only four studies addressed the CO_2 emissions due to the mitigation of the Urban Heat Island effect [035, 041, 066, 142]. One study as illustrated that follows examines the effects on CO_2 at a micro-scale and city scales [041, 066] but other two look to expand their findings to the national or even global scales [035, 142].

This micro-scale study conducts a computer simulation at a micro-individual building scale to quantify the effects of mass modification to the existing vegetation on the indirect reduction and atmospheric carbon for two residential neighborhoods in north-west Chicago. It found the effects of shading, evapotranspiration and wind speed reduction decreased the total annual reduction of carbon emissions by 3.2-3.9% per year for block (a) examined (33% tree cover) and -0.2 -3.8% in block (b) (11% tree cover) thus resulting in a total annual reduction averaging 158.7 (+/- 12.8) kg per residence in block (a) and 18.1 (+/- 5.4) kg per residence in block (b). This allowed the study to examine micro phenomena (e.g. the effects of shading and wind speed) on the annual carbon

emissions and the tree topology relevant to the buildings and their effects on during different seasonal conditions. Such methods and results provide a useful test ground for mitigation strategies and the effect of key parameters and it does indeed illustrate carbon reduction potential of such measures but these methods do not easily translate from the micro to the macro scale or even to other cities without considering the no. of heating vs. no. cooling days, fossil mix for the region, vegetation orientation with respect to the building etc.

A typical example from the other papers (both LBNL) look globally at the CO_2 reduction through increasing mitigation measures such as the urban albedo during the summertime. They estimate that by increasing the net albedo by 0.1 for urban areas on a global basis will induce a negative radiative forcing of the earth equivalent to a CO_2 offset of 44Gt. These calculations are based on aggregated results from other studies which provide inputs on aspects such as the urban area makeup (i.e. 20-25% roofs and pavements 40%) [035, 142]. These are in places over simplified calculations to approximate highly complex phenomena, founded on speculative assumptions and are not based on rigorous adapted, unified and detailed data sampling, modeling and simulations. Potential sources of error (some identified by the authors) are: estimates of radiative forcing (about 10% error); methodologies used to account for longer term effects of CO_2 on global climate aren't factored; radiative forcing effect of increasing albedo is estimated by the averaged cloud cover; estimates that the potential areas of urban surface available to increase the albedo are 1%; gross estimation of the urban make-up (roof/pavement/land areas); ability to raise albedo by 0.1 in some areas may not be technically feasible; and urban geometry isn't factored; etc. The studies are the first of their kind that aim to provide estimates at this scale and indicate that as a result of a sample of assumptions it means the CO_2 offset can range from 30Gt to 100Gt. It is however, important that the gross aggregations and assumptions made to derive offset values are addressed at the local scale and then scalable methods are derived based on higher definition models and input data before any realistic figures can emerge – therefore estimates as they stand are more ball park figures to give a feel for the range of benefits that could be attained through mass global mitigation measure deployment upon the CO_2 levels.

4.3 Review for Economic Assessments

4.3.1 Economic Assessment Principles

As mentioned earlier, the urban heat islands generated are facilitated by the rapid industrialization and urbanization which often results in replacing open green spaces with tall built surfaces that trap the sun's solar radiation as well as the fact they themselves generate large amounts of internal heat from a range of anthropogenic activities - thus resulting in higher urban temperatures and other resultant effects. As a consequence of the UHI phenomena this has an effect on the following economic aspects:

- Cost of UHI Phenomena: defined as the costs incurred by a city/state/nation/globe by experiencing the UHI phenomena - such as higher temperatures, air pollution, etc. These

are often difficult to measure but can often be indirectly measured. For example, the elevated temperatures translate into costs incurred due to increased energy consumption;

- Costs incurred by implementing UHI mitigating technologies: these are the costs incurred by implementing large scale UHI mitigation measures to combat temperature changes and other undesirable UHI phenomena.
- Savings by implementing UHI mitigating technologies: the costs which are avoided by implementing large scale UHI mitigation measures. This could be savings generated by reducing the temperature and other undesirable UHI phenomena (naturally this is dependent on the geographical location, season and time of day). For example, reductions in temperatures in urban areas that experience predominantly cooling days often translates into reductions in energy costs and thus economic savings ode to the UHI mitigation technology implementation.

This section reports the findings from UHI studies that address the above issues. Costs associated with the implementation of individual mitigation technologies at smaller scales have been addressed in the technology section that follows. This section therefore, aims to report findings which address either combined mitigation technologies at larger scales and examining the implications of the UHI phenomena upon the economics at a state, national or global scale.

4.3.2 *Economic Assessment Summary of Literature and Findings*

All the studies that provided a broader economic assessment of the UHI countermeasures emanated from the LBNL UHI Group and were US centric. The scales examined ranged from city, state, national to Global. These studies used similar methodologies to infer the economic savings by simulating the cooling/heating energy use using DOE building simulation models and often used gas and electricity prices to provide an indication of the extent of the financial savings - some studies looked at up scaling these results based on area specific data. The economic assessments demonstrated significant financial savings (particularly for the warmer climates) but indicated that the indirect savings potential was smaller than the total potential energy savings - thus greatest economic benefits arise through mass implementation of UHI countermeasures that achieve both direct and indirect savings over those that generate indirect only. Studies which provided a global estimate for the potential economic benefits of reducing CO_2 were also inferred from the CO_2 savings generated and the market trade price for CO_2 – they demonstrated significant financial benefits; however, require further investigation to improve reliability of estimates.

4.3.3 *Economic Assessment Literature Review*

There are eight studies which provide an economic assessment at a broader level (as described above) [025, 027, 028, 033, 035, 112, 142, 176]; whereas all of the mitigation technologies to varying levels of rigor have had economic assessments conducted. All the studies that provide this broader economic assessment emanate from the Lawrence Berkley National Laboratory - Urban Heat Island Group. Of these papers the economic assessments are made at the following scales: City [033]; State [025, 176]; National [027, 028, 112, 176]; and Global [035, 142].

At a City scale one study focuses on the Greater Toronto Area (GTA) in Canada [033]. This study simulates the potential of the heat island mitigation strategies (i.e. cool roofs/pavements, shade trees, wind-shielding and urban vegetation) to reduce cooling energy use in buildings in the GTA region. It accounts for both the direct and indirect effects. The study focuses on single family residential and offices and retail stores. They model defined the variety of building types available (according to their characteristics); simulate annual cooling/heating energy use and peak demand using the DOE-2 building simulation model thus determining the direct and indirect energy and demand savings for each heat island reduction strategy, finally they estimates the total roof area of air-conditioned buildings in the GTA, using existing data sources and thus were able to determine the metropolitan-wide effects of heat island reduction strategies. The gas and electricity prices were used to provide a financial estimate as to the extent of savings. Potential annual savings for GTA were found to be $11m for the heat island strategies deployed (with residential sector accounting for 59% of the savings). It is important to note that the DOE-2 model has been addressed in both this paper and others to underestimate the cooling-energy savings and potential of reflective roofs (by as much as a factor of two); the method used to estimate the actual roof area for commercial buildings was based on population and residential roof area – thus further research in this area is required to generate more accurate results and thus economic assessments. The findings indicate that the indirect savings potential appeared to be smaller than the total potential energy savings. Therefore the greatest economic benefits arise through mass implementation of cool roofs and shade trees that make both direct and indirect savings over other indirect saving methods (e.g. cool pavements – only indirect). Moreover, the study also does not address the mass use of UHI mitigating technologies in other building types within the region (e.g. hospitals, schools, restaurants, etc) thus additional financial savings aren't accounted for and may be underestimated [033].

The State and National scale studies use a similar approach to arrive at the same conclusions, therefore the principle study that is used to provide the figure for the State and National scales is examined in closer detail [025, 027, 028, 112, 176]. This study example the energy and thus monetary savings resulting from the mass implementation of cool-colored roofs on residential and commercial buildings in the main US metropolitan areas. The analysis is based on simulations of building energy use - using the DOE-2 building energy simulation program. They specify the prototypical buildings, simulate each prototypes using two heating systems (gas/electricity); then they enter this data with the weather data in to the model and run the simulation for buildings with light and dark colored roofs in a range of climates monitoring the simulation outputs (for energy use of the air-conditioning and the heating systems). Economic estimates are then evaluated from the savings generated by changing from dark to cool-colored roofs. In order to obtain the National savings the Metropolitan Statistical Area results are then extrapolated to the entire US. Annual savings for the state of California were found to be $100m per year in 2005 [025, 112]. The studies highlight that the largest savings are in individual buildings in the hottest and sunniest climates. It is important to note that the DOE-2 simulation results have been found to provide conservative estimates in comparison to field measurements. Furthermore, there is no reference in this or any other study with adapting the internal a/c system to the new cool-roofing design – e.g. buildings cooling load is shown to decrease with the use of a cool roof thus smaller units will suffice.

Only two studies ventured into the Global scale estimates with the earlier 2007 paper [142] providing the background/results used in the 2009 paper [035] looked globally at the CO_2 reduction through increasing mitigation measures such as the urban albedo during the summertime. They estimate that by increasing the net albedo by 0.1 for urban areas on a global basis will yield a CO_2 offset of 44Gt. These calculations are based on aggregated results from other studies which provide inputs on aspects such as the urban area makeup (i.e. 20-25% roofs and pavements 40%) [035, 142]. They then make a crude economic assessment based upon the price of CO_2 that is traded in Europe which at the time was $25/tone – this figure is then multiplied by the global CO_2 offset estimate of 44Gt which approximate to £1,100bn. These are in places over simplified calculations to approximate highly complex phenomena, founded on speculative assumptions and are not based on rigorous adapted, unified and detailed data sampling, modeling and simulation. Potential sources of error (some identified by the authors) are: estimates of radiative forcing (about 10% error); methodologies used to account for longer term effects of CO_2 on global climate aren't factored; radiative forcing effect of increasing albedo is estimated by the averaged cloud cover; estimates that the potential areas of urban surface available to increase the albedo are 1%; gross estimation of the urban make-up (roof/pavement/land areas); ability to raise albedo by 0.1 in some areas may not be technically feasible; and urban geometry isn't factored; etc.. The studies are the first of their kind that aim to provide estimates at this scale and indicate that as a result of a sample of assumptions it means the CO_2 offset can range from 30Gt to 100Gt. It is however, important that the gross aggregations and assumptions made to derive offset values are addressed at the local scale and then scalable methods are derived based on higher definition models and input data before any realistic figures can emerge – therefore estimates as they stand are more ball park figures to give a feel for the range of benefits that could be attained through mass global mitigation measure deployment upon the CO_2 levels.

4.4 Review for Policy/Strategic Assessment:

4.4.1 Policy/Strategic Assessment Principles

The industrialization and urbanization of land mass results in a loss of natural green space, an expansion of built surfaces both above/below ground and mass concentration of population – these all help to form the urban heat island and its well documented phenomena. In order to address the undesirable and costly side effects, referred to in chapter 2.2, a coordinated response from communities, local/national/international governments is required. Therefore, priorities for implementing urban heat island mitigation strategies must be set early on. Often the priority is given to measures that are readily available however; there is an increasing need to address these issues by adopting larger scale mitigation measures and longer term views. It is also important that such policies and strategic objectives are defined early on in order to begin to take effect upon new builds, reconstructions, adaptations and renovations in urban centers across the globe. Such policies take various forms ranging from: codes and standards, labeling, incentive/rebate and credit schemes, guidelines and educational literature.

This section reports the findings from UHI studies that address the issue of policy. Policies and strategic measures addressing the implementation of individual mitigation technologies at smaller scales have been addressed in the technology section that follows. This section therefore, in part re-iterates some salient policy findings/methods that translate from the local level but aims to report findings which address efforts made at larger scales and examine the implications of such policies upon the UHI phenomena at a state, national or global scale. Furthermore, it reports policies and strategies that have been suggested and tried/tested and their respective reported effectiveness.

4.4.2 Policy/Strategic Assessment Summary of Literature and Findings

The literature discussing the use of policy and strategy as a vehicle to enforce UHI mitigation measures was predominantly US focused, particularly for cool roofs and pavements with LBNL in California being at the forefront. Major policy exists in Europe with Germany leading the way in the green roof arena. East Asia is also developing policy relating to their mitigation efforts at national and municipal level, and a number of papers take an overview of measures and existing policies, however, these papers are less useful.

The US literature indicated that many formal mitigation strategies, policies and initiatives evolved from voluntary schemes and policy set at Federal level often just acts as a baseline for local and municipal governments to follow when developing their own strategic plans rather than dictating measures and standards.

In the warm half of the US States use the following tools to impose their cool community strategies: building and efficiency standards; offset credits; voluntary efficiency programs; and rating and labeling for building materials.

In Japan and South Korea efforts were driven by the national government and centered on developing a highly coordinated and collaborative approach amongst the ministries to develop policies and strategy to mitigate UHI. The policies focused on the reduction of anthropogenic heat emissions, improved ground surfaces and structures in urban areas and policies affecting the lifestyle of occupants all with flexible revisions founded on long-term programs. It was identified that policies should aim to be introduced early on in order to increase effectiveness in rapid expansion areas particularly addressing the architectural and urban planning dimensions. It was also identified that there is significant strategic alliance in merging policies to address climate change (at the global scale) and heat islands (at the local scale).

Natural challenges have emerged in developing policy and strategies to implement UHI countermeasures such as:

- Lack of research, modeling and general understanding of the benefits of the countermeasures; Policy development time scales;
- Developer uptake; and
- Funding and implementation complications in the retrofit market.

These issues have meant that in some areas such as pavements and urban greening, policy development is in its infancy compared to cool roofs which appears to be the most developed.

4.4.3 Policy/Strategic Assessment Literature Review

There are 24 references which discuss the use of policy and strategy as a vehicle to enforce UHI mitigation [025, 027, 034, 040, 045, 047, 060, 061, 066, 071, 073, 074, 076, 081, 093, 101, 108, 201, 210, 211, 212, 213, 214 ,215]. Of these just under 30% emanate from LBNL [025,027,034,061,066,071,201] and over 60% are studies focusing on North America [025, 027, 034, 061, 066, 071, 073, 074, 076, 081, 093, 101, 201, 212, 213]. Thus here we present the North American efforts and lessons separate from the examples from the rest of the world.

15 studies examine the policy in North America and strategy efforts. The studies indicate a strong drive across much of the stakeholder value chain with respect to addressing the UHI mitigation. It is apparent that there have been a range of initiatives from voluntary (in the form of demonstration projects) through to formal policy – in the form of codes and standards and often the implementation of voluntary standards has resulted in the adoption of more formal mandatory standards. A study conducted by LBNL in 1995 highlights the policy steps that have to be taken in order to implement such mitigation measures and uses cool surfaces (roofs and pavements) and shade tree programs as examples. It describes how a comprehensive program requires seven steps outlined in [061]:

i) Creating test procedures, ratings and labels for cool materials: this seeks to rate different paints and surface materials under a standard set of centrally controlled tests. This has helped to separate both the high from low grade materials but also drive the market towards researching and delivering high standard products that perform well in the ratings. This has been successful in the US as many manufacturers have invested heavily in achieving the 'cool status' for example: through the Energy Star for Roofing Products;
ii) Increasing information in the market by generating a cool materials central database system available to all the UHI influential value chain (e.g. from architects to contractors) – working example: the non-profit organization Cool Roofs Rating Council (CRRC) database;
iii) Integration of cool roofs and shade trees into building energy performance standards; in the US this has successfully been achieved in setting minimum requirements for commercial and residential buildings through the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE);
iv) Offering utility rebates to incentivize meeting or exceeding the performance standards;
v) Establishing well grounded information channels to distribute information at the primary level e.g. building owners;
vi) Public facility demonstrations (leading by example from the top) – throughout the US local governments have implemented or set in place demonstration and adaptation projects to promote the benefits of cool materials and other mitigation initiatives (e.g. tree planting programs); and
vii) Creating policies for the procurement of cool roofing materials by the governments from national to local level.

Recent steps taken in cities in the warm half of the US towards the integration of the cool communities strategies have been to incorporate cool roofs and pavements and green roofs and urban green areas into Building Energy Codes, Green Building Programs and Utility Rebate/ Credit and Incentive Schemes. Policy details for each mitigation measure are listed below:

North American Building Energy Codes for Cool Roofs

- **ASHRAE** is the American Society of Heating, Refrigerating and Air-Conditioning Engineers and they have developed standards for: cool materials for low sloped roofs on non-residential buildings (90.1-2007, 90.1-2004, 90.1-2001, 90.2-2004); they offer credits for cool materials for all roofs on non-residential and residential buildings in some US climates.
- The **2003 International Energy Conservation Code** (IECC) is a national model code which many States use as a basis for developing their own codes and standards. The IECC is concerned with energy conservation through efficiency in envelope design, mechanical systems, lighting systems and the use of new materials and techniques.
- **Energy Star** is a joint project between the US Department of Energy (DOE) and the US Environment Protection Agency (EPA) which demands standards on solar reflectance for low and steep sloped roofs [201].
- **The Cool Roof Rating Council** (CRRC) is involved in labelling cool roof properties as to their reflectivity and is recognized as a reference point across the US [201].
- **2008 & 2005 California Title 24 Standards**, set by the State of California, stipulate cool materials for all roofs on non-residential and residential buildings in some California climates [201].
- **Energy Conservation Codes** in Chicago prescribe materials with minimum solar reflectance and thermal emittance [201].
- **2004 Florida Building Code**, follows the ASHRAE standards and prescribes cool materials for roofs on non residential buildings

North American Green Building Programs for Cool Roofs

- The US Green Buildings Council (USGBC) run the **Leadership in Energy and Environmental Design** (LEED) Green Building Rating System which acts as a benchmark for building standards and can be used to provide credits for buildings using cool roofs through its Sustainable Sites Credit [201]. The USGBC is has a vast membership across federal, local and state government.
- The **Green Building Initiative's Green Globes**® provides a building assessment based on the building's environmental performance and sustainability, a similar program is also followed in Canada on all federal buildings called Go Green and Go Green Plus.

North American Utility Rebate/ Credit and Incentive Schemes for Cool Roofs

- **Hawaii**, cool roof credits adopted in three counties for commercial and high-rise residential buildings, based on ASHRAE
- **Sacramento Municipal Utility District** (SMUD) offers rebates for cools roofs through the use of Energy Star products [076].
- **Chicago** offers grants for green and cool roof projects [076].

- **Austin Energy** offer rebates for cool roofs that have a minimum of 75% reflectivity, the projects must also pass a cost benefit analysis [076]. Other utilities offering rebates include **Pacific Gas and Electric Company**, **Southern California Edison**, and **Idaho Power**.
- **Energy Policy Act** of 2005 offers federal tax credits for green building projects that meet ASHRAE standards

North American Green Building Programs For Cool Pavements

- **LEED Green Building Rating System** which provides credits for buildings using cool pavements through its Sustainable Sites Credit.
- Chicago's **Green Alley Initiative** uses porous paving materials whenever an alley needs to be repaved [076].
- The **Earth Craft Homes** program, developed by the Greater Atlanta Home Builders Association and Southface Energy Institute, awards points for homes that use permeable pavements [076].

North American Policy and Building Codes for Green Roofs and Urban Green Areas

- Vancouver has two green roof by-laws in cities Port Coquitlam and Richmond which mandate green roofs on all new developments over a certain size;
- Chicago, mandates green roofs on all new publicly funded and/or approved buildings;
- Tree Protection exists through ordinances which protect trees from removal or pruning, ordinances require strict enforcement through permits, ordinances can also be used for the distribution of street trees, regarding number and location [076].

North American Utility Rebate/ Credit /Grant and Incentive Schemes for Green Roofs and Urban Green Areas

- The US Senate passed the Clean Energy Stimulus and Investment Assurance Act of 2009 (S.320) and provides tax incentives for green roofs on residential and commercial buildings;
- Portland, Oregon and Seattle WA offer a Floor Area Ratio bonus written into its building code which allows an extra 3 sq/ft of building (without additional planning permission) per foot of green roof installed;
- San Francisco CA, offers expedited permits for all green building projects;
- New York City offers property tax credits for building owners who install greenery on at least 50% of their roofs. Other tax credits schemes are run in Minneapolis MN, Pennsylvania and the City of Philadelphia;
- Boston MA, tax incentives for green roofs on commercial and residential buildings;
- Green roof grant schemes in the US includes those run in Chicago and Washington DC [214]; and
- Sacramento Municipal Utility District has the longest running urban tree planting program in the US. Incepted in 1990s the program has resulted in continuous improvements in energy savings [207]; and

- Most US States encourage tree planting and urban greening, Pennsylvania's scheme TreeVitalize is an example [076].

A Canadian study has developed a multi-step approach to evaluate the feasibility and effectiveness of various UHI adaptation alternatives under financial constraints this is elaborated further in the study and applied to make policy recommendations for various parts of Montreal. It uses two fundamental guiding principles to make policy – the first is based upon a risk assessment method that seeks to target the areas which are most at risk to the UHI impacts; the second takes a pragmatic approach in seeking to adapt policy to the physical and socio-economic environment of the implementation region [101].

Three Japanese studies describe the activities undertaken by both the national and Tokyo metropolitan government to actively promote UHI mitigation measures through policy [045, 047, 210]. They appear to have taken a highly coordinated and collaborative approach amongst the ministries and in implementing comprehensive countermeasures against the urban heat island effects. The basic policies they have taken look at focusing on the reduction of anthropogenic heat emissions; improved ground surfaces in urban areas; improved urban structures and examined policies that change the lifestyle of inhabitants – these have been instigated by step-by-step approaches in order to strengthen the UHI mitigating measures with flexible revisions founded on long-term programs (allowing monitoring of the thermal environment) [045]. To date the policies implemented have seen the introduction of urban parks; tree planting schemes in both the public and private facilities; preservation of farmland; etc.. Such policies should be conducted on large scales and enforced early on in order to increase their effectiveness – more over in rapid expansion areas policy must aim to address architectural and urban planning where the study suggests the impacts on the outdoor environment have not been well considered [045].

A study from Seoul, South Korea looks at incorporating the built environment factors into climate change mitigation strategies for their city founded upon a sustainable urban systems framework [040]. It seeks to address the burden of climate change on local and regional governments developing policies that encompass the complexities of urban systems examining the entire system (including the both environmental and socio-economic issues). The framework that emerges helps decision makers evaluate climate change and mitigation strategies and these are often well coupled with urban heat island mitigation strategies [040]. This strategic framework does still require further research to model, simulate and quantify the outcomes and benefits of the individual technologies but could serve well to integrate and marry to emerging priority areas with great synergies (climate change- global and heat islands –local).

Although few papers have been found on policy developments in Europe, much work is being undertaken in green roofs. Four references consider policy for Green Roofs and Urban Green Areas. Of these sources one paper examines green roof policies with particular focus on Germany which it uses as a case study to put forward recommendations to policy makers in Canada for a similar policy outlook [212]. The other sources are websites and articles which list current policy arrangements for green roofs around the world [211, 213, 214]. Many guidebooks have been published to educate the public and building owners about green roofs and some governments

offer financial incentives for their installation [197]. Cities in Germany, Austria, Switzerland and Japan have by-laws which mandate green roofs on all new residential buildings [198].

Germany has the most formal arrangement incorporating green roofs into building codes and nature conservation acts, direct and indirect financial incentives and ecological compensation measures [212]. Little formal policy exists for urban green areas in terms of its inclusion in building codes and such, however tree planting schemes are run by Government departments, non-Government and private sector companies through incentivization and subsidization. In addition, protective legislation exists to prevent trees and parks being removed through conservation orders, tree protection orders and green belts.

The papers highlight the following Building Energy Codes, Green Building Programs and Utility Rebate/ Credit and Incentive Schemes for each mitigation measure in regions outside North America:

Building Energy Codes and Green Building Programs for Cool Roofs in Rest of World

- Cool roof codes and standards have also be introduced in **China**; **India** (Building Energy Standards), **Brazil - One Degree Less**, **Australia**, **Taiwan** and the **Middle East** although little evidence is available to discuss these codes further [201]; and
- The **European Union's Intelligent Energy Programme** is sponsoring the **Cool Roof project**. The project's aims are to investigate how to create or amend current policy to include cool roof technology as no policy currently exists [215].

Policy and Building Codes for Green Roofs and Urban Green Areas in Rest of World

- In London, UK the Mayor of London has included a Living Roofs and Walls Technical Report in the London Plan which all London Authorities must be in conformity with [214];
- Tokyo, Japan, require greening on at least 20% of the roof on all new buildings over a certain size [214];
- Toronto has initiated a green roof policy and implementation program requiring 50% of roofs to be green on all new large project buildings [214];
- Switzerland, building regulations state that green roofs must be installed for all new and renovated flat roofed buildings, this has been federal law since the late 1990s [214]; and
- Germany use the following to provide a framework for green roof policy: the Federal Building Code; the Federal Nature Conservation Act; the Environmental Impacts Assessment Act, the Land-Use Regulation; and the Wastewater Charges Act [212].

Utility Rebate/ Credit /Grant and Incentive Schemes for Green Roofs and Urban Green Areas in Rest of World

- Germany, over 80 cities offer incentives to building owners utilizing green roofs.
  - Munster in Germany offers an 80% reduction in storm water drainage fees if homeowners install a green roof on their property. 12 other cities in Germany offer similar reductions.

- 29 German cities offer subsidies to developers using green roofs [214].
- On a global scale the United Nations launched the Plant for the Planet: Billion Tree Campaign with the aim of planting 1 billion trees a year through online pledges for individuals and businesses [216].

4.5 Review for Technologies

Mitigation technologies	Number of References	Continent Considered	Climate Types Considered	List of references
Cool Roofs (including Photovoltaic roofs)	29	North America, Europe, Asia	equatorial, arid and warm temperate climates	007, 011, 015, 021, 025, 027, 028, 033, 034, 035, 047, 053, 058, 059, 060, 061, 066, 067, 070, 071, 072, 074, 079, 087, 105, 110, 112, 205, 236
Cool Pavements/Roads, etc.	26	North America, Europe	equatorial, arid and warm temperate climates	002, 021, 026, 027, 028, 033, 035, 047, 053, 060, 061, 066, 067, 068, 070, 074, 079 105, 122, 127, 128, 134, 142, 228, 229, 237
Green Roofs/Urban Green Areas	45	North America, Europe and Asia	Equatorial, arid and warm temperate climates	002, 006, 007, 010, 013, 020, 021, 027, 028, 029, 032, 033, 037, 039, 040, 041, 046, 047, 048, 053, 055, 060, 063, 066, 069, 075, 077, 080, 082, 083, 086, 087, 088, 092, 109, 111, 112, 156, 192, 193, 194, 195, 196, 206, 209
Vehicle Paints	3	North America, Asia	Equatorial, arid and warm temperate climates	059, 180, 181, 222
Other [District cooling/ Water cooling]	5	North America, Asia, India	Warm temperate, Snow	177, 178, 179, 223, 227

4.5.1 *Review for Cool Roofs:*

4.5.1.1 Cool Roof Principles

The lower the albedo of the surface roofing material of the more sunlight that falls on it is converted into heat rather than reflected back into space. The higher the emissivity of the roof surface the more that the heat stored within it is radiated away. So called "cool roofs" exploit these two phenomena by using combinations of high-albedo and high emissivity materials to minimize the amount of sunlight that is converted to heat in the roof material and maximize the amount of heat that is radiated away from the roof. This results in a cooler roof than one built of materials that trap more of the sun's heat within them. In principle the use of cool roofs will tend to lower cooling loads and cooling energy demand because they reduce the amount of solar energy entering the conditioned space from the roof and thus reduce the cooling loads. For the same reasons cool roofs tend to increase heating loads during the heating season in non-equatorial climates because less of the sun's energy is converted to heat in the roof material and conducted into the conditioned space. Nonetheless, as there is less solar energy in the winter than the summer the quantity of solar energy converted to heat within the roof is greater in the summer than the winter, thus raising the roof surface's albedo and emissivity displaces more summer heat gain than winter heat gain.

As roofs are either horizontal, or angled off horizontal, a significant proportion of the solar radiation reflected from the roof will be directed back to the sky vault. This means that increasing the albedo of roofs not only has the potential to lower air conditioning loads, and thereby lower energy use and associated CO_2 emissions, but also has the potential to reduce the amount of solar energy trapped in the troposphere by increasing the reflection of solar radiation back into space. Thus in theory there are two mechanisms by which cool roofs can mitigate global warming:

a) by lowering space conditioning loads and associated power-related emissions
b) by reducing the amount of solar radiation converted into tropospheric heat.

Cool roofs will only directly lower total annual space conditioning loads if they cause a greater reduction in cooling energy than they cause an increase in heating energy over the year. This is dependent on:

- The degree to which there is a change in the roof surface material temperature from the use of the cool roof technology.
- The thermal coupling of the roof space to the conditioned space i.e. the extent to which internal space conditioning loads are influenced by the roof surface material temperature.
- Whether or not the building stock has both active cooling and heating systems installed (otherwise the impact is only felt via changes in thermal comfort, which is the trigger event for the installation of active space conditioning when thermal discomfort outweighs the inconvenience and cost of installing and operating space conditioning).
- The respective energy efficiency of the active-cooling and heating systems.
- The control regime of the active-cooling and heating systems.

4.5.1.2 Cool Roof Summary of Literature and Findings

A majority of the studies emanated from the LBNL Urban Heat Island Group and most had a focus on North American and Canadian cities. It was demonstrated by experimentation, modeling and simulation that the use of cool roofs both light colored and dark have the capacity to reduce the roof and thus building surface and city temperatures. Of the papers that examined the implementation of cool roofs as a UHI countermeasure, it was noted that they have a marked reduction in the associated energy, peak power and CO_2 emissions. Furthermore, it was recognized that reflective roofs are most effective where there is a high roof to volume ratio and that savings are greatest for buildings located in climates with longer cooling seasons and short heating seasons. The benefits in equatorial, arid and warm temperate climates have lead to incentive programs, product labeling and standards to promote cool roofs.

The papers identified that many factors can contribute to the energy savings - apart from the roof albedo including: daily energy patterns, energy efficiency of cooling systems – if present at all, and insulation. Of the studies that examined costs it was demonstrated that high albedo alternatives are available at little extra cost. Where newly developed materials were involved the slightly higher initial costs were offset when examining the life-cycle costs due to longer roof life and energy savings. It was acknowledged that there was a loss of roof reflectivity due to weathering, dirt, pollution, microbial growth (particularly in humid climates) – however, this was proven to be effectively overcome by regular washing.

4.5.1.3 Cool Roof Literature Review

There are twenty-nine references which addressed the use of cool roof technology to mitigate the urban heat island effect, of these 60% of the studies emanate from the Lawrence Berkeley National Laboratory Urban Heat Island Group [011, 021, 027, 028, 033, 034, 035, 059, 061, 066, 070, 071, 072, 079, 105, 110, 112, 236] with nearly all recorded studies using key results, conclusions and experiments originating from LBNL studies.

Fifteen studies examined the effects of reducing the roof albedo and the associated power related emissions. This was conducted either through small scale experimentation or by using models and simulations with micro scale data inputs. It was noted through many of these studies that raising the roof reflectivity from an existing 10-20% to about 60% can reduce cooling-energy use in buildings in excess of 20%. It was also reported that reflective roofs are most effective on buildings where there is a high roof to volume ratio [007, 015, 021, 025, 027, 033, 034, 035, 058, 061, 070, 072, 074, 079, 112]. One particular study conducted in Sacramento, CA examined whitewashing buildings yielding direct savings of 14% in cooling peak power and 19% in electrical cooling energy (micro-scale). This same study extended its results to the city level (macro-scale) and found that increasing the albedo of the city in addition to whitewashing can result in savings of up to 35% cooling peak power and 62% electrical cooling energy [079]. These particular studies were focused on North-American and Canadian cities. Only one study originating from LBNL, attempted to quantify the global effect of increasing the albedo of roofs in urban areas that would induce a negative radiative forcing on the earth equivalent to a CO_2 emissions offset – it concluded that for a 0.25 increase in albedo of cool roofs and at 64kg CO_2/m^2;

the global emitted CO_2 offset potential for cool roofs was about 24Gt of CO_2 [035]. This estimate however, is a result of aggregation of previous results/estimates/phenomena observed at the micro scale, aggregated and translated to the macro scale – such estimates should be approached with caution.

Fourteen studies examined the temperature reduction ode to increasing the albedo of the roofs. It was first noted that for low albedo roofs the temperature difference between the surface and the surrounding air can be as high as 50K and secondly that for high albedo surfaces this can be lowered to 10K [007, 025, 026, 027, 028, 059, 067, 070, 072, 074, 079, 087, 112, 205, 236]. One recent study, that conducted extensive testing on cool colored roofing materials found that on average cool dark roofs were 14K cooler than the traditional dark roofs (with a 0.25 difference in albedo between them) [025].

Two studies examined the relationship between the roof temperature and the internal building. They found that for cool dark roofs conduct about 20-40% less heat into a home's conditioned space and that a building with cool colored roofing can have building air temperature inside the building reduced by 7K over the traditional colored roofs [025, 079].

Two studies tested new paints and coating for roofing and shingles:

- The first study tested eleven thermochromic coatings for building surfaces and compared them to color-matched cool surfaces and a traditional roof surface. Thermochromic coatings have the ability to change color depending on their temperature, which in this case was 30°C, from colored (absorptive) to colorless (reflective). The study showed that mean daily surface temperatures were lowest for the thermochromic coated surfaces, up to 38.4°C, up to 44.6°C for color matched surfaces and up to 48.5°C for a traditional surface. Thermochromic coatings had higher solar reflectance values at colored and colorless stages compared to the other surfaces. Further research is currently being conducted to improve the material's photodegradation [205].
- In the second paper Levinson et al at LBNL produced a recent paper on a new technique to produce cool colored roofing products. Two layers of quick-dry paints were applied to 24 tiles and shingles. The first layer was a white basecoat of titanium dioxide rutile which increased solar reflectance, the second layer was a cool color topcoat (red, brown, green and blue) with weak near-infrared absorption and/or strong near-infrared backscattering. The results of the experiment were that the dark brown tiles and shingles had the lowest solar reflectance value and the light green had the highest in both tiles and shingles. The paints increased the solar reflectance in over 50% of the samples by 0.25 which means that they can be successfully used on darker products making them more solar reflective than conventionally colored products. Further increases could be achieved by increasing the thickness of the paint and making further alterations to the materials in the top and base coats [236].

In general, most studies recognized the savings are clearly smaller for buildings with higher roof insulation and concluded that albedo modification are more effective as an energy reduction measure for buildings with little or no insulation [015, 025, 079, 176]. One study indicated that A/C energy savings were approximately inversely related to roof insulation - from 11% savings in

the insulated house to 43% savings in the un-insulated house [061]. Most simulations accounted for insulation when defining the prototypical house, others however, rejected the impact of such building design factors [021, 033, 072].

Most models generate useful estimates from mitigating measures such as cool roofs but the exact energy savings are difficult to compute for a given site. Many factors come into play apart from roof albedo: daily energy patterns; energy efficiency of cooling systems (lack of presence of cooling systems – as is the case for poorer regions and some non-commercial buildings); and the type of insulation [021, 025, 058]. Such parameters are important considerations that have to be accounted for in conducting scale up of micro phenomena. There was little attention given to control in cooling/heating systems, though it was mentioned that A/C are often difficult to regulate to produce comfortable temperatures and thus a cool roof system would help to reduce the A/C intensity and assist with the control of the building temperature [025].

Four studies indicated that there have been significant design efforts in adapting the more traditional colored roofing materials by identifying and characterizing pigments to include/exclude in the colored cool roofing material design. Cool colored roof material on average had 0.22 higher albedo than their traditional counterpart – resulting in a maximum of 12K reduction in the material surface temperature. This temperature reduction was tested and thus quoted to equate to a maximum of 600W peak power savings and an annual cooling energy saving of 650kWh – with the cost of heat loss in the winter months from reflected incident solar gain less than 30% of the cooling savings [025, 061, 071, 072, 112].

Four Studies demonstrated that roofs are typically repainted or replaced every 10-20 years, and high albedo alternatives are available at little extra cost with the exception of some newer materials (e.g. asphalt shingle roofing with ceramic coated granules). Typical payback periods for a majority of high albedo materials ranged from 0-10 years again with the exception of the very latest products quoted to be 8-19 years. High albedo roofing options for new builds may require a higher initial investment but are often more attractive when life-cycle costs are examined – due to longer roof life and energy savings [021, 025, 061, 071].

Limited studies addressed the cool roof penalties in hot vs. cold conditions and similarly these conditions at different geographical locations. A simulation study for Toronto, Canada found that for residential buildings the cooling energy savings were written off by penalties in heating energy use [033]. Another study, concluded that there was no winter penalty for the US state of Mississippi for employing cool roofs [072]. In general it was acknowledged that it depended upon the aggregation of a complex set of influential factors such as the geographical location, time of year etc. This hasn't been extensively reviewed for other climates but is indicated that savings are greatest for buildings located in climates with long cooling seasons and short heating seasons, but this requires data collection and field experimentation as conducted in the US, Japan and parts of Europe – note: over 90% of the studies referred to experiments and models were conducted for North American or Canadian cities [015, 025, 027, 033, 034, 061, 066, 071, 072, 113, 114].

The acknowledged benefits of cool-roofs in certain climates (predominantly in equatorial, arid and warm temperate climates) have resulted in several incentive programs, product labeling and

standards to promote the cool roofs. Some of these programs were through voluntary incentives and others through mandatory requirements – much of this focus and implementation has been in North America though there is a growing interest for such efforts to be implemented in Japan and Europe. It is important however, that the effects of each mitigation measure are fully understood and quantified when employed collectively and that they are adapted to the specific geographical and climatic conditions the regions looking to deploy them [028, 034, 061, 071, 074].

Most studies acknowledged the loss of reflectivity due to: weathering, accumulation of dirt/pollution, microbial growth (particularly in humid climates). Six studies looked at this issue in greater detail and concluded that the solar-reflective properties of roofs can diminish by about 15% in the first year followed by an annual 2% decline in solar reflectivity in subsequent years though this was material dependent. Other research showed that regular washing can restore the reflectivity up to 90-100% [011, 015, 025, 033, 060, 071]. Finally, further research is required to investigate the effects of soot deposition and weather degradation on cool roof performance.

4.5.1.4 Status of Cool Roof Policy Review

Cool roof standards, programs and incentive schemes are prevalent and well established across the USA championed by the US Environmental Protection Agency, LBNL and the US Cool Roof Rating Council. They are less common however in Europe, where the technology is less known and little research has been conducted [200], although the European Union are launching a project called the Cool Roof Project to counter this. Cool roof policies are commonly written into building regulations (typically building energy efficiency standards/energy codes) Green Building Programs, and Utility Rebate/ Credit and Incentive Schemes. Many guidebooks and educational information exist on the technology which raises public awareness and dispels cynicism. Codes such as ASHRAE, IECC, Energy Star, CRRC and Title 24 Standards (California) are the most well documented and further descriptions are available in section 4.3.

4.5.1.5 Critique of Cool Roof Literature and Emerging Issues

Despite great interest across the world's UHI groups in the use of cool roof technology as a UHI countermeasure, a majority of the studies have originated from the Lawrence Berkley National Laboratory UHI Group and many studies refer back to the key results in these studies. This has resulted in a narrow field of study where focus has been on North American and Canadian cities. Therefore there has been testing, modeling and simulation of cool roofing technologies in a limited range of climate types found in North American and Canadian cities.

In the LBNL study the estimates seek to present the effect of increasing world-wide albdeos of urban roofs and paved surfaces during the summertime by inducing a negative radiative forcing on the earth in terms of CO_2 emissions offsets. They estimate that by increasing the net albedo by 0.1 for urban areas on a global basis will yield a CO_2 offset of 44Gt (24Gt ode to cool roofs). These calculations are based on aggregated results from other studies which provide inputs on aspects such as the urban area makeup (i.e. 20-25% roofs and pavements 40%) [35,142]. These are in

places over simplified calculations to approximate highly complex phenomena, founded on speculative assumptions and are not based on rigorous adapted, unified and detailed data sampling, modeling and simulations. Potential sources of error (some identified by the authors) are: estimates of radiative forcing (about 10% error); methodologies used to account for longer term effects of CO_2 on global climate aren't factored; radiative forcing effect of increasing albedo is estimated by the averaged cloud cover; estimates that the potential areas of urban surface available to increase the albedo are 1%; gross estimation of the urban make-up (roof/pavement/land areas); ability to raise albedo by 0.1 in some areas may not be technically feasible; and urban geometry isn't factored. The study does indicate that as a result of a sample of assumptions it makes, the CO_2 offset can range from 30Gt to 100Gt. It is however, important that the gross aggregations and assumptions made to derive offset values are addressed at the local scale and then scalable methods are derived based on higher definition models and input data before any realistic figures can emerge – therefore estimates as they stand are ball park figures to give a feel for the range of benefits that could be attained through mass global mitigation measure deployment upon the CO_2 levels.

The models used to estimate the energy savings from the cool roofs did not always account for all the parameters which may affect the energy consumption within a building/city. Several critical parameters that contribute to the energy consumption apart from the roof albedo include: the daily energy use patterns of the occupants, the energy efficiency of cooling systems (if present – depends on climates and regions of the world e.g. in Europe A/C mainly found in commercial buildings but not always present in residential buildings except often in Mediterranean climates), and the insulation systems (grade and type) and materials used. Such parameters are important considerations and are critical particularly when scale up of micro-scale phenomena is used to establish macro-scale estimates. Limited attention was given to the control in cooling/heating systems despite a mention of the challenge in regulating internal temperatures to ensure occupant comfort and the reduction of A/C intensity (due to cool roofing) in assisting with building temperature control. It is also important to note that in different climate types and regions of the world occupant tolerance levels vary (costs associate with heating/cooling, nature of the climate, culture, etc) and it appears that such considerations have been overlooked in most studies.

Despite studies examining the costs and benefits associated with the use of cool roofs over traditional roofs, several factors were not included in the financial analysis and thus could affect the choice of roofing surface and viability of cool roofing materials. The factors that were not accounted for include: roofing design and accessibility for installation and maintenance, cost reductions associated with a decrease in the peak electric demand for cooling, extended life of cool roofs (as they are less affected by thermal cycling), any incentive schemes for cool roofing, and effectiveness in different climatic zones. Despite these shortfalls the early indication is that the newer cool roof designs often have a slightly higher initial investment but have the potential to be more attractive when examined on a life-time basis.

From the papers that addressed the penalties in hot vs. cold climates the outcomes are often case specific and not always easily transferrable to other climate types and cities. The mass aggregation of a complex set of influential factors such as geographical location, building orientation, time of year, efficiency of heating/cooling equipment, etc. are difficult to quantify.

The expected savings generated in climate types where the length of cooling seasons relative to the heating seasons is larger requires further investigation – the collection of field data, experimentation, modeling and simulation in all of the varying climate types across the US and the rest of the world are required before generalizations can be extracted for certain climate types. It is important to keep in mind that the outcomes of such studies must always be examined on a case specific basis before mass implementation of cool roofs takes place.

Studies acknowledged the loss of reflectivity in cool roofs due to factors such as weathering, pollution, dirt and microbial growth but demonstrated that regular maintenance can restore such reflectivity. It is however, important that further research is conducted to investigate effects of soot deposition and weather degradation which are consequences of densely populated functioning cities and research is targeted to investigate how reflective roofs can be designed and maintained to prevent the rapid microbial growth that hampers the roof performance especially in humid climates.

In summary:

- Cool roofs research (experimentation, modeling and simulation) needs to be expanded to cover all North American climate types and beyond;
- Further research is required to understand the effect of high albedo roofs deployed at large scale together with validation of micro/macro scale models;
- Further research should be undertaken for thermochromic coatings to improve their lifespan and make them more resistant to thermal degradation;
- Data sampling particularly to define urban area make-up and other input data, as well as, modeling and simulation are required to evaluate effect on energy consumption and CO_2 as a result of mass cool roof implementation;
- In moving from micro-scale phenomena to macro and global scale estimations it is important that research is focused on gaining a greater understanding of the basic influencing processes;
- Future studies, research and decisions need to be founded on an understanding of all parameters that affect the energy consumption (thus also CO_2 emissions): energy use patterns of occupants; efficiency and control of cooling/heating systems (if present at all); insulation grade/type; human tolerance and comfort levels;
- Investigation into the quantification of relative benefits for using higher grade insulation combined with/or instead of albedo roofs is required;
- Future cost examination should account for complete lifecycle costs including the effects of factors such as: the decrease in peak electric demand; roof design; roof maintenance; thermal cyclic effects on life span of roof, etc.;
- Further detailed investigation is required to understand the effect of soot, dirt, microbial growth on the roof performance;
- More extensive research is required in collecting data and testing reflective roofing materials in different climatic zones both at the micro and macro scale. Such research should be expanded from the US, Japan and limited parts of Europe in order to quantify the relative benefits/penalties in a range of climates. Such research still remains to be conducted to cover all climate types in the US.

4.5.2 *Review for Cool Pavements:*

4.5.2.1 Cool Pavement Principles

Similar to the principle of cool roofs, a low albedo of the paving material, implies that more of the sun's energy is absorbed thus directly increasing the pavement temperature and indirectly heating the surrounding air and helping the formation of urban smog. When solar radiation is reflected from a pavement surface some of it escapes the urban canopy and enters into space; however, depending upon the sky view factor some may be intercepted and partially absorbed by exterior building walls. The larger the thermal emittance coefficient (more significant for pavements than roofs) the less heat is stored within the paving surface and thus there is less heat stored to release after sunset hours. These two fundamental properties maximize the amount of heat that is radiated away from the paving surface. This results in a cooler pavement than ones built from materials that act to retain the sun's solar energy as heat within their structure. In principle, the cooler pavements will tend keep the surrounding air cooler and thus reduce the demands on cooling loads. With similar logic, the cool pavement tends to increase the demand on the heating load during the heating seasons in non-equatorial climates. This is ode to less of the solar energy being converted into heat in the pavement structure and thus less heat is conducted into the surrounding air which would act to warm buildings and therefore reduce the heating load. Nonetheless, as there is less solar energy in the winter than the summer the quantity of solar energy that is converted into heat in the pavements is greater during the summer months than in the winter months. Raising the albedo, thermal emittance and porosity acts to displace more summer heat gain than winter heat gain.

Pavements can reflect a significant portion of the solar radiation away from the urban surface and mostly direct it back towards the sky vault. The increase in albedo (along with the other key properties that help define a cool pavement) have the potential to significantly affect the urban air temperatures and thus reduce the A/C loads, thereby reducing the energy use and CO_2 emissions. In theory, there are two mechanisms by which the cool pavements can mitigate global warming:

a) by indirectly lowering the atmospheric temperature they can lower the demand on space conditioning loads – associated to power-related emissions;
b) by directly reducing the amount of solar radiation converted into tropospheric heat.

Cool pavements will indirectly lower the total annual space conditioning loads if they cause a greater reduction in the cooling energy than they cause an increase in heating energy over the year. This depends on:

- The degree to which there is a change in the pavement material temperature from implementing cool pavement technologies;
- The climates in which the pavements are designed to operate – i.e. permeable pavements often maintain their "cool" status better in wet conditions through evaporative cooling;

- The degree to which the change in air temperature associated from using cooling pavements will affect the buildings and their cooling loads;
- Whether or not the building stock has both active cooling/heating systems installed (otherwise the impact is only felt through changes in thermal comfort);
- The energy efficiency of active-cooling and heating systems;
- The control regime of the active-cooling and heating systems.

4.5.2.2 Cool Pavements Summary of Literature and Findings

A majority of the studies emanated from the LBNL Urban Heat Island Group and were North American centric. The term pavements were loosely defined but this review classified them as urban streets, driveways, parking areas and footpaths. It was demonstrated predominantly by modeling and simulation case studies that the use of cool pavements can have a reduction on the near ground temperatures of cities. It was however, difficult to isolate and attribute the indirect energy and peak power savings from pavements due to the nature of indirect measurements and the fact that cool pavements were often studied in combination with other UHI countermeasures. The indirect savings potential (achieved by reflective roofs/pavements and vegetation) forms only a small fraction of the total potential savings – it was concluded that higher priority should therefore be given to measures that have both direct and indirect effects on the temperature and thus energy savings and CO_2 e.g. roofs and shade trees.

A large range of different cool pavement alternatives exist and are to varying degrees constrained by their intended end-use. Apart from the reflectivity and thermal emittance the cool permeable pavement designs have the capacity to remain cooler than non-permeable equivalents when wet. Due to the immaturity and complexity of the cool pavement technology few studies addressed the associated costs – however, early indicators show that they are more costly than conventional designs. It was acknowledged that there was a loss of pavement performance (in terms of reflectivity) due to weathering, dirt accumulation/pollution, use, age, etc but this requires further case specific evaluation. The benefits, complexity and lack of data on cool pavements performance in certain climates/conditions has meant research has tended to take precedence over policy.

4.5.2.3 Review of Cool Pavements

There are twenty-six references which addressed the use of cool pavement technology to mitigate the urban heat island effect. Cool pavements were loosely defined by most papers, thus in this review the papers reviewed define pavement technologies to include: paving for urban streets, driveways, parking areas and footpaths. Over 50% of the papers emanated from the Lawrence Berkley National Laboratory Urban Heat Island Group [021, 027, 028, 033, 035, 061, 066, 068, 070, 079, 105, 112, 128, 134]. The results of the LBNL studies tended to some degree form the foundation for much of the remaining work/conclusions drawn for the other studies.

Nine studies examined the effects of albedo and other design parameters on lowering the ambient temperature and thus the associated energy savings, peak power and power related emissions of which five studies were conducted by LBNL [002, 021, 033, 035, 066, 073, 079, 112, 142]. The studies collected data on the local scale and then used models and simulations to

evaluate the savings. Most studies took the case study approach and thus concentrated on evaluating the combined benefits of increased albedo for roofs and pavements and the use of shade trees and vegetation on specific cities (mostly North American examples). It was difficult to isolate the indirect savings or peak energy savings from the pavements as aggregations of the other mitigation measures, this added to the complexity of the problem. In one study, which examined such aggregated mitigation measures employed to five North American pilot cities and simulated - collective mitigation measures yielded 17% savings for the total electricity, 20% for gas penalties and 19% for peak demand savings. The indirect contribution to peak demand savings ranged from 9% in Chicago to 30% in Houston – it was also concluded that most cold climates percentage of inner heating penalties was fairly small but indicated that the absolute penalties may be higher [021].

Another study took the approach of Modeling the effects of hypothetical scenarios such as examining the model with the input that temperatures had been lowered due to a combination of roof and pavement "cool" modifications – they concluded that in the US the increase in air temperature is responsible for 5-10% of urban peak electricity demand for A/C use and also contributed by as much as 20% of the population weighted smog [112].

Three studies examined the cool pavement phenomena on a global scale to mitigate carbon, two from LBNL and the other using results inferred from an LBNL study [035, 073, 142]. The one study made the assumption that pavements typically constitute 40% of urban surfaces – increasing the pavement albedo by 0.15 globally could lead to a negative radiative forcing on the earth equivalent to a 20Gt of CO_2 emissions [035]. The other study written in 2007 estimates that increasing the pavement albedo in cities worldwide from an average of 35% to 39% could result in global CO_2 emission reductions worth $400bn [073, 142]. Both of these studies make gross aggregations which limit the accuracy of such statements [035, 073, 142].

Another US based study conducted in Phoenix examined the option of using photovoltaic canopies over vegetative canopies to reduce the temperature of pavements and thus mitigate UHI – it concluded that even though the vegetative canopy was more effective there was still a new opportunity for photovoltaic canopies to mitigate the UHI at the micro-scale but still research was required to quantify the life-cycle benefits of this renewable energy mitigation solution [002]. A case study in Toronto, Canada indicated that the indirect savings potential (to be achieved by a combination of reflective roofs/pavements and vegetation) was only a small fraction of the total potential savings – they concluded that higher priority should be given to roofs and shade trees that have both direct and indirect effects on the energy saved [033]. The direct vs. indirect benefits and prioritizations need to be quantified and researched across different climate types in order to draw such conclusions further afield than the case study in question. Broadly, most studies indicated that measuring the impacts from cool roofs was relevantly easy compared with quantifying the benefits from cool pavement solutions – pavements affect building energy demand through influencing air temperature which is a significantly more complex relationship to isolate and measure. Furthermore, the studies acknowledged that installing pavements can be part of a wider strategy to reduce air temperatures resulting in benefits such as reduced energy use, air quality and green house gas emission reduction, water quality and increase in the effective pavement life though these

benefits are complex to measure directly. Further research is required to collect data on cool pavements and to identify methods of isolating and quantifying the benefits.

Eleven studies examined the temperature reduction capabilities ode to increasing the albedo of the pavements [026, 035, 066, 067, 070, 073, 079, 112, 127, 128]. The studies broadly confirmed that increasing the pavement albedo would decrease the pavement temperature. LBNL data quoted indicated that increasing the pavement albedo by 0.25 would reduce the pavement surface temperature by up to 10K [070, 112]. Other LBNL estimates have shown that if pavement reflectance throughout a city was increase from 10% to 35% the air temperature could be reduced by 0.6k [128]. One study stated that atmospheric models demonstrated that most of the infrared radiation from the pavement was absorbed within 200m of the lower atmosphere – thus affecting the near ground temperature [127]. Two studies study ran a simulations for Los Angeles California and examined the aggregated effect of resurfacing increasing the albedo - one of these studies looked to replace 2/3rds of the reflective surfaces (pavements and roofs) and planting three trees per house and the other to increase the average albedo in downtown LA by 0.08 during the summertime and in the Californian south coast air basin by 0.13 – results showed temperature across LA could be reduced on average between 1.5-3K and the south basin of California by 2K [026, 112]. All these studies were conducted for US cities under controlled models and simulations and therefore require further investigation for a range of different climates. One study tested the solar spectral properties of five colored thin layer asphalt samples against traditional black asphalt. Results showed that the colored asphalt had higher levels of solar reflectance, and lower surface and air temperatures, by as much as 12°C. The researchers used a range of field measurements and Computational Fluid Dynamics simulation [237]. Only one study tried to isolate and quantitatively assess the effects of paved surface on the near surface atmospheric model – critical to understand what factors affect atmospheric temperature [127]. There needs to be a focus on trying to quantify the cool pavement effects on temperature in isolation to the other mitigation measures. Moreover, pavement temperatures are affected by both radiative and thermal characteristics - these are complex to model but are essential if estimates are to be accurate.

Ten papers examined other cool pavement designs (i.e. apart from just altering the albedo) taking advantage of the effects of factors such as permeable surfaces which retain water and allow evapotranspiration [047, 067, 068, 073, 127, 128, 134, 228, 229]. One paper conducted field tests in Athens, Greece for prototype cool color painted asphalt pavements which saw 15K temperature reductions [026]. It was evident that not just albedo modifications have been examined in the studies - permeable pavements was a key area of research. These pavements allow the air and water to flow in the pavement voids, examples of such technologies being developed were: porous asphalt/concrete, permeable pavers, grid pavers to incorporating sprinkler systems in some cases. It was suggested that when wet such cool pavement technologies may remain cooler than the non-permeable equivalents – however the dry conditions may have the opposite effect [068, 073]. A recent study into the heat balance characteristics of pervious and impervious concrete pavements by Kevern, Iowa, measured samples of each for their temperatures at various depths as well as their heat storage capacity. He found that pervious concrete stores less energy than traditional pavements so can help mitigate the UHI [228]. Water retentive paving materials were tested for evaporation efficiency and heat budget in Japan and results found that surface

temperature decreased as water retention increased and evaporation efficiency deteriorated as the material lost water. The experiment accuracy was about 10% compared to the weighing of materials [229]. A complicated range of factors (apart from the albedo and emittance - accounted for to some degree in most studies) affect the temperatures of the pavements, thus more data on all types of cool pavement technologies operating in a range of different climates and functional conditions are required to determine the exact impacts pavement temperatures and thus on UHI mitigation.

Seven studies examined the costs associated with constructing or implementing various cool pavement technologies [027, 028, 068, 070, 073, 112, 187]. Few studies provided a detailed cost breakdown for each individual technology - reasoning for absence or generalizations can be attributed to the costs of cool pavements being dependent on several complex factors: region, local climate, contractor, time of year, project size, design life, etc. Most studies, however provide a hypothetical breakdown or specific scenario analysis [070, 073, 068, 112]. One economic estimate indicated that cooler pavements are more expensive by up to $10/square foot for non-vegetated permeable pavement blocks vs. conventional asphalt [073]. Most studies highlighted that there are a range of benefits and drawbacks that need to be accounted for in any costing for cool pavements (e.g. life time extensions of roads due to lower temperatures, reflective pavements may imply lower night-time artificial lighting, etc.). For example, simulations conducted in one study showed that pavements that were cooler lasted 10 times longer than hotter pavements, and pavements that were 22K cooler lasted up to 100 times longer [074]. There is the need further investigation in order to understand the life-time cost and the implications of the cool pavement that are proposed to have a lifetime on average of 20 years [068, 112].

Studies indicate that the potential benefits of cool pavements in certain climates/conditions and the drive to reduce urban temperatures has generated a growing interest predominantly in the research aspects of the cool pavements rather than policy mainly due to the lack of data and gaps in knowledge. However, in the US there is a drive in parallel to begin to create test procedures, ratings and labels for cool materials such as cool pavements [028, 061, 074].

Three studies acknowledged the loss of reflectivity due to: weathering, accumulation of dirt/pollution, use, age, etc [070, 071, 112, 128, 134]. One study tried to quantify the aging effects on new conventional asphalt surfaces – demonstrated that for new surfaces having an albedo of 0.04 and after about 5 years having an albedo of 0.12 +/- 0.02 ode to a combination of: wear (exposing lighter aggregates); oxidation; soiling/dirt of lighter color [128]. Another study conducted by LBNL provided a comprehensive analysis of varying the albedo characteristics of cements of varying composition – they found that weathering of cement can decrease albedo by as much as 0.19 [134]. Further research is required in order to assess the relative benefits/drawback this change in albedo may have on the performance of both cool and standard materials.

Apart from one study in North America [021] the studies didn't focus on the cool pavement penalties in hot vs. cold conditions and similarly these conditions at different geographical locations – all studies except one conducted in Greece were US centric. Little attention was given the effects of increases in temperatures due to pavements or the effect of the sky view factor on the effectiveness of any cool paving technologies. Moreover, factors such as efficiency and

controls of the active cooling/heating systems and building insulation appeared to be neglected in the literature reviewed to date.

4.5.2.4 Status of Cool Pavement Policy Review

The status of cool roofs policies is far more advanced than cool pavements. Currently few policies exist in this area with the exception of the LEED Green Building Rating System which provides credits for buildings using cool pavements through its Sustainable Sites Credit. A scheme in Chicago called the Green Alley Initiative uses porous paving materials whenever an alley needs to be repaved, this was borne from a demonstration of the benefits by the City of Chicago [076]. On a residential level the Earth Craft Homes program, developed by the Greater Atlanta Home Builders Association and Southface Energy Institute, awards points for homes that use permeable pavements [076]. A reason for this could be that not enough research and modeling has been undertaken, both technical and economic, and a lack of support from the government and institutions for this technology with most of the focus being on cool roofs.

4.5.2.5 Critique of Cool Pavement Literature and Emerging Issues

The cool pavement research predominantly has a US focus with a small emphasis in limited parts of Europe, with a majority of the research originating from the Lawrence Berkley National Laboratory UHI Group. This has therefore resulted in a concentrated field of research centered on North America. Thus any field experiments, modeling and simulations of the range of cool paving materials were predominantly evaluated in a limited range of climate types found in North America.

A majority of the studies used the case study approach and concentrated on evaluating the collective benefit of increased albedo for roofs, pavements and often shade trees and vegetation - it was therefore difficult to isolate the indirect savings (energy, peak power and CO_2) that could be attributed to cool pavements. Such aggregations of mitigation measures added to the problem complexity. The studies indicated that the challenges faced in measuring cool pavements as opposed to cool roofs are significant simply due to the complexity of measuring the pavement's influence upon building energy demand - this implies that there still remain significant challenges to be overcome in establishing such estimates. Only one study tried to isolate and quantitatively assess the effects of paved surfaces on the near surface atmospheric model – this remains critical to understanding how pavements affect the atmospheric temperature [127]. The modeling of radiative and thermal characteristics is highly complex but essential for accurate estimates, it is critical that the influencing factors are understood, quantified and field data is collected – these steps are essential in helping engineers, designers and planners make the appropriate designs and selections in cool paving technology and implementation.

In the LBNL study, the estimates seek to present the effect of increasing world-wide albdeos of urban roofs and paved surfaces during the summertime by inducing a negative radiative forcing on the earth in terms of CO_2 emissions offsets. They estimate that by increasing the net albedo by

0.1 for urban areas on a global basis will yield a CO_2 offset of 44Gt (20Gt due to cool pavements). These calculations are based on aggregated results from other studies which provide inputs on aspects such as the urban area makeup (i.e. pavements 40%) [35,142]. These are in places over simplified calculations to approximate highly complex phenomena, founded on speculative assumptions and are not based on rigorous adapted, unified and detailed data sampling, modeling and simulations. Potential sources of error (some identified by the authors) are: estimates of radiative forcing (about 10% error); methodologies used to account for longer term effects of CO_2 on global climate aren't factored; radiative forcing effect of increasing albedo is estimated by the averaged cloud cover; estimates that the potential areas of urban surface available to increase the albedo are 1%; gross estimation of the urban make-up (roof/pavement/land areas); ability to raise albedo by 0.1 in some areas may not be technically feasible; and urban geometry isn't factored. The study does indicate that as a result of a sample of assumptions it makes, the CO_2 offset can range from 30Gt to 100Gt. It is however, important that the gross aggregations and assumptions made to derive offset values are addressed at the local scale and then scalable methods are derived based on higher definition models and input data before any realistic figures can emerge – therefore estimates as they stand are ball park figures to give a feel for the range of benefits that could be attained through mass global mitigation measure deployment upon the CO_2 levels.

The papers demonstrate that several different innovative designs are available for cool pavements including permeable pavements that would allow air and water to flow in the pavement voids – it was suggested that although the wet porous pavement technologies remained cooler than the non-permeable equivalents, the same did not apply in dry conditions. Therefore, further research in the form of field experimentation and data collection is required in a range of operating conditions and climates in order to determine the exact impacts on pavement temperatures and thus on UHI mitigation capabilities due to various adaptations of the pavement technologies.

Despite studies to varying degrees examining the costs associated with constructing and implementing various cool pavement designs few of the studies provided a detailed cost breakdown for each individual technology. Reasoning can be attributed to the fact that pavement cost is highly dependent on a range of complex design and implementation factors including the region, local climate, contractor, project size, design life, intended use, etc. Further research is however required to understand the implications of these variables and their impact upon the life-time costs and viability of cool pavement options – it is likely that such cost breakdowns should be reviewed on a case specific basis given the range and complexity of influencing variables.

Studies acknowledged the potential loss of reflectivity due to weathering, dirt, pollution, use, age, etc. It is critical that field experimentation is conducted on implemented cool pavement designs in order to understand the effects of each of these variables upon the performance of the cool pavement technologies – there is little value in implementing an expensive cool pavement technology that loses significant performance within a few weeks of installation.

A limited number of studies examined the penalties in hot vs. cold conditions and similarly these conditions in different geographic locations. Little attention was given to the effect of

temperature increases due to pavements and the effect of the sky view factor upon the effectiveness of cool paving technologies. Furthermore, factors such as controls of the active cooling/heating systems and effectiveness of building insulation performance relative to changes in pavement albedo were not examined.

In summary:

- Cool pavement research particularly in the form of field experimentation needs to be conducted across all North American climate types as well as Europe and Asia – this will help identify the most appropriate and optimal technologies for various applications in different climates;
- Limited research has been focused on proving the benefits of cool pavement technologies through large scale practical implementation;
- Further research needs to be conducted to better understand and isolate, in theory and empirically the cooling effect and UHI reduction potentials of cool pavement implementation;
- Research needs to be conducted to understand the effectiveness of cool pavement performance in complex urban settings accounting for shadowing, building materials, sky view factor, intended use, etc;
- In moving from micro-scale phenomena to macro and global scale estimations it is important that research is focused in gaining a greater understanding of the basic influencing processes (which for indirect effects due to pavements are highly complex) and scalable methods are developed based on high resolution models and high quality input data;
- Further research is required to understand the implications of key cost variables on the final cost of implementation of cool pavements i.e. local climate, region, project size, design life, intended use, etc.
- Further research needs to be conducted to quantify potential benefits of improved air quality, reduction in energy demands, improved urban quality of life, maintenance, night-time illumination, water, etc, which collectively may help to justify the higher initial costs;
- Investigation needs to be conducted into quantifying the relative benefits and effectiveness of adopting high-grade insulation, changing daily energy patterns, energy efficiency measures and control of cooling/heating systems (if present at all) versus the use of cool paving technologies;
- More extensive data collection and field research on cool paving materials is required to understand the implications on material performance due to weathering, dirt, use, age, pollution, etc.

4.5.3 *Review for Green Roofs and Urban Green Areas:*

4.5.3.1 Green Roof and Urban Green Areas Principles

Plants, trees, and vegetation increase the shading of the surface they occupy, thus less sunlight that falls on the surface gets converted into heat. The heat that does reach the either the greenery or the ground beneath it can often be dissipated by the process of evapotranspiration – heat in the surrounding air/surfaces is used to evaporate water. Often such greenery and its cooling effects are exploited on building roof tops as "green roofs" or strategically designed/naturally occurring "trees and vegetation" around buildings/urban space. Through the processes of shading and evapotranspiration the surfaces stay cooler than conventional rooftops under summertime conditions. In principle, the use of green roofs will tend to lower the amount of solar energy entering the conditioned space from the roof and thus reduce cooling loads. Whereas, strategically positioning trees and vegetation can also provide shading to both pavements and buildings alike resulting in a less of the sun's energy being absorbed by the shaded surface resulting in less solar energy entering into the conditioned space (thus a reduction in cooling loads) and keeping the pavements cooler thus lowering the ambient temperature (indirectly reducing A/C). For the same reasons green roofs tends to increase heating loads during the heating season in non-equatorial climates because less of the sun's energy is converted to heat in the roof and conducted into the conditioned space – to some extent this also applies to trees and vegetation however, during the winter season evergreen and deciduous trees have no leaves means that they provide less shading. Furthermore, they can often offer other benefits during the winter such as shielding from cold winter winds for urban buildings/structures. Nonetheless, as there is less solar energy in the winter than the summer the quantity of solar energy converted to heat within the roof is greater in the summer than the winter, thus providing shading and evapotranspiration displaces more summer heat gain than winter heat gain.

As discussed, the positive attributes of greenery in an urban environment not only has the potential to reduce the air conditioning loads, and thereby the energy use and associated CO_2 emissions, but also to reduce the amount of solar energy trapped in the troposphere by increasing the reflection of solar radiation back into space (to a lesser extent than artificially designed reflective surfaces). Thus in theory there is three mechanisms in which greenery either on buildings or strategically positions around the urban space may mitigate global warming:

a) By lowering the space conditioning loads and associated power-related emissions;
b) By reducing the amount of solar radiation converted into tropospheric heat;
c) By directly storing or sequestering carbon dioxide.

4.5.3.2 Green Roof and Urban Green Areas Summary of Literature and Findings

Studies from North America, Europe and Asia were examined covering a range of climatic conditions investigating the use of green roofs and urban green areas as UHI countermeasures – of these studies over a quarter examined green roofs and the rest were focused on the effects of trees and vegetation. The studies reviewed for green roofs either simulated or conducted field experimentation gathering data demonstrating the temperature reduction capabilities of green roofs over conventional roofs due to evapotranspiration and shading. It was found that green roofs offered greater cooling per unit area than light surfaces but less cooling per unit area than

curb-side planting. Data gathering, modeling and simulation allowed examination of trees and vegetation on individual buildings and cities. Urban trees were found to provide evapotranspiration, shading and wind protection to buildings and pavements resulting in energy, peak power and CO_2 savings for affected areas. It was however, generally accepted that the use of urban trees and vegetation could face heat penalties in cold climates but reduce energy in hot climates – this was dependant on a range of complex variables such as tree topology, building/tree orientation and type of weather conditions (e.g. winter winds).

For both green roofs and urban green areas the initial costs and ongoing maintenance costs were found to be greater than conventional alternatives; however, studies have shown that the benefits (including aesthetic value, reduced air pollutants and GHGs, health benefits, reduced storm water, etc) of these countermeasures outweigh these costs. It was noted that in any mass urban tree planting schemes the local climatic conditions, positioning and tree species (to limit biogenic emissions) are critical variables in limiting any adverse impacts.

4.5.3.3 Green Roof / Urban Green Areas Literature Review

There are forty-six references which addressed the use of green roofs and/or plants, trees or vegetation to mitigate the urban heat island effect. Of these 30% of the papers originated from LBNL the rest are studies had a decent global coverage of the topics in question covering: North America, Europe and Asia (US, Singapore, Israel, Japan, China, South Korea, UK, Canada, and Germany). Generally 30% of the studies examined green roofs but the remaining papers focused on the effects of trees and vegetation.

Five studies attempted to either simulate or gather data on the temperature reduction capabilities ode to green roofs [053, 055, 083, 087, 206]. All studies concluded that green roofs offer lower surface temperatures than the traditional roof surfaces used. One study indicated that the surface temperature of a green roof was observed to be 18K lower than that for a conventional roof in Singapore. This same study also found that during a period of drought the green roof temperature was higher than the conventional roof [083]. A New York study which set up an array of green roofs to monitor their environmental conditions across the city found that green roofs almost eliminate the roof top as a heat source and due to the absence of extreme temperatures makes them more than twice as durable as traditional roof membranes. The paper also suggested that green roofs are used to home weather stations due to the lack of extreme temperature ranges, and due to their height offer better security for the equipment, less building obstruction issues and less extraneous heat source bias [206]. Another US study conducted in New York concluded that living roofs offer greater cooling per unit area than light surfaces but less cooling per unit area than curbside planting – thus better for neighborhoods with limited street-level redevelopment options [053]. A modeling and simulation study examining Toronto, Canada showed that when irrigated green roofs in high-density areas were provided with sufficient moisture to drive evapotranspiration, temperatures across the city were reduce between 1-2K at 1pm [055]. Such simulations need to be treated with caution as observations on the macro-scale aren't easily attributed back to processes occurring at the micro-scale, they are highly constrained and are often tailored to the individual building or local city they examine thus results are not widely applicable to other cities let alone climate types.

Six studies were found that tried to quantify the energy savings associated with the implementation of green roofs [192, 193, 194, 195, 196]; however, no studies that addressed the peak power and CO_2 savings for green roof were found. The savings were found to be dependent upon a range of parameters including the climate, building characteristics (in terms of materials, insulation, size, operation, etc). One Canadian study used Visual DOE model to evaluate the heating and cooling energy savings for a one-story office building with a 3,000m^2 green roof in the city of Toronto, Ontario in Canada. This study found that the shading and insulation of the green roof garden reduces the heating energy by 10% and cooling by 6% with an overall total energy usage reduction of 5%. The low cooling reduction was attributed to 1) increased insulation ode to green roof reduced the dissipation rate of internally generated heat and 2) building insulation reduced the heat flow into the building at summertime and reduced heat flow out in the wintertime. The exact same simulation was run in Santa Barbra, California, it became evident that with lower amounts of insulation the cooling savings were increased to 10% [195].

Fourteen studies existed that looked to monitor, model and simulate the temperature variations attributed to trees and vegetation [002, 006, 007, 010, 040, 046, 048, 069, 082, 086, 088, 092, 109, 112]. Most were case studies examining the effects of trees and vegetation on either individual buildings or specific city locations. Broadly, most studies indicated that temperature reductions ode to trees and vegetation could be observed or simulated in the range of 0.28-4K. During the summer period shade factor was found to provide 80% of the cooling effect and that the cooling effect on the site surroundings was narrow and detectable up to 100m from the site boundary [109]. A study conducted in Taipei, Taiwan ruled that on average parks were cooler than their surroundings at both day/night times in both the summer and winter months [006] – though this should be treated with caution when making broader conclusions and transfers of experimental results as this is based up on different characteristics, times, seasons and climates. An LBNL study takes a comprehensive look at identifying the costs/benefits associated with planting urban trees [080].

Fifteen studies were found that attempted to quantify the energy, peak power and CO_2 savings from trees and vegetation [007, 020, 021, 027, 028, 033, 039, 041, 046, 048, 066, 069, 080, 088, 112]. Of these nine looked at energy savings [007, 021, 027, 028, 033, 046, 066, 088, 112], seven looked at peak power [021, 027, 039, 048, 066, 069, 112] and three looked at CO_2 [020, 041, 080]. One study that simulated the effects of irradiance and wind reductions on energy performance of residences in four US cities indicated irradiance reduction measures would increase annual heating costs in cold climates and reduce them in hot climates. This same study showed that shading could reduce peak loads by up to 31-49% and a 50% wind reduction was shown to lower annual heating costs by up to 11% (in Madison) and increase annual cooling costs by 15% (in Miami) – it concluded that the planting designs for cold climates should reduce winter winds and provide solar access to south and east walls (also applies to temperate climates) and in hot climates high branching shade trees and low ground covers should be used to promote both shade and wind [039]. An LBNL study suggested that a tree planted in LA can avoid combustion of 19kg of carbon annually even though it sequesters 4.5-11kg [080]. These studies are very specific to location and are attempting to model, measure and attribute data to a complex set of variables – research is needed that better quantifies the effects of: tree cover ratio, tree size, healthy, type,

location, orientation, growth/mortality rates, climatic zones, etc if estimates from the micro to the macro and global level are to be more accurate and transferrable between communities around the world. Equally, as one study identifies there needs to be the examination of the relative benefits of decreasing energy use, peak power and CO_2 by energy conservation, efficiency and transfer to low/non-carbon based fuels [020].

Five studies examined/mentioned the costing of green roofs [075, 156, 193, 194, 209]. They all indicated that the first cost experienced by the building owners would be higher than a conventional roof, one suggested this was almost 40% higher [156]. They did however, indicate that it is important to account for the full life-cycle of the green roof in order to identify the net benefits/costs to the owner and the community. One of the studies compared the expected costs of the conventional roof with costs of the green roof along with its benefits (such as storm water management and improved public health by reducing NO_x) – it found that even though the initial cost was 40% higher than the conventional roof the green roof would save up to $200k (two-thirds of savings from reduced energy needs for the building) [156]. Another study looked at producing initial results for a cost-benefit analysis to determine the economic value of green roofs for both public and private decision makers in New York. It examined factors such as installation costs, architectural and engineering costs, service life, maintenance, increased temperatures, storm water runoff, scale factor for installation and maintenance, reduced green house gasses public health, etc. The results indicated even though the individual green roofs are not costs effective, implementing green roof infrastructure at a larger scale and including the range of benefits identified is cost effective [209]. However, further research is required to quantify the complex direct and indirect benefits to both the individual building and the community as a whole attributed to each one of these factors.

Three studies examined/mentions the costing of trees and vegetation [077, 086, 112]. All studies indicate that even though the benefits can vary considerably from one geographical location to another and from different tree species, etc. the benefits of planting trees and vegetation outweigh the expense of planting and maintaining them. Costs of planting trees were estimates to vary between $10 to $500 per tree [112]. The one study that looked at converting the asphalt parking to 60% grass covered parking found that the construction costs were 2-7.5 times higher and maintenance costs 0.1-7 times higher for green parking space over conventional asphalt solutions [086]. Similar to the green roofs, further research is required to quantify the complex direct and indirect benefits to both the individual area/buildings and the community as a whole.

Other benefits for both green roofs, trees and vegetation were shown to include a decrease in ozone concentrations assuming the additional vegetations are low emitters of biogenic hydrocarbons – this was found to be species dependent [048, 063, 077]. Furthermore, most studies to varying degrees acknowledged that there were other benefits to be gained including: reduced air pollution, GHG emissions, reduced evaporative emissions, improved human health, enhanced storm water management, reduced pavement maintenance costs, improved water quality and quality of life. Further research is required to identify the benefits that are/aren't transferable across geographical/climatic boundaries – e.g. further increases in humidity levels ode to the evapotranspiration process may in some warm temperate and equatorial fully humid climates have negative effects upon the health and comfort levels.

4.5.3.4 Status of Green Roof and Urban Green Areas Policy Review

Some local level policy exists for green roof technology but it is less established than the more familiar cool roof technology. Many guidebooks have been published to educate the public and building owners about green roofs and some governments offer financial incentives for their installation. [197] Cities in Germany, Austria, Switzerland, Japan and the cities of Toronto and Vancouver in Canada have by-laws which mandate green roofs on all new residential buildings [198]. Germany has the most formal arrangement incorporating green roofs into building codes and nature conservation acts, direct and indirect financial incentives and ecological compensation measures [212].

Little formal policy exists for urban green areas in terms of its inclusion in building codes and such, however tree planting schemes are run by Government departments, non-Government and private sector companies through incentivization and subsidization. Protective legislation exists to prevent trees and parks being removed through conservation orders, tree protection orders and green belts.

Examples of policy, building codes and incentive schemes can be found in section 4.4.2.

4.5.3.5 Critique of Green Roof and Urban Green Areas Literature & Emerging Issues

Significant global interest in the field of green roofs and urban green areas was demonstrated in the literature reviewed with just under 30% of the papers originating from the Lawrence Berkley National Laboratory UHI Group. However, most of the research was centered in North America and Asia and much of the focus was on the effects of trees and vegetation upon Urban Heat Islands.

One of the modeling and simulation studies conducted in Toronto examined the effects of irrigated green roofs in high-density areas, the model did not distinguish between existing grass areas and green roofs [055]. The outcomes indicated that if existing grass areas in the city were replaced with green roof buildings the cooling effect would not decrease – this analysis therefore does not account for the impact of tall urban structures upon the urban climate. Also, there were inconsistencies in the boundary layer modeling (roof albedo change for white roof – leaving building in the model, green roof – model removes that part of the building) in which the white roof and green roof structures were modeled – it was demonstrated that these discrepancies were small but further research is required to understand the effects of such approximations when examined at larger scales that will help understand the true mitigation potential of urban green roofs.

The studies which conducted field experiments, modeled, and simulated the temperature variations attributed to trees and vegetation were case specific studies focused on individual buildings or specific cities. Conclusions drawn from these studies cannot easily be translated beyond their local context simply due to the different urban building and city characteristics,

seasons, climate types, etc. Further research is therefore required to develop a framework that will underpin a set of fundamental characteristics that will allow simple analysis and conclusions to be drawn on the temperature reduction benefits on other buildings/cities in other regions and climate types.

Despite comprehensive coverage of the effects that trees and vegetation have on energy use, peak power and CO_2 emissions, only energy use for green roofs was given decent coverage. Such research issues are fundamental and require further investigation for green roofs in particular. Naturally, the studies examining these issues were case specific, and in the case of urban trees and vegetation further research is required to understand and quantify the effect of a complex set of variables upon the UHI mitigation potential and achieving other environmental goals: tree cover ratio, tree size, health, type, location, orientation, growth/mortality rates, climatic zones, etc. It is also important that the benefits of energy efficiency, transfer to low/non-carbon based fuels and energy conservation in place of urban green solutions are examined to see their relative effectiveness in reducing energy use, peak power and CO_2 emissions.

Of the studies that examined the costs associated with green roofs some attempted to quantify a sample of the benefits including: Storm water reduction, air pollution and greenhouse gas effects, energy cost savings, installation and maintenance costs, etc. All but one study attempted to incorporate all these factors into their costing models and thus the full range of benefits or drawbacks of the green roofs were not examined in great depth. No studies reviewed for either green roofs or trees and vegetation managed to quantify the benefits/costs of aesthetics, use of green roofs for food production and increased biodiversity. Further research is required to collect empirical data on all the proposed benefits and their respective economic benefits. Many of the proposed benefits are highly dependent upon the urban green designs and green roof designs installed in buildings – therefore their costing is highly case specific. On a similar basis to green roofs, there was limited research conducted to understand and account for the range of benefits and costs associated with trees and vegetation. It appears that no attempt was made to provide a comparison of the benefits and/or costs of green roofs or trees and vegetation over efficiency measures and other cool technologies. Such estimates could prove critical in understanding whether urban green areas and green roofs are a practical choice in mitigating the UHI effects for particular cities.

In summary:

- Future research needs to examine the effectiveness of green roofing and urban green areas across the full spectrum of climate types both at the micro and macro scales to identify optimal operating conditions;
- Further field experimentation to collect data and model refinement is required to account for the complex set of variables presented by the direct and indirect effects of green roofs and urban trees and vegetation;
- Further research development is required to understand the building specific constraints associated with green roof implementation;
- Research needs to be conducted into quantifying the peak power and CO_2 savings associated with green roofs;

- Research needs to be developed to underpin a set of fundamental characteristics of urban green areas and green roofs allowing simple analysis to be translated to other building/cities in other regions and climate types;
- In estimating energy savings of green roofs, trees and vegetation on buildings/cities, it is important that future research accounts for: daily energy patterns, energy efficiency and control of cooling/heating systems;
- Further research is required to understand and quantify the effects of a complex set of variables upon the UHI mitigation potential. Some of the listed variables have been examined but still further research is required in the following areas: tree cover ratio, tree size, tree health, type, location, orientation, growth/mortality rates, and climatic zone performance;
- Further research is required to refine the quantified benefits associated with green roofs and urban green areas, such as: air pollution, storm water reduction, greenhouse gas effects, energy cost savings, installation and maintenance costs, etc and new research needs to be developed in quantifying more complex factors such as: aesthetics, biodiversity, food production, building durability, etc.
- Research is required to examine the benefits (in terms of cost, energy use, peak power and CO_2 emissions) of energy efficiency measures, transfer to low/non-carbon based fuels, and energy conservation in place of urban green solutions – this may help justify the viability of potential green based solutions to mitigate UHIs;
- Research is required to analyze legislation and incentives used to encourage the adoption of urban trees and vegetation and green roofs in parts of the world where they are generating both significant interest and adoption e.g. in parts of Europe.

4.5.4 Review for Vehicle Paints:

4.5.4.1 Vehicle Paints Principles

The lower the albedo of the vehicle surface the more sunlight that falls on it is converted into heat rather than reflected back into space. The higher the emissivity of the vehicle surface the more that the heat stored within it is radiated away. The so called "cool vehicle paints" exploit these two phenomena by using combinations of high-albedo and high emissivity composites to minimize the amount of sunlight that is converted into heat in the vehicle shell structure and maximize the amount of heat that is radiated away from the vehicle. This results in a cooler vehicle than one which is coated with traditional paints that trap more of the sun's heat within them. In principle, the use of cool vehicle paints will tend to lower the cooling loads and cooling energy demand (and associated CO_2 emissions) because they reduce the amount of solar energy entering the conditioned vehicle space from the outer shell and thus reduce the demand from the air-conditioning (most modern vehicles). For the same reasons cool vehicle paints would tend to increase the heating loads during the heating season – though this penalty would be very small given the fact that most vehicles are already generating heat from the running engines (in turn used to heat the vehicle). Nonetheless, as there is less solar energy in the winter than in the summer the quantity of solar energy converted to heat within the vehicle structure is greater in

the summer than the winter, thus raising the vehicle's outer shell albedo and emissivity displaces more summer heat gain than winter heat gain.

As the vehicle exposed surfaces are often uneven when solar radiation is reflected from a vehicle structure some of it escapes the urban canopy and enters into space; however, depending upon the sky view factor and the incident angle some may be intercepted and partially absorbed by exterior building walls.

Despite this pavements can reflect a significant portion of the solar radiation away from the urban surface and direct it back towards the sky vault. The increase in albedo has the potential to significantly affect the urban air temperatures and thus reduce a/c loads as well as the internal vehicle temperatures.

4.5.4.2 Vehicle Paints Summary of Literature and Findings

Only four references examine/refer to the use of cool vehicle paints to mitigate urban heat island effects [025, 180, 181, 222]. Two studies (1 paper mention, 1 ppt) from the US [025, 181] and two from Japan [ppt][180, 222].

The experiments carried out were on moving and parked cars, their cabin and surface temperatures were measured along with their energy use and CO_2 emissions. The studies were few but showed that reflective paints have a beneficial effect on cabin temperature, fuel consumption and emissions however small, although many variables exist such as driving speed, level of insulation within the car and meteorological conditions. Research exists but is currently in its infancy, a major benefit of this technology which should aide further research is that it is much less expensive than other UHI mitigation technology and it is easy to roll out on mass scale.

4.5.4.3 Vehicle Paints Literature Review

The two US studies indicate that a Berkley team is actively working with the auto industry to apply such cool vehicular coatings to the exterior shells. Solar reflective vehicle paints are paints which are highly reflective in the near-infrared part of the spectrum [180]. It is thought that by lowering the temperature of the cabin (during the summer time) vehicle manufacturers can install smaller, lighter and more efficient a/c systems allowing the vehicle to run more efficiently – resulting in lower fuel consumption and therefore reducing vehicle emissions [059, 180, 181]. Furthermore, it has been mentioned in all studies that installing such cool colors on the interior surfaces would also act to increase passenger comfort and need to use the a/c unit.

Ihara's 2009 paper focused on reducing CO_2 emissions from vehicles through the use of solar reflective paint (SRP). The study used practical experiments and simulations to compare cars with conventional paint and SRP to determine differences in fuel consumption. These experiments build on previous studies led by Ihara that measured temperatures in parked cars only with few simulated conditions. This paper measured vehicles in motion so the results should be more realistic. The car's surface and cabin temperature, fuel consumption and the weather conditions were measured whilst the car was driven around a test track over a six day period, temperatures within and on parked cars were also measured and a simulation was conducted for car heat load under various conditions. The results of the tests showed that the fuel

reduction effect of SRP is not large and worked best on cars being driven in hotter climates, with little insulation and at low speeds [222].

One Japanese study indicates that the solar reflective paint was tested on the rooftop of a bus and found to reduce the air temperature within the bus by 5K [180]. The studies illustrate that there are still significant research challenges in applying the paint and in designing the pigments for effective vehicle application. Experimentation and simulation conducted in Japan seems to show mass solar reflectivity of vehicles (increase from 6.43% to 73.69%) for Otemachi in Japan yielded 0.3K reductions of the ambient air temperature (with greater difference measured in pedestrian space) and this was attributed predominantly to the reduction in anthropogenic heat from vehicle a/c [180].

Further research is required in this field despite promising early signs. It is important to investigate the effects and relative merits of using more efficient driving units versus the reflective paints or even changing the driving habits, speed limits etc. Further modeling and simulation as well as mass implementation/experimentation will confirm the benefits of such technologies. It is important to examine the costs involved and any technical application issues.

4.5.5 Other

4.5.5.1 District Cooling

A District Cooling System (DCS) is a sustainable way to cool buildings. The system transfers cold water from a central refrigeration plant, where it is generated, to a building or multiple buildings through a closed-loop piping network. The cooling energy meets its destination point, a terminal device, within the building and the user uses this cooling energy as they wish, generally through air conditioning system. The DCS means that buildings do not have to house their own chiller plants and the DCS chiller plant is more efficient than individual plants. The system can also adopt a range of thermal technologies, such as low-temperature coolant production, thermal storage, co-generation and tri-generation [177, 178].

4.5.5.2 Water Cooling

Water cooling measures describe more than one process. Deep Lake Water Cooling, a system used extensively in Toronto, uses cold water pumped from the bottom of a lake as a heat sink for climate control systems. Because heat pump efficiency improves as the heat sink gets colder, deep lake water cooling can reduce the electrical demands of large cooling systems where it is available. In Toronto's case the water comes from Lake Ontario at about 4°c and travels via pipe net work to the John Street Pumping Station where the heat exchange takes place [179].

"Water Sprinkling" Campaigns have been adopted in countries such as Japan, Spain and some parts of the USA. Water Sprinkling describes the activity of sprinkling water on gardens, pavements and paths around a residence or office building in order to reduce ground temperatures and thus the surface air temperature. If carried out on a large scale this could have significant impacts on temperatures in urban areas.

A study in Japan tested the effect of mist cooling (spraying mist water onto a surface) to reduce urban heat flux and save energy. Three types of mist cooling technologies were used on a test building: rooftop spraying, veranda spraying and spraying to the outdoor unit of a room air conditioner. The tests yielded positive results on reducing roof surface temperatures (reduced by 16.4°C), room temperatures (reduced by 1.9°C for veranda spraying alone) air conditioning usage time, consumption (reduced by 36% during the test period) and efficiency in the house. However in the veranda spraying tests humidity within the house was raised by 1.7 g/kg. The paper did not comment on the issues relating to water usage which ranged from 66 L/day for spraying the air conditioner unit to 322 L/day for the veranda spraying. This technology although proven to be effective would not be suitable for counties with water shortages. The paper also did not comment on the impact of constant water spraying to the building materials [223].

4.5.5.3 Bamboo

Using bamboo as a construction material is an experimental method of mitigating the urban heat island according to a recent paper by Kandya in India. The paper measures the thermal and structural characteristics of bamboo as a construction material. Three cubicles were constructed and temperatures taken from within. One cubicle was made from half split bamboo, one from a half split bamboo-concrete composite and one from bricks and cement but with bamboo beams to test load bearing capacity. Also solar energy was harvested using half split bamboo panels and water and air as the heat transfer agents. The results showed that the half split bamboo constructed cubicle had the lowest average temperature, followed by the half split bamboo-concrete, and finally the concrete and brick cubicle. The solar energy collector experiment found that water provided a better heat transfer agent alongside the use of PU foam insulation. Load bearing capacity was also measured but not compared to any other materials. The use of bamboo shows potential but further work needs to be undertaken to measure its creep behavior, non-homogeneity, bio degradability, durability etc [227].

4.6 Review for Implementation Issues:

4.6.1 Implementation Issues Principles

In summary, the industrialization and urbanization results in a loss of natural green space, an expansion of built surfaces both above/below ground and mass concentration of population – these all help to form the urban heat island and its well documented phenomena. In order to address the undesirable and costly side effects, referred to in chapter 1.2, a coordinated response from communities, local/national/international governments is required. Therefore, priorities for implementing urban heat island mitigations strategies must be set early on. Often the priority is given to measures that are readily available however; there is an increasing need to address these issues by adopting larger scale mitigation measures and longer term views. In addressing the UHI phenomena however the following implementation issues can occur:

- Technical: this addresses technical barriers and practical implementation issues. This could be looking for solutions to effectively enforce a mitigation strategy given practical constraints in the urban environment.
- Institutional: this addresses barriers faced due to initiatives/policies dictated from either/both governmental and non-governmental institutions;
- Legal: these are barriers of the legal nature that could act to restrict or inhibit mitigation strategies;
- Economic: financial barriers that would act to restrict or inhibit mitigation strategies.

This section reports the findings from UHI studies that address the above issues. Addressing the implementation of individual mitigation technologies at smaller scales have been addressed to some degree in the technology section. This section therefore, in part re-iterates some key implementation issues that can have impact from the local to global scale. The aim is to report findings as the literature addresses these implementation issues. Furthermore, it reports suggested solutions/outcomes that have evolved in trying to overcome some of these barriers.

4.6.2 *Implementation Issues Summary of Literature and Findings*

Limited studies explicitly examined the implementation issues faced in mitigating UHIs – of the studies that did, the focus was predominantly on the US and Japan. The US focus was in overcoming barriers to ensure mass market uptake of the cool community strategies – this included addressing issues pertaining to market understanding of countermeasure performance, examining how to incentivize adopting cool materials in new builds, and overcoming obstacles in the building standards. The US examples demonstrated that some implementation issues were overcome by developing voluntary schemes/programs that often developed mass following and developed into mandatory regulation.

The Japanese experience demonstrates the need to transist from research to policy implementation and adopt more long-term mass scale implementation measures – due to the small-scale measures not yielding expected results in performance and there being no proof of scale. This evidence showed that mass implementation, data collection and demonstration would help overcome some of these barriers and thus serve as a model to rapidly urbanizing areas throughout Asia.

The studies also suggested that the key to overcoming implementation issues for UHI mitigation strategies relies upon the ability to demonstrate synergies and links with other areas of the urban climate and climate change at the global scale. These studies however, provided little coverage of issues faced at the technical, economic and legal level.

4.6.3 *Implementation Issues Literature Review*

Only four studies attempted to address (to varying degrees) the implementation issues faced in mitigating the Urban Heat Islands [027, 047, 053, 060]. Three of these studies focus on the US experience [027, 053, 060] and only one focuses on Japan [047].

One US study written in 1998 seeks to identify the barriers that must be overcome in order to ensure mass market uptake of cool community's strategies (focus on cool materials, shade trees and demonstration strategies) [027] – naturally some of these barriers have been overcome to varying degrees through the evolution and maturing of technology, policy and strategy – some examples from the literature are presented. For cool roofing/paving materials /shade trees the following barriers have been identified [027, 053, 060]:

- Rating and Testing: lack of information from manufacturers to the market on the performance of the products – this yields product differentiation issues for the consumers. Such issues can be dealt with through the use of industry approved test measures (for the solar reflectance and thermal emittance) and product labeling and/or information database – a working example is the Cool Roof Rating Council database;
- Cool Materials in New Builds: No incentive for builders to incorporate cool roofs into new builds due to no recognition of energy performance merits of cool roofs by the codes – in the US the American Society for Heating Refrigeration and Air-conditioning Engineers (ASHRAE) included credits pertaining to cool roofs;
- Low-Emitting Trees: trees produce biogenic emissions which are precursors to smog. It is therefore important that groups looking for mass plantation to mitigate the UHI select the lowest emitting trees. Research in the US is being conducted to categorize the various species for their relative merits. A working example in the US is research conducted at the university level to quantify and catalogue the ozone-forming potential (OFP) of various tree species also developed by the USDA Forest Service and integrated in the STRATUM tree data inventory tool [077]. In the US there have also been significant efforts by government departments (Department of Energy and Department of Defense) to set-up demonstration projects on their facilities to illustrate the potential energy savings associated with mass strategic shade tree plantation.
- Building Performance Standards (Shade Trees): difficulty in the integration of energy credits for shade trees despite numerous studies proving their relative energy saving and smog reducing credentials – thus not providing incentive to building owners and designers to integrate trees and strategically locate them. It has been suggested that local/state codes and ordinances could be used to promote planting of shade trees - some states in the US have sought to implement mass tree planting programs through the State Implementation Plans (SIPs) to meet clean air standards.

A Japanese study suggests that there needs to be a rapid transition from research to policy implementation. It highlights that there is a growing need to begin to adopt more long-term mass scale implementation measures as the short-term, small scale measures currently implemented haven't necessarily yielded the results hoped for both in terms of performance and in-terms of proof of scale. The mass implementation, data collection and demonstration should help overcome some of these barriers and thus serve as model areas in Japan and rapidly urbanizing cities throughout Asia [047].

A US study suggests that the future prospects of implementation of UHI mitigation strategies rely upon: ability to demonstrate synergies with other areas of the urban climate; climate changes at the global scale – as these often have magnified effects upon the urban environments;

development of future technologies – will break down the barriers e.g. glare from highly reflective pavements; the political will and momentum of codes, standards and legislation [060].

Broadly, these studies covered a range of implementation issues but the studies examined didn't adequately cover the issues faced at the technical, economic or legal level. Technical barriers are particularly relevant in highly urbanized spaces where even though the effectiveness of a particular mitigating strategy for one urban space is high the benefits may not easily translate to another (e.g. difficult to instigate a mass tree plantation program in the urban centre if there is no available green space – thus this may restrict the capacity of this particular mitigation technology). It has been suggested however, in two studies that taking a life-cycle cost-benefit analysis would lead to the fully assessment of the merits of any mitigation strategy resulting in a breakdown of the barriers faced by first cost groups [027, 060].

Further research and mass implementation of mitigation strategies will naturally result in addressing some of these issues but as demonstrated the implementation issues faced by different cities around the world will be varied and the tools to address such barriers are rapidly evolving and often have global applicability. The US examples however, demonstrate that barriers are often overcome through the implementation of voluntary schemes/programs at the early stages which have obtained mass following and often as a result lead to mandatory regulation.

4.7 Review for Urban Design/Planning:

4.7.1 Urban Design/Planning Principles

In summary, the industrialization and urbanization results in a loss of natural green space, an expansion of built surfaces both above/below ground and mass concentration of population – these all help to form the urban heat island and its well documented phenomena. In order to address the undesirable and costly side effects, referred to in chapter 1.2, the forward planning and strategic integration of urban heat island mitigation initiatives into the design framework can help alleviate the UHI side-effects. Such designs/planning can take the form of influential design factors such as increasing the sky view factor, determining the orientation of buildings with respect to green space and one another, building design and orientation to generate wind paths, etc. Often influential individuals from across the policy/design/construction value chain can influence the evolution of new/existing urban space and dictate the type of expansion or adaptation to follow. Key stakeholders in such processes are: decision makers (e.g. the Mayor), designers (e.g. architects), through to the construction companies. It is vital that all parties involved are aware of their respective design or implementation impacts upon the UHI phenomena as well as being aware of the relative merits to using UHI sensitive technologies and designs. Clearly, such designs and planning are more effective at the early stages of urban design i.e. when cities are being planned (pre-build) however, designing and planning can still play a crucial role in mitigating the urban heat island effect.

This section reports the findings from UHI studies that address the above issues. This section seeks to highlight the key design/planning issues that can have impact from the local to global scale. The aim is to report findings as the literature addresses these designs/plans. Furthermore, it reports any activities/solutions/outcomes that have evolved within the design and planning domain.

4.7.2 *Urban Design and Planning Summary of Literature and Findings*

The studies examining the urban design and planning were limited both in number and in scope. Different approaches were undertaken ranging from defining modeling tools to aid urban design/planning to case/region-specific design and planning challenge identification. One of the studies used a simple model of heat fluxes in urban areas to evaluate the effectiveness of various planning strategies and present planners with the option to minimize resource use while maximizing social, economic and environmental goals. The case/region specific studies were predominantly focused on green infrastructure seeking to facilitate planning for future expansions of green space, identifying influencing performance factors, and predicting the cooling effect in urban areas to aid the development of tools for incorporating the climatic effects of green areas in urban design.

The studies indicate the importance that designers and planners are equipped with appropriate tools and rules of thumb to understand what urban design characteristics best mitigate the undesirable UHI effects at the micro and macro level. It was evident in Japan that the approach to urban planning and design changes were shifting away from individual isolated efforts to mitigate UHIs towards improved infrastructure of the urban areas (roads, green space, and rivers) and a desire to influence urban planning through more invasive interventions in the form of deployment measures such as developing wind paths for city scale ventilation. The presented studies are limited and only touch-upon the critical issues. Further work is required to help policy makers, planners and designers appreciate and develop tools to design buildings and cities with UHI/climate sensitive design features.

4.7.3 *Urban Design/Planning Literature Review*

Sixteen references addressed urban design and planning issues [006, 007, 010, 045, 047, 054, 056, 101, 109, 112, 202, 203, 204, 225, 226, 232]. Of these papers, six define useful modeling tools that can aid in urban design/planning issues [054, 056, 202, 204, 225, 232]; four studies examine the design and planning challenges through case studies [006, 010, 101, 109]; three provide an overview to general planning and provide recommendations [007, 112, 203]; two provide a broader perspective of urban planning from a Japanese viewpoint [047, 045], and one paper studies the use of materials in urban design [226].

The four case studies despite their regional focus generate results that have global applicability and are summarized below:

- The UK study explores the important role that green infrastructure of a city can play in adapting for climate change. It presents these climate change solutions which have significant overlap with UHI mitigation solutions. It uses the output from energy exchange

and hydrological models that simulate the surface temperatures and runoff respectively in relation to the green infrastructure under the current and future climate scenarios. This provides significant steps forward as it quantities the potential of green infrastructure to moderate climate change impacts (also some common UHI impacts) in a rigorous manner and can facilitate the planning for future expansions of green space in urban environments in meeting UHI mitigation criteria [010];

- The Taiwanese study provides a preliminary analysis on the local cool-island intensity of Taipei city parks. Given that urban green-spaces broadly relieve the urban heat island in certain climates it examines what design factors influence the performance of the urban green parks and looks at the relative effects of several parks [006];
- The Israeli study examines vegetation as a climatic component in the design of an urban street. This uses an empirically developed model to predict the cooling effect of urban green areas with trees. The findings in this study (i.e. background effect, tree shading coverage, site specific effects, effect of trees in street, cooling effect on the surroundings) permit the development of tools for incorporating the climatic effects of green areas in urban design [109]; and
- A Japanese study considers how energy consumption in buildings can be reduced through efficiency measures such as improvements to heating, ventilation and air conditioning as well as considering window types and building block characteristics through modeling and simulations. The results showed a relationship between cooling requirement, weather data and building arrangement. The model calculates the most suitable building height for the air temperature in the area [202].

It is important that designers and planners are equipped with the appropriate tools and rules of thumb as to what kind of urban design characteristics best mitigate the undesirable effects on the micro and city level [006]. The Japanese study highlights that their approach is beginning to shift away from reliance on individual/isolated measures to mitigate the UHI – there is now a move towards improved infrastructure of the urban areas (e.g. roads, green space, rivers, etc) and a desire to influence urban planning in mass deployment measures such as the development of wind paths (for city scale ventilation) [047].

A number of papers used modeling and simulation to determine the most appropriate planning approach for their cities, these papers were as follows:

- A useful design tool is presented in a US paper that can be applied in the US in collaboration with the city of Phoenix water resources department [056]. This study uses a simple model of heat fluxes in urban areas – Local Scale Urban Meteorological Parameterization Scheme (LUMPS) which examines the variation in temperature and evaporation at the 'census tract scale in 10 tracts of the urban core'. In this study it uses LUMPS to evaluate the effectiveness of various planning strategies. The limitation of LUMPS and other urban heat flux models (at all scales) is that this tool at its respective scale may not be used to define mass solutions for several areas – it does however present planners the option to minimize resource use while maximizing social, economic and environmental goals;
- A Chinese paper declared urban planning to be one of the main causes of UHI. The study used remote sensing technology to analyze UHI at a community scale to establish an urban

planning approach. Medium resolution satellite images identified surface characteristics such as temperature and vegetation and high resolution images identified land utilization, underlying surface classification and landform characteristics. By overlaying these studies the influence of planning on UHI could be seen. The results of the study showed that each type of underlying surface should be limited to the most suitable percentage, they researchers suggested: multilayered buildings; providing space around buildings; and vegetative planting around buildings. Collectively, these measures should limit the UHI sufficiently. The research was limited by the thermal infrared band of satellite, it was not precise enough and only provided medium resolution [204];

- A paper written for the government of Hong Kong discussed the issue of urban air ventilation in Hong Kong which has been identified as a significant problem due to its affect on human health and quality of life. The results of this paper informed the Hong Kong government on new policy and strategy developments. The paper described a tool for calculating the impact of the built environment on its surroundings called an Air Ventilation Assessment (AVA). The major area of concern was at street/pedestrian level as this is typically where pollutants are trapped by tall buildings and narrow streets or a 'street canyon'. Improved permeability of the urban fabric and increased air volume in the area affected to aid pollutant dispersal were identified as suitable mitigate measures. To achieve this a number of actions were suggested: ensuring there are gaps between building blocks for increased air permeability; reduced site coverage at ground level facing pedestrian ways; split or stepped podiums or void decks to reduce site coverage and promote cross ventilation; setting buildings back from the street; mixed height buildings which decrease in the direction of where prevailing winds come from; and the use of gardens at podium and roof level to achieve cross ventilation. As an interim measure, increasing building permeability will be adopted as a benchmark for building design before the official policy is rolled out. The benchmarking study will form a separate part of this project [225]; and
- A paper by Kagiya presented a national research project on the creation of ventilation paths to allow cool sea breezes in Tokyo to ease the UHI effect in the city. The techniques used were large scale measurement; numerical simulations; and wind tunnel tests. The aim of the project was to quantitatively predict the effectiveness of the ventilation paths as a mitigation measure on UHI. The idea is based on the German ecological city planning approach which uses cool air from the mountains and valleys to alleviate air pollutants in inland cities. The software developed to assess the mitigation measure will be rolled out to national and local governments. The research team also intends to promote these techniques to planners and include them in city planning guidelines, however plans require adapting to suit each city [232].

One Australian paper looks at planning on a micro scale. Housing design can play an important part by minimizing a building's impact on a potential heat island by using environmentally sensitive design, energy efficiency measures and considering the topography, vegetation and any other constraints of the land on which it's built. This paper discusses the issues of current design and climate change and the need to design for future climate and not just the climate of today, the paper suggests that designers should consider the climate for a further 100 years in their designs. The paper's suggestions for future residential design were: smaller lot sizes and smaller

housing thus limiting energy consumption per property; orientation of housing north to south to maximize shading advantages; due to the increased lot density mitigation efforts are suggested such as high albedo surfaces and tree shading on hard surfaces; and by designing high performance energy efficient housing which performs best under increased temperatures. The paper concluded that a combined approach of passive building design and mitigation planning was the best approach to combat heat islands and climate change [054].

Building design is also discussed in a Japanese paper which discusses the approach to planning and policy in UHI mitigation by the Japanese Government. The Government issued building design guidelines in 2004 which set out ways to mitigate UHI through: shading through tree planting; ground level covering through greening and reducing amount of pavements; use of building cladding materials (high albedo and green); improved ventilation through building layout; and emission reduction through efficiency measures. On top of this guidance a rating system was developed to evaluate the effects of different UHI countermeasures. This paper acknowledges that the Japanese approach to architectural and urban planning needs revision and that previously the impact of planning on the external environment has not been well considered [045].

A paper written by an institute in Florida also acknowledged that urban planning was responsible for the development of UHI due to the way it segregates land types and misuses natural resources. The paper proposed ecomasterplanning and the use of urban forests to recapture resources, reconnect society and restore public health. Ecomasterplanning attempts to balance the use of greenery, water, engineered infrastructure and human infrastructure to create the desired microclimate, enhance the built environment and reduce the undesirable effects of urban infrastructures. The paper recommended a collaborative effort between planners, engineers, scientists, ecologists, urban foresters, public leaders and any other interested parties to change the way cities are planned [203].

The use of materials in urban design was discussed by Ashie in a recent Japanese paper. He used a scale model and numerical simulation to study the spectral dependency and characteristics of the urban albedo. Few studies exist which study the behavior of radiation reflected by materials with spectral selectivity, for example materials that enhance the reflectance specifically in the near-infrared region. The study found that in the urban environment there was a large value in the near-infrared region particularly in hours with low solar elevation; values were higher in flat surfaces than ridged; and daytime variations were small for ultraviolet-visual. The paper concluded that more research was required for high albedo products on the market and on the application conditions of spectrally selective building materials [226].

Some planning issues may be faced when implementing a mitigation program, these issues vary from country to country and state to state depending on the state's legislation making planning for new build and retrofitting programs complex. The retrofit approach was deemed to be the more expensive option and harder to enforce due to planning permission requirements. It is easier to enforce mitigation strategies on new builds as you start with a 'clean slate'. Building Regulations and Building Codes are considered the best way to enforce changes but are a very lengthy process [081].

Urban design and planning is a complex but critical area for expanding cities, adapting cities and newly evolving cities. The studies presented are limited and only briefly touch upon the critical issues and therefore further research is required to help both the policy makers, planners and designers appreciate the value of adopting a systems perspective of urban city and building design rather than a more isolated view of the design architecture.

4.8 Review for Environmental Assessment:

4.8.1 Environmental Assessment Principles

In summary, industrialization and urbanization results in a loss of natural green space, an expansion of built surfaces both above and below ground and mass concentrations of population all help to form UHIs and their well documented phenomena. UHIs have undesirable and costly side effects for the environment; these are highlighted in chapter 1.2. The UHI side-effects often have unwanted environmental consequences upon the urban space in terms of air pollution, destruction of habitats/ecosystems, water pollution, etc.

This section reports the findings from UHI mitigation studies that address the above issues. This section seeks to highlight the key environmental issues which can be mitigated thus having an impact from the local to global scale. The aim is to report findings as the literature addresses them and report any activities/solutions/outcomes that have evolved within the environmental mitigation domain.

4.8.2 Environmental Assessment Summary of Literature and Findings

Despite not being a focal point of this study, it was noted that the majority of the studies that reviewed the environmental impacts were predominantly US centric with some emphasis in Japan, China and parts of Europe. They addressed the environmental impacts to varying degrees using modeling, simulation and experimental field work, but were predominantly focused on evaluating the UHI environmental implications in terms of understanding their impact on air quality rather than how mitigation programs alleviate impacts on the environment.

4.8.3 Environmental Assessment Literature Review

Most papers to some degree reference the potential of UHI countermeasures in addressing the environmental impacts. Although important, these studies are not the focus of this particular task, thus below is a list of the range of studies that examine this through modeling, simulation or experimental field work and to a greater extent have been covered through the individual technology and modeling/simulation sections of the report.

The list of studies that aim to provide an environmental assessment include a total of twenty-seven papers. Of these papers about 80% are US centric and the remaining 20% are studies in parts of Japan, China and Europe.

Akbari in his 2005 paper on the potentials of urban heat island mitigation discussed the various benefits associated with the implementation of mitigation measures such as reflective surfaces for roofs and pavements and urban vegetation planting. He studied various papers by Rosenfeld and Taha that modeled mitigation strategies and measured the resulting energy savings. He discussed:

- A cool roof study by Taha which recorded 10-20% smog reductions as a result of raising the albedo of all roofs and roads in an urbanized area;
- A cool pavements study by Rosenfeld that found that by raising the albedo for 25% of the city studied resulted in a 12% decrease in ozone exceedance over the California Air Standard, of the 12%, 21% was attributed to pavements;
- A study on street trees and vegetation by Rosenfeld which simulated the impacts of a mass tree planting program (11 million trees) in the LA Basin, Rosenfeld calculated total energy savings of $270m made up from direct and indirect energy savings and smog benefits [070].

The papers listed below describe similar experiments, but generally papers seem to simply look at the UHI impact on air quality & CO_2, climate, trees and vegetation and ecosystem planning regardless of mitigation activities.

It is evident, given the studies referenced below, that much of the focus centers on evaluating the UHI environmental implications in terms of understanding their impact upon air quality.

Subject	**Papers**
Air Quality & CO_2 Emissions	012, 013, 014, 048, 049, 050, 051, 059, 063, 064, 070, 080, 093, 104, 108, 112, 139, 141
Climatic Factors	005, 024, 027, 038, 061, 106, 115
Trees and Vegetation	003, 020, 070
Ecosystem Planning	008

5 CRITICAL REVIEW OF UHI COUNTERMEASURES

5.1 Introduction

The earlier sections of this study looked to report and review all the seminal research conducted in the urban heat island space and examine their mitigating potential. In this section, we undertake a critical analysis of the studies and the opportunities for scale-up efforts leading from local to national and national to international efforts.

This analysis begins by examining the two principal methods that were addressed by the papers to reduce the ambient temperatures and building surface temperatures resulting in lower space conditioning requirements. This is followed by a critical review of the policy actions for each of the key mitigating technologies (cool roofs/pavements, green roofs and urban green areas) that highlights the current status across the globe, the identified barriers to scale-up, the reach and level of implementation of these policies and a conclusion presenting a forward path. An economic review/analysis follows that seeks to identify the climates where the energy savings alone justify the mitigation efforts and where incentive schemes may be required to justify their implementation. This is followed with a high level analysis of the barriers and catalysts that may hinder the mass adoption of urban heat island strategies and technologies and their rate of deployment. This section concludes by examining the urban planning issues and the degree to which current practice across the globe may inhibit or facilitate the deployment of the urban heat island countermeasures.

5.2 Critique of Negative Radiative Forcing Studies

5.2.1 Review of Negative Radiative Forcing and Direct/Indirect Effect Studies

UHI countermeasures mitigate global warming impacts in two principal ways: by lowering ambient and building surface temperatures, which in turn can reduce the amount of energy required for space conditioning and the associated energy-related CO2 emissions, or by increasing the overall albedo of the Earth's surface which causes less solar radiation to be converted into heat in the Earth's troposphere. This review presents a critique of the two different classes of studies that have been conducted to date. It is apparent that the first class of studies are where the large majority of research has been focused and has examined the effects of increasing the albedo of roofs and pavements and the use of green roofs and urban green areas to both directly and indirectly reduce urban temperatures and building/city energy use and consequently CO_2 emissions. The second class examines how the increase in the urban albedo induces a negative radiative forcing effect on the Earth and equates this to CO_2 emission offsets. Interestingly, the literature suggests that the magnitude of mitigation potential delivered via the negative radiative forcing effect might be much greater than the mitigation potential from reduced space conditioning energy use; however, perhaps because the former brings no direct economic benefits to the end-users it has been much less thoroughly researched.

5.2.2 *Negative Radiative Forcing Studies*

There was only one study that provided a review of the global potential of negative radiative forcing. This study originates from the Lawrence Berkley National Laboratory Urban Heat Island Group - "Global cooling: increasing world-wide urban albedos to offset CO_2" [35]. It is the first study of its kind that attempts to examine the mass scale up effects of both roof and pavement albedos in urban areas on a global basis in order to induce a negative radiative forcing and equate it to a carbon offset value.

The study takes inputs from previous estimates based on other studies and available databases to establish estimates for urban areas, the percentage of urban/roof/pavement coverage, potential net albedo change of an urban space and thus the overall Earth's albedo change. The study then generates an estimate for the increase in the radiative forcing due to an increase in atmospheric CO_2 by one tonne. Then a simple comparative analysis enables the authors to evaluate the change in radiative forcing due to the urban surface albedo modifications to the changes in the atmospheric CO_2. Then an estimate for the radiative forcing associated with CO_2 is established based on several different sources and thus methodologies which broadly yield similar results.

This study therefore examines the hypothetical example where the urban albedo of the world's pavements and roofs is increased through material modification. It is estimated that increasing the albedo of pavements by 0.15 and roofs by 0.25, where they are estimated to constitute 35% and 25% of the world's urban areas respectively, would increase the total albedo of urban areas by 0.1 - this yields an Earth albedo increase of approximately 3×10^{-4}. The global urban land surface was conservatively estimated at 1% of the Earth's surface area and with these modifications was estimated to induce a negative radiative forcing of 4.4×10^{-2} Wm^{-2}. The emerging global CO_2 offset approximation for cool roofs and pavements combined was found to be 44Gt with 24Gt attributed to cool roofs and 20Gt to cool pavements. This 44Gt CO_2 emission offset value is over one year of the 2025 estimated world-wide emission of 37Gt of CO_2 per year – a figure from the 2003 International energy outlook.

Such estimates are the first of their kind and an important indicator of the potential of UHI mitigation measures; they do however, as the authors recognize in some elements of the methodology and data suffer from some shortfalls:

- Global Urban Area Estimates: there are several methods that could be used to estimate the magnitude of global urban areas and they all demonstrated slightly different outcomes; however, this study ended up using an estimate of 1% which is thought likely to produce a conservative estimate of the effect of increasing the albedo of urban areas in terms of the global CO_2-equivalent emissions offset;
- Surface Modification Estimates: the fractions of urban areas subject to modification are estimated based on aerial color photography, statistical data sampling methods and land-use/cover data from the US Geological Survey from limited major city types in the US and then adjusted to account for metropolitan urban areas from across the world which are often have lower vegetative cover than the US. These figures are therefore not necessarily representative of the city makeup across the globe and are a gross aggregation;

- Implementation Issues: The estimates for pavements and roofs accounting for 35% and 25% of global urban areas respectively assume that 100% of the identified surfaces can be replaced with high albedo equivalents. This analysis therefore does not account for any constraining implementation issues that could arise and does not consider the feasibility of converting existing materials to a cool material equivalent – therefore these assumptions are likely to overstate the practically realizable CO_2 emission offset potential;
- Aging and Albedo values of Cool Materials: The albedo values selected for this study are based upon materials which are commercially available, to some degree their application sector and aging – an aggregated albedo value is therefore selected to account for these factors. It is however, important to note that material effective albedo values are often case and region specific as they depend upon the surrounding structures and the buildings they are applied to, their use and maintenance, and their aging – therefore these gross aggregations generate estimates that are likely to give rise to some degree of error;
- Cloud Cover and Atmospheric Pollutants: The study uses a global average cloud cover in order to establish an estimate of the radiative forcing effect from increasing the albedo of urban surfaces. It is, however, important to note (as the authors indicate) that the cloud cover is often lower for urban spaces than the global average value used. Furthermore, the effects of different pollutants such as aerosols across the globe were not accounted for in this study. The balance of these factors could produce an error of the radiative forcing effect and thus the emission offset values;
- Urban Structure Complexity: the effect of shadowing and absorption on the performance of modified albedo surfaces (pavements and roofs) due to the tall complex urban structures that are present in many cities are not accounted for in this study – such factors as the authors suggest have been estimated for roofs to reduce the equivalent potential by 10-25% but this has not been factored into the analysis nor has this impact upon modified paved surfaces been considered;
- Radiative Forcing from Atmospheric CO_2: In developing an estimate for the radiative forcing linked with atmospheric CO_2 four different methods were examined with three yielding similar results with an average of 0.91 kW/tonne of CO_2 (which is what is used in the study). The author recognized that the fourth method that accounts for CO_2 changes with time demonstrated a rise in the temperature by 0.175°C for every 100Gt of CO_2 – this affects the effective radiative forcing from CO_2 when carbon cycling effects are accounted for. It therefore indicative of an area that requires further investigation as this is likely to change the estimates of the radiative forcing and thus introduce errors in the emissions offset value potential – in this particular case it is likely this would result in an underestimate of the mitigation potential;
- Worth of CO_2 Offsets: The study indicated that in Europe the emitted CO_2 was traded at \$25/tonne. Using a roof area of 100m^2 (for a typical house) the total CO_2 offset is 6t worth \$150 and for a typical paved area also at 100m^2 the total CO_2 offset is 4t worth \$100 - working out at \$1.5/m^2 for cool roofs and \$1/m^2 for cool pavements. This yields at an approximated collective worth of \$1,100 billion with the greater contribution originating from cool roofs. It is important however, to recognize that the financial benefits are not straightforward and that additional costs and obstacles need to be to be considered e.g.:

- The magnitude of the costs incurred from implementing such measures on an global basis;
- The time it would take to instigate and implement such a mitigation program;
- That existing CO_2 markets are currently not designed to support CO_2 equivalent offsets from cool material technologies;
- Furthermore, the study assumes that albedo of urban surfaces remains constant i.e. at the installed value throughout the lifetime of the scenario – studies have shown that this is not the case due to dirt/pollution, use, age, weathering and microbial growth particularly in humid climates which cause the material performance to deteriorate.

The authors seek to find the upper and lower boundaries for the potential emission offset from radiative forcing in considering a selection of the above issues. They estimated that the global potential of increasing the reflectivity of urban surfaces would yield between 30–100Gt of CO_2 emission offset over one year of the 2025 projected world-wide emissions of 37 Gt of CO_2 per year. Furthermore, this study recognized the potential gains from implementing high albedo solutions in terms of direct/indirect effects on cooling/heating energy use of buildings and cities but these benefits were not account for in these estimates. It is important to note that these estimates although preliminary in nature indicate a colossal mitigation potential but evidently there remain a number of issues that need to be addressed to establish more accurate global estimates not least how to translate them into realizable financial gains.

5.2.3 Direct/Indirect Effect Studies

The use of urban trees, green roofs and high albedo surfaces were reported to provide both practical and in most cases financially feasible solutions to reducing the temperatures both within buildings and the ambient temperatures across the city. The vast majority of studies examined the urban modifications with respect to the type of contribution the countermeasure made i.e. direct or indirect contributions. The direct effect was classed as a countermeasure that would alter the energy balance of the individual building i.e. the effect on energy consumption of an individual building by installing a high albedo roof and/or shade trees. The indirect effects were viewed as the reduction on temperature upon a greater area due to large scale modification through a combination of modifying albedo of surfaces (roofs and pavements) and the use of urban trees and vegetation. These factors were reduced to be dependent upon size and time frame with direct effect providing instantaneous benefits to the individual building modified and indirect effect benefits attained with mass scale implementation.

The majority of studies reviewed used a combination of experimentation, modeling and simulations to evaluate the direct/indirect effects on energy, peak power savings and air quality from implementation of UHI countermeasures predominantly on case specific examples at the building and city scales – most were conducted in a limited set of climate types, namely: equatorial, arid and warm climates. Some studies that evaluated the direct effect on the building energy use found that increasing the roof albedo by 40% could yield up to 20% cooling energy savings – in scaling up these effects to the rest of the United States this would yield savings greater than $1 billion/year in the net annual energy bills. Another study indicated that the energy savings were greater where countermeasures that provide both direct and indirect energy

savings are used over solutions that provided just indirect energy savings e.g. pavements. Most studies indicated that cool roofs and urban tree planting held the key to providing energy, pollution and temperature reduction benefits and suggested that cool pavements also had a role to play but due to their indirect nature and lack of data on their performance no accurate quantification of these indirect benefits were established. There are however, certain shortfalls in the broader direct/indirect effect analyses that were conducted, these are highlighted below:

- Climate Types: most of the research focus in examining the urban heat island mitigation potential upon the building energy load has been U.S. centric and at best has typically covered only a select range of climate types - equatorial, arid and warm temperature climates. Naturally, the performance and effectiveness of the key UHI countermeasures (roofs, pavements and urban trees and vegetation) are affected by their regional climate they operate in. Therefore of the studies that extrapolated results from observations in a select range of regions do not necessarily yield accurate evaluations of a mass implementation scale-up of the national energy savings potential;
- Model/Simulation Calibration: the studies were founded predominantly on small scale direct/indirect observations and then translated the observed phenomena into models. There was no mass implementation/experimentation conducted such that the outcomes could be used to verify and calibrate models at the macro-scale. This validation process is critical particularly for the indirect effect countermeasures such as pavements, where the benefits are difficult to quantify;
- Direct Benefits of Thermochromic Coatings: a study examining the use of thermochromic pigments to modify the material surface color with temperature indicated that they could be used to save energy both at winter and summer periods. These were based upon small scale material tests. Significant research efforts are required to achieve material stability that will allow the confirmation of such performance characteristics. Therefore the claims of direct energy performance benefits for both winter and summer periods are premature;
- Higher Quality Data/Mapping: In the studies which evaluated countermeasure implementation at city and national scales it was evident that approximations had been made on the urban city makeup. Although in some cases they did provide respectable estimates on the roof areas based on building/housing stock data, they did not account for built structure complexity which would affect the effectiveness of the indirect benefits associated with countermeasures such as cool pavements (e.g. shadowing, building materials and sky view factor) – naturally these factors are complex to model but are critical if scalable estimate are to be established;
- Fundamental Influencing Processes: Before reliable estimates of the energy savings attributed to mass cool pavement and urban trees planting programs can be established the studies need to develop their understanding of the basic influencing processes. This is particularly true of studies examining cool pavements where the radiative and thermal phenomena of pavements are complex to model – this could lead to the emerging indirect estimates being inaccurate;
- Building Energy Consumption Factors: Few studies addressed the internal building parameters that directly impact the energy use and resulting CO_2 emissions. These internal parameters take the form of; occupant energy use, efficiency and control of the

heating and cooling systems if present, building insulation levels (addressed by some studies), and the human tolerance and comfort levels;

- Complete Costing: The studies that produced financial estimates for the cost of implementation did not always account for the complete lifecycle costs e.g. design, maintenance, thermal cyclical effects upon lifespan, changes in water quality, night time illumination, project size, design life and intended end-use. These effect are complex but could counter or enhance the financial savings attributed to the direct/indirect effect of any particular countermeasure but they require further investigation and integration into any potential estimates;
- Performance Effects on Cool Roofs/Pavements: Although most studies acknowledged that soot, dirt, microbial growth and end-use affect the performance of cool roofs and pavements there was no attempt to incorporate such performance diminishing characteristics in the direct/indirect energy savings that resulted – these factors therefore require further investigation as they can give rise to errors in the potential energy and CO_2 savings attributed to such direct/indirect effect countermeasures;
- Isolation of Indirect Effects: A select number of studies did examine the benefits attributed to the indirect effect of countermeasures such as cool pavements. This was examined using a modified ambient temperature vs. base case scenario model to develop the estimate. Further investigation in a range of different climate types accounting for vast array of different cool pavement types is required. Such research should take the form of theoretical and empirical studies that seek to quantify the cooling effect in isolation to other indirect countermeasures (e.g. vegetation) – this will enable not only more accurate savings potential estimates but also the evaluation of the performance range for the different cool pavement solutions.

The benefits of an increased surface albedo and the use of green roofs/urban areas to directly and indirectly reduce urban temperatures (thus the building/city energy use, peak power and thus CO_2 emissions) were proven to be significant. There are however, as illustrated, several obstacles that remain for the present methodologies and data sets to address before they can be used to accurately evaluate the savings at both the micro and macro scales.

5.2.4 *Conclusion*

If we were to standardize the key findings from the literature to evaluate the potential of the direct and indirect effect vs. the negative radiative effect at a global scale in terms of Gt of CO_2 per year, then we obtain the following offset estimates:

- 44 $GtCO_2$ emissions per year from the negative radiative forcing effect if the albedo of all the world's existing urban roofs and pavements was increased by 0.1;
- 30 $MtCO_2$ emissions per year from the direct energy reduction effect of cool roofs, assuming that the US scales to the global level in proportion to its share of energy consumption;
- 12 $MtCO_2$ emissions per year from the direct energy reduction effect of shade trees, this again assumes that the US scales to global in proportion to its share of energy consumption;

- 10.5 $MtCO_2$ emissions per year from the in-direct energy reduction for all UHI countermeasures, assuming that the US scales to global in proportion to its share of energy consumption and the in-direct effect is about 25% of the direct effect in energy reduction impacts, as quoted in an LBNL study.

Therefore, the total energy reduction mitigation effect potential is about 53 $MtCO_2$ per year and is slightly greater than a 1000th of the only global estimate for the negative radiative potential effect. It is important to note however, that 44Gt could be approximately 50% lower were a different approach used to compare the equivalency of the radiative forcing reduction to a tonne of CO_2.

It is clear that both principle methods examined by the literature demonstrate that the urban heat island countermeasures have significant potential to mitigate global warming impacts. The simple estimates established above are derived from claims made in the literature indicating that the negative radiative forcing effect has a much greater mitigation potential than the direct/indirect effect methods. It is important to recognize that although both methods demonstrate significant mitigating potential there is a particular need for further research efforts to verify the magnitude of the negative radiative forcing mitigation potential as there are far fewer assessments of this phenomenon and yet the studies which have been conducted suggest a very considerable mitigation potential. Furthermore, greater emphasis needs to be placed on exploring the sizable benefits that can be achieved through the mass implementation of the high albedo surfaces that induce the negative radiative forcing effect.

5.3 Policy Review

There has been significant work in the cool roof arena, particularly in the US by the Lawrence Berkeley National Laboratory (LBNL) based in California. They have been at the forefront of research, modeling work and testing of materials and their work has been the catalyst to many pilot programs and policies in the US. Green roofs & urban green areas and cool pavements however, have received less attention and as a result knowledge, testing and quantified benefits are less well known and thus far fewer examples of policy exist solely for these measures.

In general terms current policy is hard to keep track of. Frameworks for policy exist at a Federal level but building codes, standards and programs are run at a State and Local Government level. The programs developed at Federal level simply act as a framework or reference point for State and Municipalities. In Germany 14,000 Municipalities exist each with different building laws and related policies.

It was clear from the papers that a comprehensive policy review for all measures across the globe has not been undertaken, LBNL have undertaken one for the USA and specific studies of activities in the UK, Germany and Tokyo have also been undertaken.

Significant barriers are faced in implementing policy which explains why some mitigation measures are more advanced than others, these include a lack of research, modeling and general understanding concerning the benefits of the countermeasures, policy development time scales,

developer uptake, funding and implementation complications in the retrofit market. Another important barrier to acknowledge is that the research undertaken in this section is restricted due to language barriers, most of the policy information we found was in English and many policies, particularly in countries in Europe and Asia are written in their native languages. All of these issues are explored further in the paragraphs that follow.

5.3.1 *Cool Roofs*

Current Status

Cool roof standards, programs and incentive schemes are prevalent across the US championed by the US Environmental Protection Agency, LBNL and the US Cool Roof Rating Council. They are less common however in Europe where the technology is less known and little research has been conducted [200]. Cool roof policies are commonly written into building regulations and standards (typically building energy efficiency standards), guidebooks and educational information and incentive/credit schemes. A list of these schemes can be found in section 4.4.3.

LBNL is at the forefront of organizing a collaborative program between the world's top 100 cities from tropical and temperate climates to form a program that promotes the use of cool roofs and pavements [201]. In Europe, the European Union (EU), acknowledging that it does not have any formal policy in place, has launched a cool roof project as part of its Intelligent Energy Programme which will review existing cool roof policy and evaluate the best way to proceed with a similar policy in the EU.

Potential Barriers

- **Undervalued Benefits**: Cool roof technology is typically focused on energy savings to specific buildings and does not take into consideration the climatic benefits of the roofs and where they are grouped with other more common energy efficiency measures such as insulation and air sealing, so the benefits of a cool roof is often undervalued [201]. Without a full understanding of the benefits of cool roofs policy makers will be unlikely to promote their use.
- **Winter Penalty Misconception**: Another barrier is winter penalties, general misgivings are that a building's winter heating bills will rise as a result of the installation of a cool roof. However, LBNL stress that the energy savings in the summer greatly outweigh the penalties due to the high sun positioning in the summer and low sun positioning in the winter meaning that cool roofs will only have an impact during seasons of high sun [066]. 'Negative press' like this means that if a national program for cool roofs was launched, the public consultation would result in homeowners unlikely to be in favor of such a program.
- **Durability**: Traditional acrylic coatings lose a substantial amount of reflectivity in their first year and up to 55% after 3 years due to discoloration, fading, chalking, dirt pick-up, mildew and water damage. Technological advancement is starting to overcome these issues however, these products are more expensive [238].

- **Preparation**: Substantial preparation is needed to the surface before the paint can be applied [238].
- **Aesthetics**: Given the choice homeowners and building owners typically prefer a darker colored roof [238].
- **Knowledge and Enforcement of Building Codes**: Lack of knowledge and enforcement of the Title 24 reflectivity requirements in California inhibits their full deployment [238].
- **Funding**: Another barrier to rolling out these approaches in a retrofit market is funding. Akbari et al suggest selling albedo-based offsets into the carbon market as a means of funding UHI mitigation projects, this has never been done before and provides a good alternative to making lengthy building code revisions [201].
- **Time**: A drawback of using building codes to implement roof products is the time the codes take to implement, it can sometimes take over 10 years.

Scale and Magnitude

In the US national model codes and standards exist for cool roofs as well as green building programs and incentive schemes, however they are adopted and enforced at state and municipal level so take up is fragmented across the country. Outside of the US the technology is not so widely promoted or implemented but it is considered very likely that it will as a result of the increasing popularity and demand in the US.

Building codes are an effective way of incorporating cool roofs into new buildings. On a global scale however, building codes vary significantly from country to country, some having rigorous processes rolled out on a country by country level, e.g. Europe, and some have a one-size-fits-all approach for example, The National Building Code of India. This variation could be seen as a positive in that a variety of strategies can be adopted to promote cool roofs [201], or as a negative in that it is currently difficult to capture all the policy that exists in the world due to the process currently being something of a silo. Without information on other policies around the globe it is hard to build knowledge and understanding of the benefits and pitfalls associated with policy.

Conclusion

The increasing demand for cool roof products in the US fuels technological advancement, meaning that materials with improved durability and resistance to UV are currently being developed. It is also expected that synergies will be developed between cool roof technology and other efficiency measures such as insulation and air spaces under roofing, thus achieving the maximum benefits for the building. Building codes for sloped roof designs and government requirements for cool roofs are also expected to increase in the future if current trends continue [238].

A key message emerging from the paper review was that incremental strategies such as cool roofing requirements, are easier to incorporate into policy than comprehensive measures and are a good way of raising awareness of the technology [081]. A mixture of policy and incentive schemes are the most advisable and appear to get the most favorable results as they capture the retrofitting market which is easily overlooked as it is harder to enforce and monitor than new build schemes.

5.3.2 *Cool Pavements*

Current Status

The status of cool roof policy is far more advanced than cool pavements and few formal policies exist in this area. The LEED Green Building Rating System provides credits for buildings using cool pavements through its Sustainable Sites Credit, and through a scheme called the Green Alley Initiative the City of Chicago replaces all old pavements with porous paving as part of their renewal strategy [076]. On a residential level programs such as Earth Craft Homes exist, developed by the Greater Atlanta Home Builders Association and Southface Energy Institute, the program awards points for homes that use permeable pavements [076]. One paper by LBNL discusses cool pavements alongside cool roofs and made a case for a new policy to implement cool surfaces on all new build and resurfacing projects in temperate and tropical climates in the US [201].

Potential Barriers

- **Technical Research**: Lack of research and modeling of benefits
- **Economic Research**: Too few cost benefit analysis studies undertaken
- **Organizational Support**: Lack of awareness of technology in the public and private sectors
- **Institutional Support:** Lack of industry support to communicate benefits, promote technology transfer and address barriers.

Scale and Magnitude

Due to the nature of policy uptake, roads and pavements are typically under the control of local government, so policy would have to be rolled out on a local scale. Where policy exists in the US it has been borne from a pilot project or community project instigated a local government which has been deemed successful and rolled out on a larger scale through procurement; design guidelines; building standards and codes; or council issued resolutions. Outside the US, similarly to cool roofs, little information and policy exists relating to cool pavements and more research and promotion is required before this situation can be remedied.

Conclusion

Some policy exists for this technology, predominantly in the US, and it is the least developed when compared to the other technologies featured in this section due to the lack of research, both technical and economic, and lack of support from organizations and institutions.

Due to the substantial drawbacks of using policy and legislation to enforce changes to building materials, primarily the lengthy timescales, a strategy which may help promote cool pavements is to target the decision makers and influencers in the resurfacing industry such as roofing specialists, construction contractors and architects and educate them on the benefits of cool materials. [081].

5.3.3 *Green Roofs and Urban Green Areas*

Current Status

Some local level policy exists for green roof technology but it is less established than the more familiar cool roof technology. Many guidebooks have been published to educate the public and building owners about green roofs and some governments offer financial incentives for their installation [197]. Cities in Germany, Austria, Switzerland, Japan and the cities of Toronto and Vancouver in Canada have by-laws which mandate green roofs on all new residential buildings [198]. In the US most states have some kind of urban planting program.

Germany has the most formal arrangement for incorporating green roofs into building codes and nature conservation acts, direct and indirect financial incentives and ecological compensation measures [212]. As such Germany is a particularly good example and is considered to be the world leaders in the green roof industry due to their advanced green roof technology (where it originated 30 years ago [214]) and practices. Their industry is estimated to be worth $77 million annually and they are reported to have 50 million m^2 of green roofs in their cities which make up 14% of total roof area [211, 212]. As a result of its inception in Germany, it has become popular in Europe where there is a steady trend in the design of sustainable buildings.

The benefits of urban parks are well understood and discussed in many papers and architects are increasingly designing them into urban areas, but again no formal policy exists with regards to their implementation [210].

Potential Barriers

General barriers to Green Roofs and Urban Green Areas are:

- **Cost**:
  - there is an underdeveloped method of costing green roof technology, initial, life-cycle or cost benefit analysis. In Germany annual storm water fees offset the price;
  - the cost benefit analysis of trees require further research including their planting, maintenance and disposal;
  - developers may protest over the extra cost of a green roof. Developers may be more intent on delivering a low cost building and may not consider the long term energy savings of a green roof which recuperates the initial cost;
- **Repairs**: repairs on a green roof are more difficult than a traditional roof; and maintenance of trees and greenery can be expensive and therefore an unattractive;
- **Aesthetics**: some people do not like the appearance of a green roof;
- **Associations:** there are a lack of associations to advocate green roof technology;
- **Collaboration:** there is a lack of collaborative R&D efforts to develop green roof technology;
- **Technical Capability**: manufacturing firms have insufficient technical capabilities to produce green roof technology;

- **Spatial Constraints and Suitability**: Some cities do not have the space for extra trees and green areas so the technology is not suitable; and green roofs are not always appropriate due to gradient and positioning
- **Lack of knowledge and awareness**: public knowledge about green roofs is lacking and opinions that roofs are faulty and problematic affects the credibility of the entire industry; and
- **Lack of research and standards**: this is true for many countries outside of Germany, although the German system could be used as a benchmark [212].
- **Implementation of Building Codes**: Codes are difficult to implement particularly for retrofitting, an approach which combines building codes and incentive schemes could be more successful;

Scale and Magnitude

Again, national policy does not exist across any country in the world due to the way governments are structured. However, cities in Canada, Germany, Austria, Switzerland and Japan have by-laws which mandate green roofs on new residential buildings and new buildings over a certain size. Studies are planned across North America to further analyze the benefits of green roofs. These studies are being sponsored by city governments, public/private partnerships and university research [214]. One paper encourages businesses, individuals and governments to promote green roofs by example in order for benefits to be realized by a wider audience and thus translate into policy [214]. It appears that setting an example at community level is the best way to influence policy.

Conclusion

The most important barrier identified was the lack of research undertaken into areas outside of cool roofs which results in poor public perception and cynicism. A way of combating this is to publish more guidance and manuals to educate the public and those that could be involved in the technology in its life cycle. A paper written by researchers at the University of Athens acknowledges that education is an important issue in the success of a mitigation program and aims to remove these barriers through the implementation of an action plan that targets a change in behaviors, and promotes and transforms the technology market [200].

Another idea put forward by LBNL is that utility companies offer incentives to customers to plant shade trees around their homes, the benefit to the utility is that in California utilities are allowed to slightly increase their prices if they are seen to promote green projects and energy savings and share the savings with their stockholders [066].

5.4 Economic Review

The magnitude of U.S. potential energy bill savings (cooling-energy savings minus heating-energy penalties) has been estimated to be between $1 billion and $4 billion per year, while the value of the abatement in local air pollution is estimated to be roughly equivalent. The range in these estimates reflects the uncertainty that still pertains to many of the economic assumptions and their input values. Arguably more important than this is the value of the CO_2 mitigation impact, especially from the few estimates of the negative radiative forcing impact. If these are correct the global mitigation benefit from this effect alone could be worth $1.1 trillion (assuming a shadow carbon value of $25 per tonne abated). This sum is over two orders of magnitude greater than the value of the other effects and yet has the least research to support. Furthermore unless and until carbon markets allow abatement through the negative radiative forcing effect to be eligible for carbon credits, which is not currently the case, this value is of a theoretical public good nature and offers no self-interest economic value to private sector actors. In general the existing assessments of UHI countermeasures provide quite crude assessments of cost-benefits and there is a considerable need to improve them; however, they leave the impression that the weight of evidence favors adopting UHI countermeasures on a large scale, especially as one of the win-win or low cost means of addressing climate change. When the value of all other public and private good factors are considered: improved local air quality, lowered energy costs, enhanced greenery, increased nighttime road safety etc. it is probable the economic arguments favor the adoption of UHI countermeasures and especially cool roofs.

5.4.1 Cool Roofs

Cool roofs can already be a cost effective option especially in hot areas and especially in commercial buildings. The insulation levels in the ceiling and roof space are a major factor influencing the cost effectiveness of cool roofs as are the degree of air conditioning use and whether the savings occur at peak power demand or not (increasingly they do as utilities around the world are moving toward summer peaking at latitudes progressively further from the equator). For example over a twenty year period a cool roof retrofit in Phoenix (AZ) for a ceiling with only R5 insulation levels will save peak power costs of roughly $130 per m^2 of roof whereas if the insulation is R20 level this falls to $30/$m^2$. In Chicago the figures are typically $34/$m^2$ for R5 insulation and $8/m2 for R20 insulation levels, thus if the insulation value is quadrupled the savings from the cool roof are quartered. The value of the heating penalty is generally very small however in comparison to this.

Other factors of relevance to this are:

- the aged performance of the cool roof
- commercial sector roof replacement can often be done at zero cost premium compared to a conventional roof replacement
- commercial sector retrofit where the sole motivation is energy efficiency improvement is not cost-effective in most cases

- residential sector – not yet cost effective except for premium roofs (metal, tile), could be very cost effective especially when ducts are in attic

In other words cool roofs become a cost effective option in many cases where other aspects of the building and HVAC design are inefficient.

5.4.2 *Cool Pavements (Roadways)*

The existing economic calculations regarding cool pavements suggest they struggle to break even if just the life cycle value of energy and local pollution abatement are considered. If the value of the negative radiative forcing abatement impact is monetized they become far more cost effective. Reflectivity of pavements is also a safety factor in visibility at night and in wet weather, affecting the demand for electric street lighting. Street lighting is more effective if pavements are more reflective, which can lead to greater safety; or, alternatively, less lighting could be used to obtain the same visibility. These benefits have not yet been monetized.

5.4.3 *Economics of Shade Trees*

UHI reduction from tree planting has been found to lower peak urban diurnal temperatures by 0.3 to up to 3K and to give air conditioning savings of $5-$10 per 100m^2 of roof area for residential and commercial buildings. For example a study of the impact of planting 100m trees in the Los Angeles basin estimated $270 million from direct and indirect energy savings and smog reduction benefit of which the value of smog reduction accounted for about 2/3^{rds} of the total. The present value of planting trees was found to be $68 per tree for the direct energy savings and $24 per tree for indirect energy savings. The present value of smog savings was about $120/tree. Estimates of the cost of planting, pruning and tree removal vary and have been found to vary from $45 to $500 per tree. On this basis tree planting is often not cost-effective in pure energy savings terms and even if the value of local air quality improvement is incorporated the cost-benefit calculations do not always favor tree planting, however, the aesthetic and quality of life benefits of greener spaces are not included in this assessment and they may well tip the balance firmly in favor of greater urban greenery.

5.4.4 *The Value of Mitigation Benefits from the Negative Radiative Forcing Effect*

The value of the negative radiative forcing effect is purely in terms of the public good value of reduced global warming. According to the only global estimate so far conducted this would be worth a massive US$1,100 in carbon offsets were CO_2 valued at ~$25/tonne of CO_2 and were all viable urban roofs and pavements to have their albedo increased by 0.1. This is equated to a 44 Gt CO_2 emission offset.

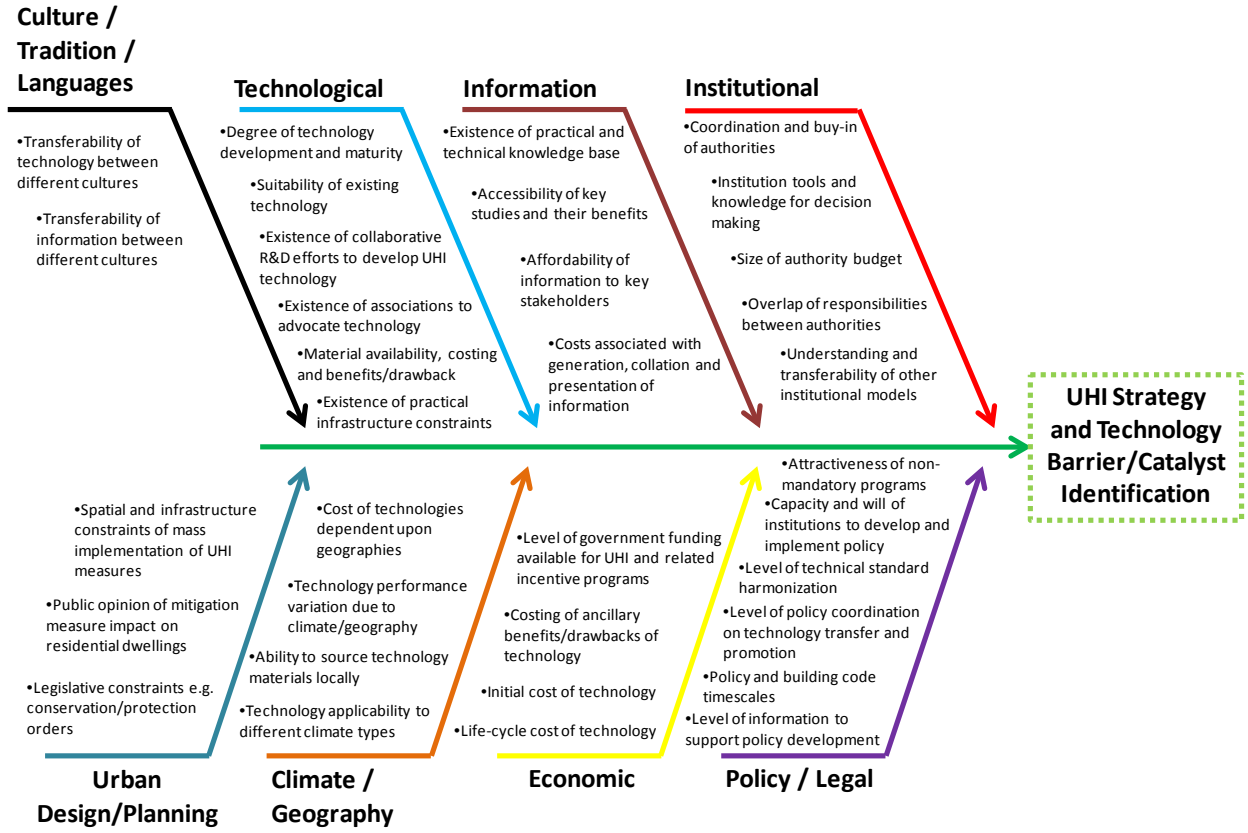
5.5 Opportunities for Scale Up (Barrier and Rate Analysis)

5.5.1 Introduction

In order to understand the actions that can either catalyze or hinder the mass adoption of UHI strategies and technologies we attempt to identify the typical barriers/catalysts that can affect the deployment rate and large scale urban city adoption across the world. Some of the reported barriers have been identified through the literature reviewed and others are based upon experience from other sectors. Naturally, the type and extent of the barriers faced across different regions will depend upon numerous parameters and thus this process seeks to provide a high level identification of the broad issues in some cases elaborated through UHI specific examples.

5.5.2 High-level Barrier Diagram

The diagram illustrated below provides a high-level interpretation of the key barriers and/or catalysts for the Urban Heat Island implementation and scale-up with some key examples listed under each category. The section to follow provides: a definition of each of the categories, an analysis founded on the 5A's analysis conducted on each category, factors which can affect the rate of scale-up and thus some recommendations to overcome barriers and enhance the catalysts.



5.5.3 *Five A's Barrier Classification*

5.5.3.1 Introduction

The 5A's framework enables the identification and characterization of market barriers. The 5A's framework considers all the steps in the value chain from manufacturer to end-user: Availability - does the technology exist? Awareness - does the market know about the technology? Accessibility - does the market have easy access to the technology? Affordability – is the technology affordable? Acceptance – are the form, fit and function of the technology acceptable? Each "A" in the framework represents a critical step along the path of new technology adoption in the market place.

Once barriers are classified, programmatic solutions may be developed to overcome the barriers to the particular UHI product, technology, or strategy.

5.5.3.2 The 5A's Framework for Market Transformation

This framework considers all the steps a UHI product follows as it moves from the manufacturer to the end-user, starting with "Availability" of a technology and proceeding through to end-user "Acceptance". Each "A" in the framework represents a critical aspect of the market adoption path for the new technologies. By considering the full market cycle of a technology from production through to installation and operation, the framework facilitates group discussion and identification of all barriers to market transformation. While the applicability of each of the steps in the cycle will vary depending on the UHI technology under review, this approach enhances the analysis by characterizing the market barriers and understanding how the barriers can affect different market participants.

The diagram below shows each of the 5A's in sequential order, from Availability through to Acceptance. While it is presented here in a simplistic linear flow, it is recognized that unique dynamics of a specific market can result in some reverse or concurrent activities in the full market cycle characterization.

The Stages of the 5A's Barrier Analysis Tool

Each of the 5A's addresses a critical step in the movement of product from the manufacturer to the end-user. These steps are described below.

Availability - Does the technology exist? What information or policy mechanisms are available to support and promote the adoption of the given technology? Availability addresses the existence of a technology, policy or other element targeted for market transformation. And for that

technology, it evaluates the availability and/or barriers of these three elements in promoting its market adoption.

Awareness - Does the market know about the technology? What is the overall level of awareness among all UHI stakeholders with respect to the more efficient technology being evaluated? This critical step evaluates to what extent market participants (i.e., distributors, retailers, designers, contractors, and end-users) are aware of a more efficient technology, and what barriers might be preventing them from becoming informed.

Accessibility - Does the market have easy access to the UHI technology through traditional distribution channels? Once a technology is available and people are aware of it, the market needs to have easy access to purchasing the technology. Accessibility concentrates on the flow of products, technologies, and information to all stakeholders.

Affordability - Is the market able to bear the selling price? Does the higher purchase price of the UHI technology represent a market barrier? Some sectors (e.g., residential) can be particularly first cost sensitive, while others (e.g., commercial) are more likely to look at life-cycle cost and payback periods. If the UHI technology is more expensive than the source it seeks to supplant, it may experience an affordability barrier to capturing a greater share of the market.

Acceptance - The last step of the 5A's barrier analysis brings together elements of the preceding four A's, with other factors that impact a purchasing decision - the form, fit and function of a product. These attributes of a particular product (e.g., operating life, performance quality, noise production) can represent a barrier to market acceptance. Market barriers found in Acceptance typically lead to programs or solutions being carried out in one or more of the preceding four A's.

5.5.4 Barrier/Catalyst Category Review

5.5.4.1 Institutional Barriers/Catalyst

The five A's are now examined for influential structures that act to govern collective behaviors – in this analysis institutions take the form of both government and non-government agencies, authorities, bodies, etc.

Availability: it is important the appropriate agencies and authorities exist that can take responsibility for driving the implementation agenda for the key UHI mitigating countermeasures. These bodies must have the authority and relevant policies, standards and frameworks in place that address UHI issues and provide the foundations for mass implementation of UHI technologies. Furthermore, it is critical that the enforcing bodies are coordinated in their action and don't have split authority and overlapping mandates. Bodies such as the US Department of Energy, US Environmental Protection Agency, Building Associations and Federal, State and Municipal Governments exist and have the appropriate authorities described. These bodies were discussed in part by the papers reviewed.

Awareness: the bodies that have the potential to influence UHI countermeasure deployment and enforcement e.g. Environmental Protection Agencies must have the appropriate knowledge and understanding of the UHI impacts, UHI mitigating technologies and their potential to reduce UHI impacts in particular reduce the costs, energy use, peak power and related CO_2 emissions – these are likely factors to incentivize the adoption of policies that would seek to increase the adoption of these technologies. The Government Bodies etc previously discussed are reliant on studies from research institution such as the Lawrence Berkeley National Laboratory, other universities and environmental groups to provide them with the appropriate scientific insight to make decisions on policy and strategy. The papers identify certain gaps in research particularly around quantifiable benefits of some mitigation measures which makes decision making more challenging for the Bodies.

Accessibility: N/A

Affordability: the authorities seeking to encourage the large scale implementation of UHI countermeasures need to have adequate budget to provide demonstration projects and in some cases incentivize the adoption of UHI technologies that are often more expensive than conventional alternatives.

Acceptance: the countermeasure benefits must be understood and accepted by all institutional stakeholders to ensure there is clear scope and coordination between the involved parties and policies that are developed. This buy-in and coordination are critical to the rate of uptake and success of any large scale UHI countermeasure program. The literature indicates that there is a broad acceptance for the UHIs as an observed phenomenon across most parts of the world; however, in the US there are still significant steps that remain to be taken to achieve mass coordination between all relevant stakeholders, in Japan and China it appears that the efforts are led from the national government and thus they adhere to a more coordinated mandate, although the rate of urbanization and new developments presents their own challenges to enforcing UHI countermeasures at large scales.

Primary Barriers:

- Coordination and buy-in of authorities, no overlap in responsibilities;
- Existence of appropriate institutions;
- Institutions have the appropriate knowledge and tools to enable decision making and prioritization of UHI;
- Understanding and transferability of other institutional models; and
- Authorities having the appropriate budgets to run large scale mitigation programs.

5.5.4.2 Information Barriers/Catalyst

The five A's are now examined to identify the barriers associated with the level of information provision in the market.

Availability: the level and type of information available. Both qualitative backed by quantitative information on the benefits of UHI mitigating technology and their performance characteristics over conventional alternatives is critical for uptake of the potential countermeasures. Such information could be made available by developing simple rules of thumb that could easily be used by designers and planners. Such rules of thumb have not been found in any of the literature sources; however, databases and studies that help to identify the relative benefits of UHI technologies do exist.

Awareness: it is important that the relevant stakeholders are aware of the information pertaining to the benefits and superior performance (including an appreciation for penalties in different climates types and seasons) and life-cycle cost benefit credentials of advanced UHI technologies over conventional technologies. Such awareness can be achieved through publicly available databases and studies, labeling, advertising and demonstration projects. Such databases for cool roofs and shade trees are already available and numerous public building demonstration projects exist across the world.

Accessibility: this defines who has access to the required information that will inform stakeholders across the UHI value chain. For example, if architects have access to a database that identifies the relative costs, proposed benefits, and sourcing of traditional dark roofs and high albedo dark roofing alternatives then they may feel more willing to incorporate cool roofing alternatives into their future designs. The literature indicated that the availability of information was broadly aimed at policy makers but should be extended to include designers and planners who adapt existing urban structures and cities – providing them with access to such information could act to encourage them to use UHI countermeasures over more conventional alternatives.

Affordability: the information must be affordable, ideally free and publically available such that all stakeholders have access to the required information relevant to their domain. For example modeling studies, measured data research, policy recommendations etc. The majority of the literature was found to be free and publicly available through a range of internet based sources and targeted websites. Another point to consider is the cost of producing such information and whether this acts as a barrier to research institutions.

Acceptance: in order for the information to be acceptable to potential influential stakeholders it is necessary that all the required information on UHI mitigating technologies i.e. operating life, performance, cost, and other ancillary benefits are identified, made available, and collected in one place to allow informed decision making. The literature indicates that such information and its concentration is readily available for cool roofs, shade trees and green roofs; however, more data and research is required to develop such information and tools for cool pavements.

Primary Barriers/Catalysts:

- Existence of demonstration projects, technology knowledge base, reports and guidelines to inform all stakeholders;
- Accessibility of key studies on mitigation technologies and their benefits;
- Affordability of this information to key stakeholders; and

- Costs associated with the generation, collation and presentation of the information.

5.5.4.3 Technological Barriers/Catalyst

The five A's are now examined to identify the barriers associated with the UHI technologies.

Availability: this examines the status, existence and level of maturity of UHI technology including whether it has been fully tested and developed. This should also consider whether all the required materials and tools are available for the mass manufacture of the technology. The key technologies being discussed were: green roofs, shade trees, cool roofs and cool pavements. The literature indicates that all (apart from cool pavements) technologies had reached maturity and thus were readily available. Cool pavements, however, were demonstrated to still require further research and development to overcome technical issues highlighted in chapter 4.4.2.

Awareness: this component examines the key stakeholders' knowledge of the UHI technology, performance benefits and what issues may prevent them from becoming informed. For example the labeling of roofing materials and cool paints. The literature demonstrates that there is a general awareness of technology existence however, when the stakeholders make decisions it is often difficult to know what UHI sensitive alternatives exist and clearer labeling was mentioned to help differentiate their relative benefits and often justify the higher initial purchase cost over traditional alternatives.

Accessibility: it is important that once stakeholders are aware of the key UHI technologies and their existence that they have access to the source of suppliers of UHI mitigating technologies and materials across the entire supply chain. For example, if a state intends to launch a mass retrofit of roofs on public buildings it must have access the appropriate materials to undertake the task. The literature didn't comment on any supply chain issues; however, in any mass scale up it is important that the materials and equipment used can be sourced locally to avoid supply chain bottlenecks.

Affordability: the price of the UHI technology is a vital component for the mass uptake of UHI technologies. The literature indicated the importance of examining the life-cycle costs and in quantifying the benefits resulting from UHI technologies that would often help outweigh the high initial costs. The price component was indicated to be dependent upon the performance level of the UHI technology as well as if the technology was to be retrofitted or installed in new developments. Moreover, it was indicated that the residential sector would be more sensitive to the first cost element whereas the commercial sectors were more focused on long-term issues such as life-cycle costs and the payback periods. The cool roof technology was indicated not to suffer from first cost issues due to similar prices to traditional technologies they sought to replace whereas cool pavements were demonstrated to be costly and life-cycle benefits unproven.

Acceptance: the acceptability of UHI technologies depends upon the balance of drawbacks and benefits, the level of benefits attributed to the UHI technology, price and availability. The literature for cool roofs reported that their competitive pricing, range of alternatives, and ease of

integration would make them acceptable; however, potential issues could arise with the use of highly reflective sloped roofs which could cause glare. With regard to cool pavements the key challenge is in quantifying and thus proving the benefits. Furthermore, some pavement users are likely to object to highly reflective pavements if the solutions generate high glare surfaces – this could render such technologies unacceptable. Regarding green roofs, their proven performance capabilities in terms of energy savings, improved building insulation, storm water runoff reduction, noise reduction, aesthetics, etc have made them highly acceptable as demonstrated by significant uptake in cities in Germany, Austria, Switzerland, Canada, Japan and the UK.

Primary Barriers/Catalysts:

- Level of UHI technological development;
- UHI technology maturity;
- Suitability of existing technology to meet UHI mitigation requirements;
- Existence of associations to advocate technology;
- Availability of locally sourced raw materials to develop mitigation technology;
- Existence of practical infrastructure constraints;
- Existence of collaborative R&D efforts to develop UHI technology;
- Technical capabilities of manufacturing firms in producing the UHI technology;
- Method of costing UHI technology, initial, life-cycle or cost benefit analysis; and
- Trust and understanding of the benefits and drawbacks of each technology by all stakeholders.

5.5.4.4 Culture, Tradition, and Language Barriers/Catalyst

The five A's are now examined to identify the barriers associated with the culture, traditions and languages.

Availability: examines the existence of any cultural barriers and how they would act to hinder the adoption of UHI mitigating technologies. The literature did not refer to culture, traditions or language despite the importance of considering the impacts these factors can have upon the uptake of UHI technologies and strategies.

Awareness: evaluates the key stakeholders' knowledge of the various cultural, traditional and linguistic barriers. For example, in Greece, the Greek islands have traditionally painted their island houses white (for practical as well as cultural/traditional purposes) and thus cool light colored roofing materials take precedence over dark roofing materials. Furthermore, most of the UHI literature has been published in English, and the UHI phenomenon is experienced in numerous communities around the world that aren't English speaking therefore this could also act as a barrier to UHI knowledge transfer - potentially reduce the uptake of UHI mitigating technologies in those communities. This area was also overlooked by the literature reviewed despite the importance in understanding the market knowledge of any cultural, traditional preferences and the associated merits upon the rate of uptake of UHI mitigation technologies.

Such prior knowledge may allow market adaptation to increase the appeal and acceptability to the local market they address.

Accessibility: is a critical issue - without an understanding of culture and traditions and linguistic capabilities to communicate the relative performance and cost benefits associated with UHI mitigating technologies and strategies there is likely to be low uptake of these solutions. For example, accessibility is particularly important in developing countries and emerging economies where an understanding of the local culture and traditions and ability to communicate in the same language can influence the urban design and planning at the early stages before rapid urbanization takes place. The literature did not address such issues.

Affordability: can refer to the markets' ability to adapt to preferences associated with certain cultural/traditional preferences. Again this was not reviewed in the literature. It could be noted that certain cultures and traditions would be more willing to invest in green roofs/gardens simply due to their lifestyles which they have become accustomed to; thus such green solutions in this setting would take precedence over other high albedo roof solutions.

Acceptance: is a combination of the above described parameters and in this context would take the form of what is culturally acceptable. Following on from the earlier example of the Greek islands it is unlikely that the use of high albedo dark roofs could form a large scale UHI mitigation program simply due to the cultural/traditional significance of the light colored buildings. These issues were not examined in the literature but could prove to be significant barriers to some communities/cultures across the world.

Primary Barriers/Catalysts:

- Transferability of technology between different cultures;
- Transferability of information between different cultures.

5.5.4.5 Urban Design/Planning Barriers/Catalyst

The five A's are examined for Urban Design and barriers are indentified:

Availability: Urban design and planning frameworks exist and will impact on the implementation of mitigation measures, it is important to consider planning when implementing policies for UHI mitigation. Planning frameworks and process differ from country to country and state to state. Some have strict planning processes and permits must be sought for any structural changes and others have a more relaxed approach. UHI mitigation measures can be encouraged through comprehensive plans and design guidelines, set at a State level and implemented at a local level through zoning codes. Comprehensive plans are directed by State Implementation Plans which are set at Federal level and dictate targets for air quality standards for example. Some literature discusses planning requirements and issues, these papers are predominantly US focused.

Awareness: Planners and designers will be aware of planning policies and will work restrictions into designs, they will also be aware of the procedure involved in the approval process for a building or city plan. Planning restrictions include conservation and protection legislation. On a domestic level knowledge of planning requirements vary from person to person and changes to properties can be made without planning permission/building permits. The literature does not reflect this issue in any detail.

Accessibility: The market has access to planning information through the media and local government websites. Thought must also be given to the process of developing planning legislation and how legislation can be changed. The papers identified that building codes would be a direct way of influencing building design but acknowledged that there would be lengthy timescales associated with the changes. Planning policy is administered at government level so influence would be required at that plane.

Affordability: The affordability of urban design and planning is borne by the originator. Incentive schemes to encourage the use of cool roofs and increased greening on domestic properties are not mandatory so consumer choice and affordability is a factor. The government may offer incentives or tax credits to encourage take-up. The retrofit market is more prone to funding issues, due to issues like building age and tax so consideration should be given as to how to proceed in this area.

Acceptance: Some planning requirements are enforceable by law through building regulation, planning permissions and building permits. Others such as guidelines can only be encouraged and incentivized. The public and businesses much accept that the technologies will benefit them and their surroundings considerably in order to implement them. This can only be done through raising awareness of the technologies through the media and other outlets, making them affordable and accessible.

Primary Barriers/Catalysts:

- Legislative constraints in the form of conservation and protection orders and building codes;
- Public opinion concerning the mitigation measure's impact on residential dwellings;
- Spatial and infrastructural constraints of mass implementation of UHI measures;

5.5.4.6 Climate/Geography Barriers/Catalyst

The five A's are now examined to identify the barriers associated with climate and geography.

Availability: the existence of different climates and geography can have significant impact upon the adoption of UHI mitigation technology. For example, the various UHI countermeasures are likely to have different performance characteristics in different geographical locations and climatic conditions. Such concepts have been examined to varying degrees throughout the literature.

Awareness: examines the level of understanding that relevant stakeholders have of challenges in addressing the UHI for different climate types and geographies. For example, using UHI mitigating technologies that increase the humidity levels through the evapotranspiration process may in some warm temperate and equatorially fully humid climates have negative effects on health and comfort levels – this therefore could act to inhibit deployment of UHI technologies that use evapotranspiration in such climate types. The literature has addressed a wide range of climate types and identified scenarios which may have penalties on key UHI mitigating technologies.

Accessibility: examines the extent to which geography or climate may restrict the use of UHI mitigation strategies and technologies. Such restrictions can take the form of either lack of supply of appropriate materials due to the geographical location or inability to enforce urban green solutions due to the climatic constraints. The literature did not adequately cover these factors.

Affordability: examines the extent to which different climate types and geographical locations may yield higher initial and life-time costs. The literature did not address such issues; however, they could take the form of increased initial costs simply due to inability to locally source raw materials used to produce key UHI technologies or the increase in maintenance/running costs of hydrating the urban green solutions. In some regions these could pose significant financial burden and thus act to limit mass market implementation.

Acceptance: acceptability is dependent upon a combination of the above factors and the degree to which they are affected by the geographical location and/or the climate type experienced by a region. For example, it might not prove a practical solution for a hot desert arid climate to implement green roofs at large scales simply due to the water requirements, maintenance costs, and lack of water resource in the region. The literature did not explicitly examine the issues raised; however, it did indicate that some technological solutions are more effective in certain climate types and geographical locations.

Primary Barriers/Catalysts:

- Technology applicability to different climate types;
- Ability to source local raw materials for mass implementation of mitigation measures;
- Variations in performance of technologies due to climate type and geographic location; and
- The cost of the technology varies depending on different geographies.

5.5.4.7 Economic Barriers/Catalyst

The five A's are now examined to identify the barriers associated with the economic and financial elements of the UHI technology uptake.

Availability: Examines the existence of economic barriers and what financial mechanisms are in place to support UHI countermeasures. For example, establishing funds financed by utilities that

would seek to incentivize UHI countermeasure investments by making them affordable would likely act to increase the uptake of UHI sensitive designs. The economics behind UHI measures are covered to varying degrees and most studies looked at quantifying the life-cycle costs to help justify the often higher first cost associated with the countermeasures. There was however, no mention of potential financial mechanisms that could support the mass deployment of such schemes within the literature.

Awareness: Examines the market awareness of any financial/economic barriers associated with the UHI countermeasures and the level of understanding amongst the key UHI stakeholders. For example, is the commercial sector aware of the financial benefits they can achieve by employing UHI mitigation technologies? The literature did not indicate the level of awareness or identify any barriers that may prevent stakeholders from becoming informed.

Accessibility: Examines if stakeholders with the potential to enact mass deployment of UHI countermeasures have appropriate access to funds, financing tools and mechanisms. For example, the use reduction of tax on green solutions may render green roofs more affordable for mass implementation. The literature did not indicate any barriers that may prevent stakeholders from having access to such funds where they existed.

Affordability: Examines whether with the price of UHI mitigation technologies is affordable to key stakeholders. Does the higher price with some UHI technologies present a market barrier? For example, different sectors will examine costs in different sensitivities; the residential sector is likely to be more sensitive to the first costs whereas the commercial sector is more focused on the life-cycle costs and payback periods. In the literature, only cool roofs have been demonstrated to on average costs the same as conventional equivalents.

Acceptance: A combination of the above factors will determine the acceptability of any UHI technology purchasing decision. This will be dependent upon the form, fit and function of the product, the presence and awareness of funds and financial mechanisms to incentivize uptake, quantification and interpretation of performance benefits of UHI technologies in monetary terms. The literature indicated that often the superior performance benefits of UHI technologies over conventional solutions would often make the higher initial prices more palatable; however, there was no discussion of funds or financial mechanisms to support such decisions. Cost-benefit analysis exercises highlighting the UHI countermeasure's benefits would make them more financially appealing.

Primary Barriers/Catalysts:

- Initial costs of technology;
- Life-cycle cost benefit analysis of technology;
- Costing of ancillary benefits and drawbacks of technology; and
- Level of Government funding available for UHI and related (e.g. climate change) incentive programs.

5.5.4.8 Policy/Legal Barriers/Catalyst

Availability: If policy does not exist enforcing mitigation activities is unfeasible, the mechanisms in place to support the development of policy should also be acknowledged and alleviated where possible. Policy is a vital part of the process to mitigate UHIs particularly as it allows implementation on a mass scale. An example of where policy does not exist is in cool pavement technology, therefore it cannot be enforced in Local Government planning. The papers we referenced showed that policy (which typically relates to building codes, building programs and incentive, credit and rebate programs) is covered to some degree for most mitigation measures except cool pavements and urban greening. The papers reflected that policy in the US is more cool roof focused and in Europe it is more green roof centric. Little information exists for Africa, Asia and Australia.

Awareness: Those stakeholders affected or influenced by policy must be aware of it if policy is to make any impact on mitigating UHI, therefore it is important to identify any barriers to awareness. For example a tree planting incentive scheme available to homeowners maybe explained in a small section on a Local Government website and not well publicized, therefore it is unlikely that all homeowners in that authority will be aware of its existence and able to take advantage of it. The awareness of policy was not discussed comprehensively in the papers we reviewed, but generally speaking new policy is communicated through the media (television, radio and the internet), journals, trade associations and will be available on government websites. The public are made aware of local grant and incentive schemes through the media, retailers and local government portals.

Accessibility: If the market does not have access to the policy, it cannot be read, understood and used to implement the mitigation measure. Policy, not being a physical property can only be accessed through the media. Policy only applies in the state or country it is written for and thus is only applicable to anyone undertaking a project in that state or country. The papers reviewed did not reference the accessibility of policy. More formal policy will be evident to the developer through the planning process. Voluntary schemes, incentives and grant programs will be accessible through the media and government portals. It would be useful if information on global policy was stored in one location, as it currently stands it is scattered and difficult to locate.

Affordability: If policies and programs are not affordable they will not be successfully implemented. Thought must be given to how schemes like tree planting programs and tax credits etc are funded. The papers reviewed did make reference to the funding of these types of schemes but generally the state is responsible for funding new policies and legislation. New programs developed by the private sector or not for profit organizations may be part funded by the government. Programs in developing countries may not be given priority if funding is an issue. Voluntary schemes such as tree planting schemes again may be funded through government grants or fundraising.

Acceptance: If the market does not accept a policy that is not a legal requirement it will not be implemented. Acceptance is a result of the success of the previous four factors. Some policies, like voluntary or incentive schemes are not mandatory but encouraged and it is the choice of the

homeowner for example to choose whether they install a green roof or plant a tree in their garden. Therefore the scheme has to be deemed suitably attractive to warrant its uptake, this can be tested by undertaking public consultation and pilot schemes. The papers reviewed did not make reference to this area, generally any legislation passed must be accepted and adhered to avoid risk of prosecution. Objection to legislation occurs and petitions are written to the Government, it is then up to the Government as to how they respond.

Primary Barriers/Catalysts:

- Level of information, measurement and modeling of benefits to support policy development;
- Timescales relating to policy development and particularly building codes;
- Level of political will to develop appropriate policy;
- Ability to enforce policy particularly at local level if set at a national level;
- Level of coordination of policies on technology transfer and promotion;
- Degree of harmonized technical standards;
- Level of development of regulatory frameworks;
- Level of capacity of institutions to develop and implement policy;
- Attractiveness of non mandatory mitigation programs to general public.

5.6 Urban Planning and Retrofit

This section examines the urban planning issues and the degree to which current practice could act to inhibit or facilitate the deployment of Urban Heat Island countermeasures. The planning issues that face the retrofit market versus the new build market are often different and thus they are examined in greater detail. The planning issues faced between countries may also vary depending on the regional/local regulation, government priorities, climatic conditions, etc. Retrofit measures can take the form of energy efficiency measures, roof replacements, pavement alterations, planting and potentially upgrading of transport networks to reduce the use of personal vehicles. We report the general issues that have been identified and discuss potential measures to resolve for each countermeasure.

Sky view, green infrastructure, building materials and population density are all elements of urban design and planning and are largely controllable, these elements also help form the causal factors of the UHI [007]. When planning for cities, planners and designers should first consider the urban microclimate in order to ensure the design approach is compatible with the urban characteristics and UHI effects. In order to assist this process, the research and scientific community could supply planners and designers with guidelines about the most appropriate measures to relieve the effects such as, the best use of open areas and parks and urban geometry [006]. In the UK, the Government Office for London (GLA) are currently (October 2009) developing a model in collaboration with University College London and various partners called LUCID (The development of a Local Urban Climate model and its application to the Intelligent

Design of cities) this model will be used to understand the physical processes involved in creating London's UHI and will be used to develop strategies to mitigate the effects. These types of activities have been undertaken all over the world for example the US, Mexico, Singapore and Japan [005, 052, 097, 091].

Strategic planning frameworks are generally set at Federal level and are filtered down to State then to the Local Government through the state's General Plan. The General Plans are wide reaching and visionary for Local Governments to take direction. Design Guidelines provide the link between higher level policy and implementation regulations on a local level. Measures are then implemented through Zoning Codes [076].

Barriers

In general terms barriers to planning are faced if significant changes are proposed to:

- protected areas which include conservation areas, sites of special scientific interest and listed buildings; and/or
- the character of a street or building so it is not in keeping with its surroundings

Barriers to planning schemes are also encountered when:

- There is public objection; and/or
- There are spatial or infrastructural restraints

Legislative barriers include the Planning (Listed Buildings and Conservation Areas) Act 1990 (UK), National Historic Reservation Act (USA); and Land Planning Policies such as Green Belts and Urban Growth Boundaries. Other potential barriers include funding and public objection which is why wide and thorough public consultation is a seminal part of any planning process.

Generally when constructing or making a major change to a building or the local environment, planning permission must be sought from the local government or state. Building Regulations also exist to set standards for the design and construction of buildings and to ensure they adhere to health & safety codes, fuel & power conservation and disability provision. Building regulations vary from state to state which if a national program was launched could cause overlap and complications relating to approvals and enforcement.

5.6.1 Cool/Green Roof Planning Issues

Cool and Green roofs means either light colored and therefore reflective and vegetative cover. Not all roofs are appropriate for such measures, roofs must be load bearing, have a suitable gradient and mounting surface.

Planning issues for new builds, the roof would be incorporated into the designs at inception stage by the developers and architect and therefore objections are unlikely to be raised.

Planning issues for retrofit, either private or state owned, as long as the roof does not affect neighboring buildings, or raise objection from its tenants it will not be deemed as a major material planning issue.

Several guidebooks have been published to educate the public and building owners about green roofs and some governments offer financial incentives for their installation [197]. Germany, Austria, Switzerland, Japan and now Toronto, Canada have by-laws which mandate green roofs on all new residential buildings of over six stories and buildings with above 2,000m^2 gross floor area [198]. Germany have the most formal arrangement incorporating green roofs into building codes and nature conservation acts and Porto Alegre, Brazil have set up a building code for green roofs where ground space is limited, New York has also set up a pilot incentive scheme for green roofs [199].

Cool roof standards, programs and incentive schemes are prevalent across the USA championed by the US Environmental Protection Agency and the US Cool Roof Rating Council. They are less common however in Europe where the technology is less well known and little research has been conducted [200].

Potential Barriers

Problems may arise when painting the roofs a light color as some building materials are not adaptive to painting, also if the material has to be renewed regularly then it may be costly and unattractive to building owners [112]. In an adaptation planning exercise in Montreal white and green roofs were identified as one of the most expensive mitigation measure tested [101]. Also for New Build a choice of light colors would be preferable as architects and developers are known to prefer an option so as to compliment the overall design [112].

Another barrier for cool roofs exist as they can create issues that affect the public, these include increased glare and visual discomfort, particularly for sloped roofs. Therefore detailed planning is required to minimize these effects [112].

Barriers identified in a recent paper as to why Europe is behind in promoting cool roofs were attributed to a lack of awareness due to minimal legislative frameworks, as a result of a lack of awareness there is limited experience, resulting in a lack of incentive schemes and public skepticism due to people thinking that cool roofs will significantly increase their heating bills in the winter. This paper by researchers at the University of Athens presents the Cool Roofs Project which will be run across all countries within the EU and aims to remove these barriers through the implementation of an action plan that targets a change in behavior, and promotes and transforms the cool roof market [200].

5.6.2 *Cool Pavement and Road Planning Issues*

For retrofit, lightening could easily be incorporated into the pavement and road renewal process which would be the responsibility of the State. No planning permission requirements would apply unless the renewal process conflicted with an Act relating to congestion or street blocking, if this was the case a license would have to be sought.

With the right materials and done as part of an organized renewal, lightening is no more expensive than darker materials and some papers suggests that lighter roads and pavements become more durable due to less ultra violet degradation and less thermal fatigue [011, 200]. These factors should make cool pavements and roads attractive to local governments and officials.

5.6.3 *Urban Green Area Planning Issues*

Gill et al consider green infrastructure to be the most promising adaptation strategy and propose that it be factored into all urban planning strategies. The mitigation measures we will be discussing in this section are tree planting programs; grassed areas such as parks; and increased vegetation in streets such as grasses and shrubbery [010].

In Seattle, USA a Green Factor Standard was launched on all new developments in certain areas using a score card to calculate points for the greenness of a project. More points would be awarded for the use of larger plants, permeable paving, green roofs, preservation of trees etc and bonuses awarded for food cultivation and rainwater harvesting. All permit applications must apply to this standard which was achieved by amending the Commercial Zoning Requirements within Seattle's Neighborhood Business District Strategy [218].

In an adaptation planning exercise in Montreal, trees were the only measure that did not come up against major stakeholder opposition, it also identified street trees in residential areas as one of the most expensive measures [101].

Sacramento Municipal Utility District has the longest running urban tree planting program in the US. Incepted in 1990 the program has resulted in continuous improvements in energy savings [207].

Potential Barriers

Urban tree planting raises the issue of maintenance and may elicit public objections to viewing restrictions, unwanted sun blockage and impacts on property prices and insurance premiums. Trees must not interfere with utilities and tree species should be considered as some species are more suitable for urban areas as they require less water and are better at sequestering carbon and emit less volatile organic compounds. The Greater London Authority holds tree databases which keeps a record of the benefits of certain tree species.

5.6.4 *Energy Efficiency Measures Planning Issues*

Measures such as insulation, air sealing, exterior shading and glazing are included in this area, some efficiency measures include reflective surfaces and cool roofs which we have covered separately.

Energy Efficiency measures are well documented and part of most planning frameworks. Sustainable construction is largely promoted in most countries and is well demonstrated in building regulations. Problems maybe encountered where planners and architects disagree as to the most appropriate measure.

In terms of New Build the building can be designed with efficient features from inception and numerous guidelines exist encouraging less glazing, design solutions that minimize the use of lighting and heating, decentralized energy systems, and the use of solar and wind turbines. In the UK it is predominantly driven by the reduction of CO_2.

National/Central Government generally set minimum standards for energy efficiency and local government follows the set standards and try to push the boundaries beyond those targets.

In New York the Mayor proposed new laws to improve the energy efficiency of over 2,000 buildings aiming to reduce their energy consumption and emissions. The plans are said to result in billions of dollars in private investment and the generation of jobs. Only buildings that can recoup the cost of the energy efficiency measures in the reduction of their energy bills will be considered for the program [219].

Potential Barriers

Life cycle refurbishment offers a big opportunity and again guidance is plentiful; however, significant issues arise relating to funding, time pressures and methods of enforcement. Standards are easy to enforce with New Builds but refurbishments do not have to go through any formal planning procedure and so can pass through unnoticed, another barrier in the UK is that refurbishment, refit and repairs to buildings are charged full VAT whereas New Builds are not which acts as a major disincentive. Programs such as the one undertaken in New York described earlier would not work in the UK for this reason unless the government could offer businesses and homes grants or set up a borrowing scheme where the money accrued from energy savings is used to repay the loan.

5.6.5 *Transport System Design Planning Issues*

When discussing transport we include: rail systems; bus schemes; cycle routes; trams; pedestrianising schemes; and private vehicle disincentives.

The public's use of transport is culturally entrenched, so in order to change an individual's transport use pattern they must undergo an attitude and behavioral change also. This can be

aided by improvements to infrastructure, management of infrastructure and pricing through taxes and subsidies.

Urban population density and the way in which the land is arranged in terms of the proximity of residencies to businesses reduces the need for private transport and encourages walking, cycling and public transport use. Public transport options are also increased due to the economies of scale of the increased demand in urban areas. To further promote public transport, planners should locate stations and bus stops close to journey origins and destinations and ensure they are compatible with demand to maximize their use [234].

Private vehicle disincentive schemes that have been successful implemented in parts of the world include: congestion zone charging and/or tolls - which require drivers to pay to enter the metropolis; parking restrictions - by the use of permits to make it difficult/expensive to park in urban areas; increasing the space on roads for public transport and bicycles; car taxing; fuel pricing and taxing; heavily subsidizing public transport fares; and traffic smoothing - which involves the phasing of lights to restrict the stop start nature of city traffic which reduces emissions.

Using clean energy in transport systems such as biofuels, liquid or gas; hydrogen and fuel cells; and battery electric and hybrid electric vehicles is being discussed by the European Commission as part of their Green Cars Initiative in the European Economic Recovery Plan [220]. In the US the Department of Transportation has launched a Clean Fuels Grant Program with the objection of meeting national attainment targets for ozone and carbon monoxide emissions, the program also supports the development of clean fuels and advanced propulsion technologies for public transport [221].

The timescales from concept of a transport strategy to implementation is commonly between 15 and 20 years. A number of barriers exist, outlined below, and it is important that these barriers are identified early on so they can be adjusted or mitigated to allow the strategy to be acceptable [234].

KonSULT, a Knowledgebase on Sustainable Urban Land use and Transport undertook a survey which asked a number of European cities what they considered the barriers were to implementing a transport strategy. The survey identified that road building, pricing and land use experienced the most legal constraints. Road building and public transport infrastructure experienced the most financial constraints (80% of cities surveyed said finance was a major barrier and small cities are more susceptible to pricing issues than large cities), road building and pricing experienced the most acceptance restraints. Some practical constraints were also identified but weren't weighted/rated by the cities in terms of their importance; they included: land acquisition; enforcement and administration; and engineering design and availability of technology [234].

Potential Barriers

The barriers identified for transport design planning are:

- Political will – The government must make transport strategy a priority if it is to launch a successful program;
- Enforcement – Suitable measures for enforcement must be implemented in conjunction with the strategy;
- Acceptance - By the Public, Private and Government sectors;
- Technology – The technology must be suitably advanced, available, affordable and accessible;
- Available land – The required land must be available, purchased and permissions for use granted, more pertinent to road building and train lines;
- Funding – The government must have available funds in order to launch the program: and
- Partners - A broad spectrum of partners are required at all levels.

5.6.6 Conclusion

Incorporating mitigation planning into new build and retrofitting programs is complex. Difficulties arise from uncertain and changeable data relating to climate change; the science is complex; and a range of highly skilled experts and significant stakeholder /public consultation is required. The anthropogenic causes of UHI are so culturally entrenched that only a mass movement on a national scale from all levels of government, public, non government and private sectors can combat it [101, 203].

It appears to be easier to set policy and targets at a local level as it is easier to align over a Borough or State as opposed to a country. Also if forward thinking Boroughs or States implement successful schemes which result in proved benefits, these are more likely to be adopted at a national level.

Ideally mitigation planning would be worked into a building design at the pre-application or even master planning stage by the architect. Architects and developers would also be made aware of any new policies to work the requirements into their designs. Planners should also consider attitude and behavioral patterns when considering a strategy, and design infrastructure and programs around these patterns to maximize their acceptance and adoption.

6 RECOMMENDED PRIORITY AREAS

6.1 Introduction

The evidence thus far assessed regarding the potential for energy savings and mitigation efforts from countermeasures to urban heat islands presents a mixed picture. On the one hand there are clearly cost effective energy and CO2 savings to be delivered in many circumstances, on the other hand there is still much uncertainty about the overall magnitude of those savings and about how feasible it is to access them through public policy initiatives. Our recommendations reflect this pattern. We divide them into research based recommendations and policy/programmatic ones. Despite existing uncertainties about the overall magnitude of savings that can be accessed through public policy driven UHI counter measures the latter are still justified in many cases because the uncertainties are not so great as to require the delay in measures within urban areas that clearly stand to derive significant benefits from commencing ameliorative actions. Furthermore, the apparent potential scale of mitigation impacts from countermeasures targeting negative radiative forcing are so large that they justify a significant policy and research effort to clarify the phenomena and respond with policy efforts if the mitigation scales are validated.

6.2 Policy priorities

This section puts forward proposals for the key priorities for policymakers who have the potential to put in place policy portfolios influencing UHI countermeasures at the national, local and international level.

6.2.1 Policy needs at the national level

At the national level there are the following policy needs:

- to establish policy dialogues that help raise awareness of the UHI phenomenon, the significance of its impacts and mitigation potentials and of the range of policy options that can be deployed
- to establish high-level policy fora that consider the best way to roll-out UHI countermeasures while supporting efforts to minimize uncertainties
- to establish policy fora and mechanisms to inform and brief key state and city level officials such as state and municipal energy and planning advisors of the significance of the UHI phenomenon and the opportunities and mechanisms to abate it
- to develop a UHI clearinghouse where all relevant information is stored and maintained and through which decision makers can have access to tools and expertise

It is important that these efforts should consider the two key UHI mitigation opportunities of reduced energy use and negative radiative forcing within a common framework while appreciating the issues which are distinct to each. In particular, it is significant that that the negative radiative forcing effect has no direct monetary value aside from the value of equivalent-carbon mitigated yet is apparently of much greater mitigation magnitude than the direct/indirect energy-related savings effect. This means policy dialogues would need to consider whether or

not to create dedicated policy vehicles to attribute value to the negative radiative forcing effect so that municipalities have an incentive to apply UHI countermeasures that are independent of the local energy savings they produce. Furthermore, efforts may be needed to countenance the development of a third-party certification process to enable verification of negative radiative forcing countermeasures implemented at the local level so that municipalities or other countermeasure "owners" can have their mitigation effects valued for potential sale to CO_2 offset markets. There would be related policy efforts necessary for such measures to be recognized in the CO2 markets as discussed under the international section.

To set up national mechanisms to:

- assess the expected temperature, radiative forcing, urban air quality and energy use impacts of the systematic adoption of key countermeasures such as cool roofs, roadways, pavements and green areas at the national level
- calculate and value the CO_2-equivalent mitigation impact of the countermeasures, were they to be adopted at the national level
- determine the cost-benefits of the adoption of such measures from a public-good and private stakeholder perspective
- assess the range of policy measures that would be needed to stimulate the adoption of the countermeasures
- identify and engage with the key stakeholders who will either implement and/or be affected by the countermeasures to be adopted
- monitor and report on national progress in implementing countermeasures and on determining the associated impacts and cost-benefits

6.2.2 *Policy tools/support service needs for municipal authorities*

Policy makers need a set of tools to enable them to act authoritatively and appropriately in response to the UHI issue. In particular municipal authorities need access to practical tools and/or support services that enable them to:

- quickly assess the magnitude of the UHI phenomenon in their jurisdiction and work towards refined estimates as appropriate. An assessment tool that exploits satellite-based thermal & color imaging data might be the most pragmatic approach, especially if it allowed real-time and sub-regional specific data to be gathered and assessed so that local "hot spots" could be identified. The tool would need to be able to access and process such data to give information on the UHI magnitude and ideally how it varies by location, time of day and season. Equally it should enable average surface albedos to be determined by district and sub-district and the subsequent mapping of this information against the UHI magnitude data to support the estimation of the expected impact of the adoption of high albedo countermeasures.
- assess the expected temperature, radiative forcing, urban air quality and energy use impacts of the systematic adoption of key countermeasures such as cool roofs, roadways, pavements and green areas.
- calculate and value the CO_2-equivalent mitigation impact of the countermeasures

- determine the cost-benefits of the adoption of such measures from a public-good and private stakeholder perspective
- assess the range of policy measures that would stimulate the adoption of the countermeasures
- identify and engage with the key stakeholders who will either implement and/or be affected by the countermeasures to be adopted
- monitor and refine UHI countermeasure implementation

6.3 Research priorities

In general there is a need for more detailed and sustained efforts to quantify the energy and/or CO_2 mitigation potentials from adopting portfolios of UHI countermeasures across major urban settlements. The research recommendations below are divided into those that target direct/indirect mitigation methods and those that address mitigation through negative radiative forcing.

Direct/Indirect methods to mitigate the UHI (including cool roofs, pavements and green solutions):

- Most of the research focus has been on examining the mitigation potential of cool materials upon building energy load in a limited range of climates typically equatorial, arid and warm temperate climates – this needs to be expanded further to include the effects to cover all North American climate types and beyond;
- Further research and mass implementation testing is required to understand, demonstrate and calibrate models for the effect of high albedo surfaces deployed at large scales upon the affected building energy use and the attributed CO_2 reduction;
- Research is required to prove the benefits of using thermochromic coatings upon the building energy use and in order to develop coatings to have longer lasting coatings with greater resilience to thermal degradation;
- Higher quality data and sampling needs to be completed to define urban area make-up (green areas, roof surfaces, pavements, structure heights/widths etc) in areas where mitigation measures are anticipated to be deployed – applies both to small scale implementation but particularly important to address large scale mitigation potentials upon city building's energy use and CO_2;
- Before larger scale estimations on the mitigation potential of cool material and green solutions can be made there needs to be a greater emphasis on understanding the basic influencing processes at the micro-scale e.g. the radiative and thermal effect on pavements are complex to model which often leads to ignoring these influencing impacts;
- Few studies examined the parameters that affect the energy consumption and thus CO_2 emissions therefore, more it is important that future focus is on understanding factors such as: the energy use of the occupants, efficiency and control of cooling/heating systems if they are present, insulation (but has broadly been addressed by most studies to varying degrees), human tolerance and comfort levels;
- There needs to be focus on identifying the relative benefits of using higher grade insulation for buildings over cool roofs, pavements and green solutions;

- When developing costing analyses they should include complete lifecycle costs including the effects of factors such as: peak electric demand; roof design; roof design; roof maintenance; thermal cyclical effects upon lifespan;
- Detailed investigation into the effect of soot, dirt, microbial growth and end use upon the performance of cool materials (pavements and roofs) and their effectiveness in mitigating the urban heat island;
- Limited research has been conducted to provide/quantify the UHI mitigation potential of cool pavement technologies through larger scale practical implementation;
- Further research needs to be conducted to better understand and isolate, in theory and empirically the cooling effect and UHI reduction potential of cool pavement implementation;
- Significant research (a priority area) needs to be developed to understand the effectiveness of cool pavements performance in complex urban settings accounting for shadowing, building materials and sky view factor;
- It is important that future research is focused can quantify the relative benefits of improved air quality, improved water quality, night time illumination, etc which may affect the uptake and cost effectiveness of UHI mitigating solutions;
- Research needs to focus on understanding the UHI mitigation potential of cool pavements in isolation to the other UHI mitigating technologies and strategies if their benefits are to be full understood;
- Further research is required to understand the cost implications of key cost variables on the final cost of implementation of cool pavements i.e. local climate, region, project size, design life and intended use;
- Research is required to analyze legislation and incentives used to encourage the adoption of urban trees and vegetation and green roofs in parts of the world where they are generating significant interest e.g. Europe.

Negative Radiative Forcing to mitigate the UHI (high albedo surfaces):

- There has been no account for practical implementation issues associated with any mass high albedo surface modification scheme. Such issues could take the form of: grade listed buildings, commercial vs. residential roofing requirements, lack of availability of space, building geometry rendering any pavement albedo change ineffective, etc therefore future research needs to be focused on obtaining further high quality information on the specifics of the urban cities across the globe;
- Further research methods are required to establish accurate urban areas and their make-up in order to be able to develop accurate UHI mitigation potential scenarios;
- Future research must account for long-term effects of atmospheric CO_2 on global warming;

Further research is required to produce more accurate models that account for variations in cloud cover across different land types and for the effects on absorption from different types of atmospheric pollutants across different regions of the world;

6.4 Developing a UHI road-map

For climate change mitigation and energy savings from UHI countermeasures to be determined and delivered will require a coordinated strategy and activity plan to be developed. This "Road Map" needs to be developed in a manner to address the requirements set out in sections 6.2 and 6.3. Task 2 of this study proposes an international scientific panel that would be charged with assisting the development of such a road map. The key elements that will need to be included within the road map process are:

- Assessments of UHI magnitudes including the relative importance of the contributory factors
- Mitigation, energy saving and air quality improvement potentials and cost-benefit assessments
- Countermeasure technology development and pathways to commercialization and competitiveness
- Awareness raising measures among key decision-makers and stakeholders
- Fostering of policy dialogues and linkages
- Assisting the development of policy portfolios
- Policy design and implementation tools
- Implementation monitoring and verification mechanisms
- Valuation of UHI direct/indirect and negative radiative forcing CO2-equivalent mitigation and the steps required to have this recognized within carbon markets
- Development of UHI clearing houses
- National and international cooperation

As far as global mitigation efforts are concerned it will be essential to engage with the rest of the OECD and the major emerging economies where the bulk of the mitigation potential resides.

7 GLOBAL SCIENTIFIC PANEL

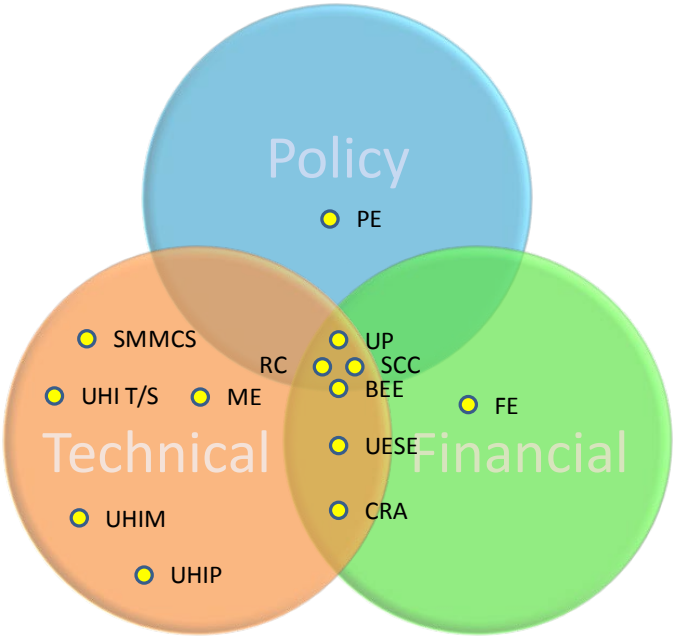
7.1 Introduction

This study has provided a complete review of the existing urban heat island literature and has culminated in a recommended set of priority areas. This section of the report seeks to propose a high level scientific panel that will convene in Washington DC in the 2010 financial year equipped to discuss the identified emerging issues and develop the research priority plan that will help validate the CO_2 mitigation potential of cool roofs and pavements.

The global scientific panel proposed comprises experts from not only the urban heat island field but also from other relevant disciplines from several regions of the world. Each proposed individual has been briefed and profiled to identify their potential role within the panel. The profiles seek to highlight relevant experience in their respective technical fields, backed by their financial and policy experience.

7.2 Role Identification

The proposed panel consists of eleven different defined roles founded on experience in the technical, financial and policy fields. The aim is to cover the complete spectrum of the urban heat island value chain as well as provide an insight from outside the field to help formulate the research priority plan and understand the practical implementation issues faced in mass adoption of cool roofs and pavements. The diagram below illustrates the fundamental experience areas each role is expected to cover. Naturally, there is some overlap between roles and experience but the perspective of each panel member is critical for the research priority plan development.



Role Key

CRA: Climatic Response Architect
BEE: Building Energy and Efficiency Expert
UHI T/S: UHI Technology and Strategy Specialist
UHIP: UHI Phenomenon Expert
UP: Urban Planner
UHIM: Urban Heat Island Materials Expert
SCC: Sustainable Construction Contractor
SMMCS: Satellite Measurement of Meteorological Conditions Specialist
ME: Modeling Expert
UESE: Urban Energy Systems Expert
RC: Roadmap Coordinator
PE: Policy Expert
FE: Finance Expert

The roles are defined as:

Climatic Response Architect (CRA): This role is proposed to be for a researcher/architect with understanding of building design with focus on adaptive architecture to deal with climate change, and micro/macro scale urban phenomena. The individual(s) fulfilling this role will have an understanding of: energy use - not only as a function of the building's physical construction, the interface of buildings and cities between humans and climate, energy efficient building design accounting for human behavior, comfort and patterns, and designing environmentally responsive urban spaces to aid adaptation of urban human behavior.

Building Energy and Efficiency Expert (BEE): This role is proposed for an individual(s) with extensive knowledge of building design its effects upon energy use, efficiency both at the micro building scale and upon the surrounding city buildings. The individual(s) fulfilling this role will have an understanding of: energy use - as a function of the building's physical characteristics; the interface of buildings and cities between humans and climate; building energy modeling tools; policies and strategies to adapt and develop new efficient building designs sensitive to final energy use; key building technologies and their integration; building design accounting for human behavior, comfort and patterns.

Urban Heat Island Materials Expert (UHIM): This role is proposed for an individual(s) with an active research record with urban heat island materials and a full understanding of the developments of all membranes, paints, roofs and pavements from a theoretical, experimental and implementation perspective.

Urban Heat Island Technology and Strategy Specialist (UHI T/S): This role is proposed for an individual(s) with a complete understanding across the entire urban heat island technology and strategy spectrum. They will have a complete understanding and be active in the field of the technical research for trees and vegetation, green roofs, cool roofs and cool pavements. They must also have an appreciation of technical and practical barriers as well as the mass implementation potential of these strategies/technologies.

Urban Heat Island Phenomenon Expert (UHIP): This role is proposed for an individual(s) with a complete understanding of the key urban heat island impacts and ability to attribute them to their root cause. This expert(s) must have the following technical research understanding: the human impact of urbanization and industrialization upon the climate at all scales; exchange and balance of heat, mass and momentum of evolving urban areas; the impact of UHI on air quality, the local and macro environment and upon human health; and an appreciation for the greater impacts of urban heat islands at the global climate scale.

Urban Planner (UP): This role is proposed for an expert with field experience in urban planning across a broad technical and geographical scope. It is important that they understand: planning regulations, practical and theoretical urban constraints, policy, and architect and contractor thought process. Furthermore, they must have the capacity to address a broad range of issues including: sustainability, pollution, congestion, and legislation; and have specific technical understanding of the impact of urban design and topology upon the urban heat island.

Sustainable Construction Contractor (SCC): This role is proposed for a contractor with extensive experience in developing and implementing sustainable construction solutions. They must have

an understanding of planning policy, implementation constraints on a practical level and have a practical feasibility approach to potential urban heat island mitigating technology/strategy integration upon building construction and their effects on issues such as longevity, energy use and building structure. It is preferable that this construction contractor has had exposure to urban heat island sensitive materials, their selection, and implementation.

Satellite Measurement of Meteorological Conditions Specialist (SMMCS): This role is proposed for an individual(s) with expertise in remote satellite meteorological measurements. They must have an understanding of the technologies and techniques that can be used to identify the urban heat island, its intensity, and thus measure the potential changes of mitigation strategies ode to mass scale implementation.

Modeling Expert (ME): This role is proposed for an individual(s) with capabilities and experience in measuring and modeling a wide range of: environmental impacts, climate change and urban heat island phenomena including: air quality, storm water temperatures, ecology, and atmospheric temperatures at local and global scales. Therefore this individual/s will be familiar with a range of relevant modeling tools and processes that may be used to understand and monitor any climatic changes ode to mass urban heat island countermeasures.

Urban Energy Systems Expert (UESE): This role is proposed for an individual with an intimate understanding of the fundamental energy systems, their use (transport, land-use, urban environment interactions, supply networks, buildings), efficiency and technical issues in an urban setting. They must have experience in monitoring and adapting, modeling, and evaluating different urban energy set-ups and their implications upon energy security, urban heat island and climate change.

Roadmap Coordinator (RC): This role is proposed for an individual with extensive experience in guiding and defining roadmaps. They do not have to be directly related to the field of urban heat islands but they must have a systems dimension that provides them with the appropriate tools and capacity to tie the large range of complex issues and variables, express their interactions at the micro/macro/global scales, and thus enable them to guide and unify a path for the integration of technologies and strategies to mitigate the urban heat island effect culminating in a roadmap.

Policy Expert (PE): This role is proposed for an individual(s) with an understanding of existing relevant policy, barriers and implementation issues, processes and tools, effectiveness and has an innovative approach to policy integration with other established initiatives. It is important that such an individual has been actively involved in researching and developing climate change and environmental policy - and preferably has had some involvement in advocacy and policy development for urban heat island mitigation. It is likely that such a role can be fulfilled by more than one individual given the different approaches, lessons and experiences gained from different parts of the world.

Finance Expert (FE): This role is proposed for an individual(s) with an understanding of existing relevant financial mechanisms, barriers and implementation issues, tools, effectiveness and has an innovative approach to using and developing financial mechanisms to integrate and complement other established initiatives/efforts. It is important that such an individual has been

actively involved in researching, developing and pioneering financial mechanisms to incentivize efficiency and carbon reduction schemes.

7.3 The Proposed Panel

The diagram and table to follow provide an overview of the individuals under each of the roles defined in section 2 accompanied by their country and institution of origin.

Role	Name	Institution	Country of Origin
Climatic Response Architect	Professor Koen Steemers	University of Cambridge, Department of Architecture	United Kingdom
	Professor Edward Ng	Chinese University of Hong Kong, Department of Architecture	China
Building Energy and Efficiency Expert	Professor Shuzo Murakami	Building Research Institute	Japan

Role	Name	Institution	Country of Origin
	Professor David Sailor	Portland State University, Department of Mechanical Engineering	United States
	Danny Parker	Florida Solar Energy Center, Buildings Research	United States
	Professor Geoff Levermore	University of Manchester, School of Mechanical, Aerospace, and Civil Engineering	United Kingdom
UHI Materials Expert	Professor Mattheos Santamouris	University of Patras, Applied Physics Division	Greece
	Dr Paul Berdahl	Lawrence Berkley National Laboratory, Laser Spectroscopy and Applied Materials Group, and Urban Heat Island Group	United States
UHI Technology and Strategy Specialist	Professor Hashem Akabri	University of Concordia, Department of Building, Civil and Industrial Engineering	Canada
	Greg McPherson	US Forest Service, Center for Urban Forest Research	United States
UHI Phenomenon Expert	Professor Tim Oke	University of British Columbia, Department of Geography	Canada

Role	Name	Institution	Country of Origin
	Professor Sue Grimmond	King's College London, Department of Geography	United Kingdom
Urban Planner	Adam Freed	NYC Mayor's Office of Long-Terms Planning and Sustainability	United States
	Mary McDonald	Climate Change Advisor to the Mayor of Toronto	Canada
	Simon Reddy	C40 Cities – Climate Leadership Group	United Kingdom
Sustainable Construction Contractor		Al Ahmadiah Contracting	United Arab Emirates
		Hip Hing Construction	China
Satellite Measurement of Meteorological Conditions Specialist	Dale Quattrochi	NASA, Earth Science Office	United States
Modeling Expert	Professor Hashem Akabri	University of Concordia, Department of Building, Civil and Industrial Engineering	Canada
	Associate Professor Ryozo Ooka	University of Tokyo, Institute of Industrial Science , Environmental Technology for Urban Architecture	Japan

Role	Name	Institution	Country of Origin
	Dr Haider Taha	Altostratus Inc., Atmospheric Modeling and Research	United States
	Joe Huang	Lawrence Berkeley National Laboratory	United States
Urban Energy Systems Experts	Professor Yasunobu Ashie	Building Research Institute, Environmental Research Group	Japan
Roadmap Coordinator	Mr Doug Brookman	Public Solutions Inc.	United States
Policy Expert	John Wilson	Energy Foundation, Buildings Program Director	United States
	Professor Eduardo Maldonado	Energy Agency of Portugal	Portugal
	Neelam Patel	US Environmental Protection Agency, Urban Heat Island Program	United States
Finance Expert	Jaquelin Ligot	***IDEAcarbon / The Carbon Rating Agency, London***	United Kingdom

7.4 Team Member Profiles

The key personnel recommended to join the panel are listed below.

Name: Koen Steemers

Current Position: Professor at the University of Cambridge, Department of Architecture

Role: Climatic Response Architect

Telephone Number: +44 (0)1223 331712

E-mail: kas11@cam.ac.uk

Professor Koen Steemers is the Director of the Martin Centre for Architectural and Urban Studies and the Head of Research for the Department of Architecture at the University of Cambridge. An architect and sustainable design specialist, Koen's current work deals with the architectural potential of environmental issues such as energy, light and comfort. His research activities are focused on the environmental performance of buildings and cities - with a particular interest in human perception and behavior - which are the topics of funded research projects. He has produced over 150 publications and works with architects, engineers, developers and government. Professor Steemers is a Director of Cambridge Architectural Research Ltd and the President of PLEA International (an association of 2500 members worldwide interested in 'Passive and Low Energy Architecture').

Name: Edward Ng

Current Position: Professor at the Department of Architecture, Chinese University of Hong Kong

Role: Climatic Response Architect

Telephone Number: + 852 2609 6515

E-mail: edwardng@cuhk.edu.hk

Edward Ng is a Professor at the department of Architecture at the Chinese University of Hong Kong. Professor Ng's research focus is in the areas of daylight design, urban climatology and

sustainable architecture. He is an architect (RIBA, HKIA, ARB - Hong Kong and UK). He is a fellow of the Royal Society of Arts (FRSA) for his contribution to sustainable design. He has published over 200 papers, book chapters and reports; and has secured over US$8 million of research grants over the years. Recently, his research interest is on high density city design issues. He has collaborated with numerous distinguished individuals across the world including scholars from Hong Kong, the UK, Germany, Japan and Singapore, and with Hong Kong government offices like ED, BD and PlanD. His "Air Ventilation Assessment" (AVA) Project with Planning Department HKSAR has won the 2005 HKIA Research Awards; the 2006 PGBC Grand Awards; and the Runner-up of the RIBA Research Awards 2007. Recently, he has focused on offering strategic design advice to policy makers, governments, organizations and professionals.

Name: Shuzo Murakami

Current Position: Special Research Professor in the Faculty of Science and Technology at Keio University and Chief Executive of Building Research Institute Japan

Role: Building Energy and Efficiency Expert

Telephone Number: +81 45 566 1777

E-mail: murakami@kenken.go.jp

For more than 30 years, Professor Shuzo Murakami has been in charge of the research on Building and Environmental Control Engineering at the Institute of Industrial Science, University of Tokyo (from 1972 to 2000), and at Department of Engineering, Keio University (from 2001 to 2007) since graduating from the University of Tokyo (Department of Engineering, Faculty of Architecture). He has been engaged in special research into the experimental study and the numerical simulation of turbulent airflow in rooms and around buildings. He has had a great deal of experience on CFD analysis of wind climate from human scale to urban scale and has initiated a new field of CFD research. He has also conducted extensive interdisciplinary studies concerning computational wind engineering, healthy cities, human comfort and health, and numerical simulation of turbulent flow. Professor Murakami is the Chief Executive of the Building Research Institute in Japan.

Name: David Sailor

Current Position: Professor at Portland State University in the Department of Mechanical and Materials Engineering

Role: Building Energy and Efficiency Expert

Telephone Number: +1 503 725 4265

E-mail: sailor@cecs.pdx.edu

David Sailor is a Professor of Mechanical and Materials Engineering at Portland State University. His research is in the general area of Energy and the Environment. Professor Sailor's recent research focus has been on modeling the urban climate, with applications in air quality, building energy consumption, human health, and climate change. He has particular research interest in the feedback mechanisms between energy systems and climate with a focus on building energy consumption and renewable energy resources, developing high resolution weather and climate models in application areas for short-term energy load forecasting and long-term climate change scenarios, and has particular interest in urban heat islands.

Name: Geoff Levermore

Current Position: Professor the University of Manchester, School of Mechanical, Aerospace, and Civil Engineering

Role: Building Energy and Efficiency Expert

Telephone Number: +44 (0) 161 306 4257

E-mail: geoff.levermore@manchester.ac.uk

Professor Levermore read Physics at Imperial College, London gaining his BSc, ARCS in 1971 and his PhD, DIC, on the Johnsen-Rahbek Effect, in 1974. He then worked at the GEC Hirst Research Centre and then the Jules Thorn Lighting Laboratory. In 1980, whilst heading the Wandsworth Energy Conservation Section he founded the London Boroughs Energy Management Group. He joined UMIST in 1991 from South Bank University. He is currently Chair of the CIBSE Weather Panel and coordinator of the CIB Task Group21; Climatic Data for Building Services and a Lead Author on the IPCC (WG3). His research focus centers on weather data – for design of buildings, plant and natural ventilation, climate change; Control and Modeling – intelligent buildings, low-

energy buildings, natural and mixed mode air-conditioning; Occupant Feedback – related to the interior environment with overall linking score and fingerprint, and Lighting Perception – related to colored light sources and daylight in buildings.

Name: Danny Parker

Current Position: Principal Research Scientist, Florida Solar Energy Center, Buildings Research

Role: Building Energy and Efficiency Expert

Telephone Number: +1 321 638 1405

E-mail: dparker@fsec.ucf.edu

Mr. Parker specializes in collecting and analyzing measured data taken from residential and commercial buildings to determine how results may be applied to reducing energy needs. Over the last 16 years, he has studied technologies to improve energy efficiency in Florida's buildings. He has extensive experience with building energy and field monitoring. Mr. Parker has spent the last 25 years of his career in the field of energy-efficiency research. He has been involved in a number of field projects in residential and commercial buildings and is an expert in building energy measurement and monitoring. He also has extensive experience with large-scale utility monitoring projects and evaluation of load control options. He holds several patents associated with innovative energy efficiency technologies. Over the last decade, Mr. Parker's residential research includes the following: impact of white roofing on residential cooling energy use, impact of utility load control on appliance demand profiles in large-scale monitoring, impact of attic radiant barrier and attic ventilation performance, evaluation of the impact of programmable thermostats, whole house fan impact on thermal comfort, evaluation of residential AC sizing methods, photovoltaics and solar energy sources as optimized for buildings, potential of energy efficient lighting in residences, impact of reduced evaporator air flow on AC performance, development of a zero energy home where cooling was reduced by 84% and development of a low-energy high performance ceiling fan.

Name: Mattheos Santamouris

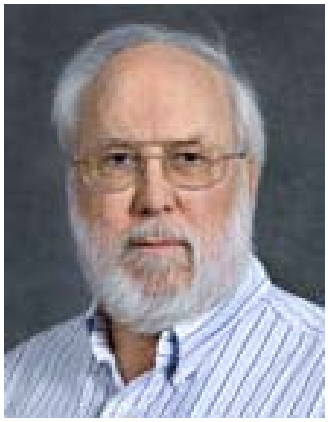
Current Position: Professor at University of Athens in the Department of Physics

Role: UHI Materials Expert

Telephone Number: +30 210 727 6847

E-mail: msantam@phys.uoa.gr

Mattheos Santamouris is a Professor of Energy Physics at the University of Athens. Over the last decade, he has been involved in measurement and analysis of urban heat islands in Athens. His pioneering work includes the development of regionally suitable cool materials and use of advance thermochromic coatings for urban surfaces. Professor Santamouris is the Editor in Chief of the Journal of Advances Building Energy Research, and Associate Editor of the Solar Energy Journal.



Name: Dr Paul Berdahl

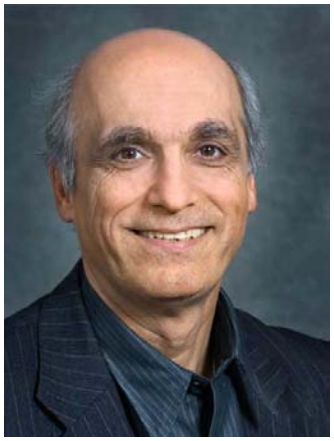
Current Position: Senior Staff Scientist at the Lawrence Berkley National Laboratory, Laser Spectroscopy and Applied Materials Group, and Urban Heat Island Group

Role: UHI Materials Expert

Telephone Number: +1 510 486 5278

E-mail: PHBerdahl@LBL.gov

Dr Paul Berdahl is semi-retired and is investigating how surface roughness reduces the solar reflectance of materials, the soiling and weathering of roofing materials and the destruction of air pollutants by photocatalytic oxidation using the semiconductor TiO2. Prior to his retirement in 2005, he worked on synthesis of high-temperature superconducting YBa2Cu3O7 tapes (with R. Russo and R. Reade). World record critical current values were achieved in 1992. Other topics were infrared luminescence of semi conducting InSb, infrared radiative cooling, long wave radiative transfer in the atmosphere, and the availability of the solar radiation resource.



Name: Hashem Akbari

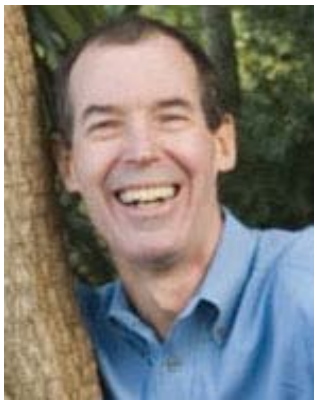
Current Position: Professor in the Department of Building, Civil and Environmental Engineering at the Faculty of Engineering and Computer Science at Concordia University

Role: UHI Technology and Strategy Specialist / Modeling Expert

Telephone Number: +1 514 848 2424 Ext. 3201

E-mail: hakbari@bcee.concordia.ca

Prior to joining Concordia, Professor Hashem Akbari was a Group Leader, Senior Scientist, and principal investigator in the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory (LBNL). He was the leader of the Heat Island Group and has led LBNL's efforts to investigate the energy conservation potential and environmental impacts of increased tree planting and modifications of surface albedo. His research has identified the attributes of these energy efficiency strategies to mitigating the urban heat island effect and cooling the globe. In addition, he has performed research in energy use and conservation in buildings; advanced energy technologies; utility energy forecasting; advanced utility-customer communication, computation, and control systems; energy-efficient environment; air pollution control; and environmental simulation and modeling. Professor Akbari is the author of more than 200 articles and coauthor of four books. His pioneering research has been widely quoted in both scientific and public media. In 2007, as a contributing author of the Intergovernmental Panel for Climate Change (IPCC) and along with other authors, he received the Noble Peace prize shared with Vice President Al Gore. He is an active member of the American Society of Mechanical Engineers, the American Society for Testing and Materials, the Cool Roof Rating Council, and the American Society of Heating, Refrigeration and Air-conditioning Engineers and serves on several technical committees within each society.



Name: Dr Greg McPherson

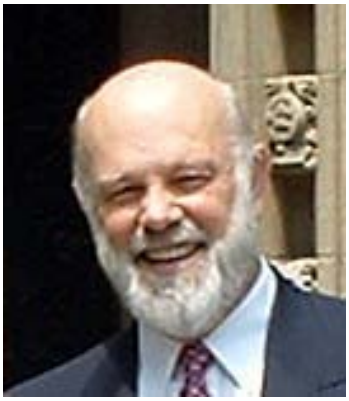
Current Position: Director of the Center for Urban Forest Research, US Forest Service and Faculty Member of UC Davis, Department of Plant Sciences

Role: UHI Technology and Strategy Specialist

Telephone Number: +1 530 759 1723

E-mail: gmcpherson@fs.fed.us

Dr Greg McPherson is the Center Director for Urban Forest Research at the US Forest Service. In addition to Dr McPherson leadership responsibilities, he conducts research that measures and models the benefits and costs of urban forests. He teaches urban forestry courses at UC Davis and is a faculty member of the Graduate Group in Geography and the Horticulture Graduate Group. He received a Bachelor's of General Studies from the University of Michigan in 1975, a Master's degree in Landscape Architecture from Utah State University in 1981, and a Ph.D. in Forestry from the SUNY College of Environmental Science and Forestry at Syracuse in 1986. After completing his Ph.D., Dr McPherson was an Assistant and Associate Professor at the University of Arizona's School of Renewable Resources for six years. He then joined the Forest Service as the lead scientist on the Chicago Urban Forest Climate Project in 1991. Dr McPherson has been at the Center since 1993.



Name: Tim Oke

Current Position: Professor in the Department of Geography and Member, Atmospheric Science Program, University of British Columbia, Vancouver

Role: UHI Phenomenon Expert

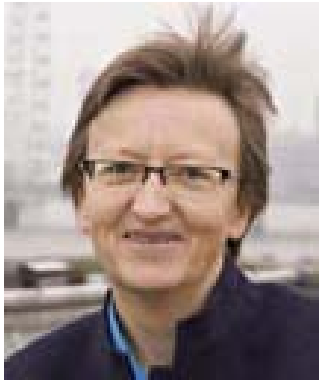
Telephone Number: +1 604 822 2900

E-mail: toke@geog.ubc.ca

Professor Tim Oke is a recognized leader in the study of microclimates and is the foremost authority on urban climates. His research focuses on seeking to understand the way humans alter climates through urban development. Specifically, exchanges of heat, moisture, pollutants and

momentum in cities are measured and their effects on temperature, humidity, winds, and other climate factors are assessed. This leads him, for example, to assess the way the cumulative effect of every new building, road and garden creates the heat island effect of whole cities.

Since 1978, he has been a Professor of Geography at the University of British Columbia. Professor Oke was the founder and chair of the U.B.C. Atmospheric Science Programme. From 1991 to 1996, he was the Head of the Department of Geography. In 2002, he received the American Meteorological Society's Award for Outstanding Achievement in Biometeorology in recognition of his contributions to the teaching, theory and applications of knowledge on the interaction between atmosphere and biological systems. Professor Oke also serves as a meteorological consultant on legal cases, appeals to boards and environmental matters, and as an advisor to government organizations and business.



Name: Sue Grimmond

Current Position: Professor at King's College London, Social Science and Public Policy – Geography Department

Role: UHI Phenomenon Expert

Telephone Number: +44 (0) 207 848 2275

E-mail: sue.grimmond@kcl.ac.uk

Professor Sue Grimmond is an urban climatologist who studies the bio-physical processes involved in the generation of urban climates through the measurement and modeling of surface-atmosphere exchanges of heat, mass (water and carbon dioxide) and momentum at a range of spatial and temporal scales (individual urban canyons, to neighborhoods, to entire cities). Professor Grimmond originally conducted her MSc and PhD under Professor Oke and is now a full professor at King's College London. She previously held the post of President of the International Association of Urban Climate (IAUC) and Lead Expert for the WMO on Urban and Building Climatology. She is the 2009 recipient of the Helmut E Landsberg Award from the American Meteorological Society 'for numerous important contributions that have greatly advanced urban meteorology and urban climate sciences, and for sustained and effective leadership that has energized the urban climate research community'.

Name: Adam Freed

Current Position: Deputy Director, NYC Mayor's Office of Long-Terms Planning and Sustainability

Role: Urban Planner

Telephone Number: Not available

E-mail: afreed@cityhall.nyc.gov

Mr Adam Freed is the Senior Policy Advisor for Climate Change Adaptation in the New York City (NYC) Mayor's Office of Long-Term Planning and Sustainability. He leads NYC's climate change adaptation program. In this capacity he is working to quantify the regional impacts of and the City's vulnerabilities to climate change and develop adaptation strategies to mitigate these risks. Mr Freed chairs the City's Climate Change Adaptation Task Force, which consists of city, state, and federal agencies and private sector companies that are developing coordinated adaptation strategies to protect the City's critical infrastructure.

Previously, he served as the Assistant Comptroller for NYC in the Office of the New York State Comptroller, where he reviewed large-scale economic development projects and crafted corporate governance strategies for the $160 billion state pension fund. In addition to his work in city and state government, Mr Freed has worked on several city, state, and national political campaigns. Freed received his master's in Urban Planning from NYU and is a member of the American Institute of Certified Planners.

Name: Mary MacDonald

Current Position: Climate Change Advisor to the Mayor of Toronto

Role: Urban Planner

Telephone Number: +1 416 338-7132

E-mail: Not available

Ms MacDonald was formerly Director of Sustainable Development Systems at Ch2M Hill Companies Ltd, Director of Policy and Research at Earth Council, Senior Researcher at Earth Council, Affiliated Scientist at Stockholm Environment Institute and Principal at Bingera Associates for the Canadian Centre for Pollution Prevention. She is an Advisor on the Sustainability Reporting Program and was a Senior Research Fellow at the Stockholm Environment Institute.

Name: Simon Reddy

Current Position: C40 Cities – Climate Leadership Group

Role: Urban Planner

Telephone Number: Not available

E-mail: simon.reddy@c40cities.org

Mr Simon Reddy is the manager of the C40 Climate Leadership Group (C40) secretariat and responsible for co-ordinating and communicating the work of the C40 cities. The C40 is a group of the world's largest cities committed to tackling climate change. The C40 secretariat is based in the Mayor of London's offices at City hall in London. Prior to taking this position in March 2007, Mr Reddy worked for Greenpeace UK and Greenpeace International since 1992, and most recently as Director of Policy and Solutions for Greenpeace UK. He was responsible for setting up a solutions department within Greenpeace UK and led and co-ordinated work on 'decentralised energy'. He also led Greenpeace's work with the Mayor of London and the GLA on various 'Decentralised Energy' reports and the Gallions Park zero carbon development. Over a 15year period at Greenpeace, Mr Reddy also worked as a political adviser on ocean issues representing Greenpeace at various International political fora, a campaigner working on oil and gas issues and platform dumping and as a deckhand on Greenpeace ships. Mr Reddy has an MSc in Marine and Fisheries Biology and a BSc in Ecology.

Name: Al Ahmadiah Contracting

Current Position: N/A

Role: Sustainable Construction Contractor

Telephone Number: +971 398 1999

E-mail: www.alahmadiah.com / admin@alahmadiah.ae

Based in Dubai, United Arab Emirates, Al Ahmadiah has over 8,000 employees which include 650 qualified engineers, architects, draughtsmen and administration staff. Al Ahmadiah work in the public and private sectors and the majority of their work is undertaken in Dubai, Abu Dhabi, Umm Al Quain, and Al Ain. Al Ahmadiah was established in 1970 and its parent company is Al Fajer Group which is owned by HH Shaikh Hasher Maktoum Juma Al Maktoum. The company is split into the following divisions: Theming; Marine; Refurbishment; Civil Maintenance; and Air Conditioning. Al Ahmadiah was selected due to its work on the Masdar City eco project.

Name: Hip Hing Construction

Current Position: N/A

Role: Sustainable Construction Contractor

Telephone Number: + 852 2525 9251

E-mail: www.hiphing.com.hk / email@hiphing.com.hk

Hip Hing Construction is a member of NWS Holdings Limited. NWS Holdings Limited is the infrastructure and service flagship of New World Development Company Limited. It embraces a diversified range of businesses in Hong Kong, Mainland China and Macau. Its Infrastructure portfolio includes Roads, Energy, Water and Ports projects. Its Service & Rental division comprises Facilities Rental (the management of Hong Kong Convention and Exhibition Centre and ATL Logistics Centre), Contracting (Hip Hing Construction and NWS Engineering), Financial Services (Taifook Securities and New World Insurance) and Other Services (New World First Bus, Citybus and New World First Ferry). Hip Hing Construction was selected due to its work on the Masdar City eco project.

Name: Dr Dale Quattrochi

Current Position: NASA, Earth Science Office

Role: Satellite Measurement of Meteorological Conditions Specialist

Telephone Number: +1 256 961 7887

E-mail: dale.quattroch@msfc.nasa.gov

Dr. Dale Quattrochi is a Senior Research Scientist with the NASA Marshall Space Flight Center in Huntsville, Alabama and has over 23 years of experience in the field of Earth science remote sensing research and applications. He received his Ph.D. degree from the University of Utah, his M.S. degree from the University of Tennessee, and his B.S. degree from Ohio University, all in geography. Dr. Quattrochi's research interests focus on the application of thermal remote sensing data for analysis of heating and cooling patterns across the diverse urban landscape, which form the dome of elevated air temperatures over cities known as the urban heat island effect. He is also conducting research on the applications of geospatial statistical techniques, such as fractal analysis, to multiscale remote sensing data. Dr. Quattrochi is the recipient of the NASA Exceptional Scientific Achievement Medal, NASA's highest science award. He is the co-editor of two books: Scale in Remote Sensing and GIS (with Michael Goodchild) published in 1997 by CRC/Lewis Publishers, and Thermal Remote Sensing in Land Surface Processes (with Jeffrey Luvall) published in 2003 by Taylor & Francis.

Name: Ryozo Ooka

Current Position: Associate Professor at the University of Tokyo, Institute of Industrial Science, Environmental Technology for Urban Architecture

Role: Modeling Expert

Telephone Number: +81 3 5452 6435

E-mail: ookaiis.u-tokyo.ac.jp

Associate Professor Ryozo Ooka's research Interests are focused on wind tunnel experiments on flow and diffusion fields around buildings; development of measuring equipment for

environmental research; CFD analysis for turbulent flow in rooms and around buildings; development of new turbulence models; parallel processing of computational fluid dynamics; Indoor climate in large enclosures; CFD analysis for smoke movement in a building on fire; ventilation efficiency of indoor space; CFD analysis of urban climate; and Evaluation of thermal comfort using numerical thermal mannequin. He has extensive knowledge and experience in working with models of all scales to analyze urban heat island effect.

Name: Dr Haider Taha

Current Position: Altostratus Inc., President, Atmospheric Modeling and Research

Role: Modeling Expert

Telephone Number: +1 925 285 5221

E-mail: haider@altostratus.com

Professor Haider Taha has been actively engaged in meteorological and photochemical/air quality modeling and research since 1984. He joined the Lawrence Berkeley National Laboratory as a graduate student research assistant in the Applied Science Division and later became lead meteorological and photochemical modeler for the HIG's studies and projects on meso-meteorology, urban climates, heat islands, and air quality. His masters and doctoral theses developed methodologies and incorporated early efforts in "urbanizing" mesoscale meteorological models, improving boundary-layer parameterizations and urban canopy-layer representations, thus improving the regional specificity of simulations and the accuracy of dependent photochemical, energy demand, and thermal environmental modeling. In 2003 Professor Taha started Altostratus Inc. and in 2004 was appointed as an Adjunct Professor in the Department of Meteorology at San Jose State University. In 2008, he was appointed Adjunct Professor at the College of Engineering and Computer Science at Portland State University.

Haider has published on the topics of heat islands, urban climates, meteorology, and regional/mesoscale meteorological-photochemical modeling (see partial list of publications for example), has served as a technical reviewer for scientific peer-reviewed publications, technical proposals, guest editor, and invited contributor to book and encyclopedia sections on meteorology and heat islands.

Name: Joe Huang

Current Position: Lawrence Berkeley National Laboratory

Role: Modeling Expert

Telephone Number: +1 510 486 7082

E-mail: YJHuang@LBL.gov

Mr Joe Huang has been at LBNL since 1981, working primarily in analyzing building energy performance using DOE-2 simulations. His current work including research into low-energy cooling technologies in both residential and commercial buildings, evaluating the energy savings from improved HVAC systems and controls in a large office building in San Francisco, and developing simulation-based user programs which is the subject of his talk today. Mr Huang will compare the advantages and disadvantages of interactive simulation-based PC programs to parametric data base methods with which he has direct experience, having created the DOE-2 data bases of residential building energy use used for ASHRAE 90.2 residential energy standard and DOE's COSTSAFR and ARES voluntary energy guidelines.

Mr Huang is also a leading consultant to China's Ministry of Construction and provincial and local governments in the development of residential and commercial building codes. Since 2000, Dr. Huang has provided technical assistance to the China Building Energy Conservation Association (CBECA) and the China Academy of Building Research (CABR) in drafting regional energy standards for both residential and commercial buildings in the Hot-Summer Cold-Winter region (Central China) and the Hot-Summer Warm-Winter region (South China), as well as national standards for both regions.

Name: Professor Yasunobu Ashie

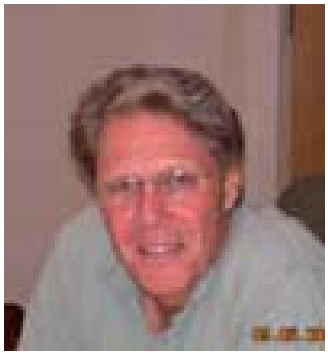
Current Position: Building Research Institute, Environmental Research Group

Role: Urban Energy Systems Experts

Telephone Number: Not available

E-mail: ashie@kenken.go.jp

Dr Yasunobu Ashie began his career in 1991 as a Research Engineer at the Building Research Institute, Ministry of Construction, Government of Japan. He later became Senior Research Engineer, then Chief Research Engineer for the Building Research Institute, Independent Administrative Organization of Japan. In 2009, Dr Ashie became Head of the Environmental and Equipment Standards Division, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan.



Name: Doug Brookman

Current Position: Founder and President of Public Solutions Inc.

Role: Roadmap Coordinator

Telephone Number: **+1** 410 719 0580

E-mail: publicsolutions@earthlink.net

Doug Brookman, is a nationally recognized facilitator, mediator and trainer, that has conducted collaborative planning and problem-solving processes full-time for over 15 years. His company, Public Solutions facilitates effective decision making among divergent interests to serve human, technical, and political needs in complex, public contexts.

Mr. Brookman's specialty is facilitating large, complex public processes to graceful solutions. In this period he has conducted over one thousand public, stakeholder-driven meetings and collaborative processes. His work is focused at the intersection of energy, environment and natural resources. A sampling of his recent federal clients includes the U.S. Departments of Agriculture, Commerce, Defense, Education, Energy, Homeland Security, Interior, Transportation, the Environmental Protection Agency, The President's Council's on Environmental Quality and Sustainable Development, the White House Office of Science and Technology Policy, the National Institute of Standards and Technology and the Nuclear Regulatory Commission. He has a broad array of non-profit and private sector clients as well.

Prior to founding Public Solutions, Mr. Brookman was Senior Manager/Mediator for the American Energy Assurance Council's (AEAC) National Energy Strategy Consensus Building project. Prior to joining AEAC, Mr. Brookman acquired extensive experience mediating and facilitating a wide range of government, community and commercial disputes at the Dispute Resolution Center in Austin, Texas and in his leadership roles in Texas State Government. Mr. Brookman completed his Masters Degree in Public Affairs (Economics) at the Lyndon B. Johnson School of Public Affairs at the University of Texas and obtained his B.A. in Sociology at Ohio

State University. He is former President of the Maryland Council for Dispute Resolution and a member of the Association for Conflict Resolution.

Name: John Wilson

Current Position: Energy Foundation, Buildings Program Director

Role: Policy Expert

Telephone Number: +1 415 561 6700

E-mail: john@ef.org

Mr John Wilson spent 30 years with the California Energy Commission (CEC), and is now the Program Director for Buildings with non-profit organization Energy Foundation in San Francisco. During his time with the CEC, Mr Wilson's activities emphasized developing new building and appliance efficiency standards, oversight of the Commission's US$80 million per year Public Interest Energy Research (PIER) program, and developing long-term scenarios for California's energy system. Mr Wilson was a winner of the American Council for an Energy Efficient Economy's "Champion of Energy Efficiency" Award in 2006 for his work on increasing the efficiency of external power supplies. He was a member of the Boards of the Consortium for Energy Efficiency, the New Buildings Institute, the Building Codes Assistance Project, and the Appliance Standards Awareness Project. He was also chair of the Buildings Committee of the National Association of State Energy Officials. Mr Wilson has B.A. and M.A. degrees in economics from the University of California (Berkeley and Davis).

Name: Professor Eduardo Maldonado

Current Position: Energy Agency of Portugal and Professor at Universidade do Porto

Role: Policy Expert

Telephone Number: Not available

E-mail: eduardo.maldonado@gppq.mctes.pt / ebm@fe.up.pt

Professor Maldonado is a Professor at the University of Porto, he is a member of the Energy Demand Management Committee of the European Commission, Coordinator of the Buildings Concerted Action (CA) for the Transposition of the EPBD and a member of the Energy Advisory Group (AGE) of the European Commission. Professor Maldonado holds a PhD in Mechanical Engineering on HVAC and Indoor Air Quality. Professor Maldonado spoke at the 2009 RESNET Building Performance Conference and will be speaking next year at the World Sustainable Energy Days 2010 conference and Clima 2010 the 10th REHVA world congress.

Name: Neelam Patel

Current Position: US Environmental Protection Agency, Urban Heat Island Program

Role: Policy Expert

Telephone Number: +1 202 343 9384

E-mail: patel.neelam-r@epa.gov

Mr Neelam Patel is the manager of the EPA's Urban Heat Island Program.

Name: Jaquelin Ligot

Current Position: IDEAcarbon / The Carbon Rating Agency, London

Role: Finance Expert

Telephone Number: +33 (0) 684 220 437

E-mail: jacqligot@googlemail.com

Mr Ligot Jacquelin has nearly 20 years of experience in project financing (debt and equity) and policy dialogue, with private and public clients. He has concentrated much of his career in project finance on projects involving sustainable development, climate change, sustainable energy, infrastructure and carbon markets and has over 15 year experience in emerging markets, notably countries in transition (C&E Europe, CIS), Turkey, South Africa. As head of the European

Bank for Reconstruction and Development's energy efficiency and climate change team for 8 years (2000-2008), he has designed funds or financing facilities that finance energy-efficiency upgrades of existing buildings and combined heat and power / district heating networks in Central and Eastern Europe. Mr Ligot was also Head of Unit – Borrowing and Treasury for the City of Paris in the Finance and Economic Affairs Department.

8 CONCLUSION

The research conducted has reviewed a total of two-hundred and thirty-eight papers across the entire urban heat island value chain with the greatest interest (descending order) from the following continents: North America, Asia, Europe, Australia, and Africa. The predominant focus was in warm, arid and equatorial climate types with a majority of the seminal studies relating to UHI emanating from the Lawrence Berkley National Laboratory, UHI Group.

The UHI phenomenon itself was well documented and universally interpreted by all research groups and found to be a consequence of rapid urbanization and industrialization. It is apparent that the focus of climate on the global scale has shifted from the global to local scale with most of the research groups and studies addressing the urban climate. The research conducted to identify the UHI causal factors and measuring the impact of UHI clearly demonstrates that the impacts have greater implications than simply temperature increases. It is clear that the UHI problem is not going to subside with time, if anything it is likely to increase in intensity as the population in urban areas increases in the years to come.

It was clear in the literature reviewed and the analysis conducted that the evidence assessed regarding the potential for energy savings and mitigation efforts from countermeasures to UHI presents mixed findings. There are clearly cost effective energy and CO_2 savings to be delivered in many circumstances, however, still much uncertainty about the overall magnitude of those savings and about how feasible it is to access them through public policy initiatives. The recommendations made in this report reflect this pattern and were divided into research based and policy/programmatic recommendations.

Despite existing uncertainties about the overall magnitude of savings that can be accessed through public policy driven UHI countermeasures the latter are still justified in many cases because the uncertainties are not so great as to require the delay in measures within urban areas that clearly stand to derive significant benefits from commencing ameliorative actions. The apparent potential scale of mitigation impacts from countermeasures targeting negative radiative forcing are so large that they justify a significant policy and research effort to clarify the phenomena and respond with policy efforts if the mitigation scales are validated.

Furthermore, it is important that local, national and international efforts consider the two key UHI mitigation opportunities of reduced energy use and negative radiative forcing within a common framework while appreciating the issues which are distinct to each. In particular, it is significant that that the negative radiative forcing effect has no direct monetary value aside from the value of equivalent-carbon mitigated yet is apparently of much greater mitigation magnitude than the direct/indirect energy-related savings effect. This means policy dialogues would need to consider whether or not to create dedicated policy vehicles to attribute value to the negative radiative forcing effect so that municipalities have an incentive to apply UHI countermeasures that are independent of the local energy savings they produce. It is therefore clear that policy makers need a set of tools to enable them to act authoritatively, appropriately and in a coordinated manner in response to the UHI issue; and of equal importance is that urban

planners/designers are equipped with the appropriate tools/methods to counter the UHI development at the early stages in rapidly evolving environments.

Paper Ref	Title of Paper	Author	Institution	Journal	Publication Citation	Other Authors
001	A case study of urban heat islands in the Carolinas	Vereda Johnson King	North Carolina Agricultural & Technical State University, Economic, Transportation and Logistics Department, USA	Environmental Hazards	Environmental Hazards 7 (2007) 353-359	Cynthia Davies
002	A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures	Jay S. Golden	Arizona State University, National Center of Excellence on SMART Innovations for Climate + Energy, School of Sustainability, Civil and Environmental Engineering, US	Solar Energy	Solar Energy Volume 81, Page 872–883, 2007	Joby Carlson , Kamil E. Kaloush , Patrick Phelan
003	A comparison of municipal forest benefits and costs in Modesto and Santa Monica, California, USA	E Gregory McPherson	USDA Forest Service, California, USA	Urban Forestry & Urban Greening	Urban for Urban Green 1 (2002) 61-74	James Simpson
004	A demonstration that large scale warming is not urban	David E Parker	Met Office, Hadley Centre, Exeter, UK	Journal of Climate	Volume 19, pp. 2882	
005	A new method to select appropriate countermeasures against heat island effects according to the regional characteristics of heat balance mechanism	Kiyoshi Sasaki	Institute of Technology, SHIMIZU Corporation, Tokyo, Japan	Journal of Wind Engineering and Industrial Aerodynamics	Journal of Wind Engineering and Industrial Aerodynamics 96 (2008) 1629-1639	Akashi Mochidab, Hiroshi Yoshinob, Hironori Watanabec, Tomohiro Yoshida
006	A preliminary study on the local cool-island intensity of Taipei city parks	Chi-Ru Chang	Chinese Culture University, Department of Landscape Architecture, Taipei, Taiwan	Landscape and Urban Planning	Landscape and Urban Planning 80 (2007) 386-395	Ming-Huang Li, Shyh-Dean Chang
007	A review on the generation, determination and mitigation of Urban Heat Island	Rizwan Ahmed Memon	University of Hong Kong, Department of Mechanical Engineering, Hong Kong, China	Journal of Environmental Sciences	Journal of Environmental Sciences Volume 20, Page 120–128, 2008	Dennis Y.C. Leung, Liu Chunho
008	A scale-hierarchic ecosystem approach to integrative ecological planning	A. Vasishth	California State University, Department of Urban Studies and Planning, California, US	Progress in Planning	Progress in Planning, Volume 70, Page 99-132, 2008	
009	A survey of urban heat island studies in two tropical cities	CP Tso	Nanyang Technological University, School of MPE, Republic of Singapore	Atmospheric Environment	Atmospheric Environment, Volume 30, No. 3, pp. 507-519, 1996	
010	Adapting Cities for climate change: the role of the green infrastructure	SE Gill		Built Environment	Built Environment Vol 33 No 1	JF Handley, AR Ennos, S Pauleit

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012	Air pollution prevention through urban heat island mitigation: an update on the urban heat island pilot project	Virginia Gorsevski	US Environmental Protection Agency, Washington DC, USA			Haider Taha, Dale Quattrochi, Jeff Luvall
013	Air Pollution removal by urban trees and shrubs in the United States	David Nowak	USDA Forest Service, New York, USA	Urban Forestry & Urban Greening	Urban Forestry & Urban Greening 4 (2006) 115-123	Daniel Crane, Jack Stevens
014	Air quality influences by urban heat island coupled with synoptic weather patterns	Li-Wei Lai	Shu-Zen College of Medicine and Management, Department of General Education, Taiwan, ROC	Science of the Total Environment	Science of the Total Environment 407 (2009) 2724-2/33	Wan-Li Cheng
015	An integrated empirical and modeling methodology for analyzing solar reflective roof technologies on commercial buildings	J.H. Jo	Arizona State University, School of Sustainability	Building and Environment	Building and Environment, Pages 1-8. 2009	J.D. Carlson, J.S. Golden, H. Bryan
016	Analysis of urban heat island effect using ASTER and ETM+ Data: separation of anthropogenic heat discharge and natural heat radiation from sensible heat flux	Soushi Kato	Nagoya University, Division of Earth and Environmental Sciences, graduate School of Environmental Studies, Japan	Remote Sensing of Environment	Remote Sensing of Environment 99 (2005) 44-54	Yasushi Yamaguchi
017	Assessment of urban heat island and possible adaptations in Enugu urban using landsat-ETM	Adinna E. N.	Enugu State University of Technology, Nigeria	Journal of Geography and Regional Planning	Journal of Geography and Regional Planning Vol. 2(2), pp. 030-036, February, 2009	Enete Ifeanyl Christian, Arch. Tony Okolie
018	Assessment of urban heat islands: a satellite perspective	KP Gallo	Satellite Research Laboratory, NOAA/NESDIS, Washington DC, USA	Atmospheric Research	Atmospheric Research 37 (1995) 37-43	JD Tarpley, AL McNab, TR Karl
019	Assessment of urban versus rural in situ surface temperatures in the contiguous United States: No difference found	Thomas Peterson	National Climatic Data Center, Asheville, North Carolina	Journal of Climate	Vol. 16, No. 18	

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021	Calculating energy-saving potentials of heat-island reduction strategies	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Energy Policy	Energy Policy, Volume 33, page 721-756, 2005	S. Konopacki
022	Changes in year round air temperature and annual energy consumption in office building areas by urban heat-island countermeasures and energy-saving measures	Tomohiko Ihara	National Institute of Advanced Industrial Science and Technology (AIST), Japan	Applied Energy	Applied Energy 85 (2008) 12-25	Yukihiro Kikegawa, Kazutake Asahi, Yutaka Genchi, Hiroaki Kondo
023	Characteristics of the urban heat island in the city of Salamanca, Spain	MS Alonso	Universidad de Salamanca, Dpto. De Fisica General y de la Atmosfera. Facultad de Ciencias. Espana	Atmosfera	Atmosfera (2003) 137-148	JL Labajo, MR Fidalgo
024	Control of Urban Night Temperature in Semitropical Regions During Summer	Masakazu Moriyama	Kobe University, Department of Environmental Planning, Japan	Energy and Buildings	Energy and Buildings, 11 (1988) 213-219	Mamoru Matsumoto
025	Cool Color Roofing Materials	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group		California Energy Commission PIER Program, February 2006	P. Berdahl, R. Levinson, S. Wiel, B. Miller, A. Desjarlais
026	Cool colored coatings for passive cooling of cities	A Synnefa	National and Kapodistrian University of Athens, Physics Department,Greece		International Workshop on Energy Performance and Environmental Quality of Buildings, July 2006, Milos Island, Greece	A Dandou, M Santamouris, M Tombrou
027	Cool Communities: Strategies for heat island mitigation and smog reduction	Arthur Rosenfeld	US Department of Energy, Washington DC, USA	Energy and Buildings	Energy and Buildings 28 (1998) 51-62	H Akbari, J Romm, M Pomerantz
028	Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Solar Energy	Solar Energy Vol 70, No. 3, pp. 295-310, 2001	M Pomerantz, H Taha

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029	Countermeasures to Urban Heat Islands: A Global View	Alan Meier	International Energy Agency			
030	Design of a porous-type residential building model with low environment load in hot and humid Asia	Shuzo Murakami	Keio University, Faculty of Science and Technology, Japan	Energy and Buildings	Energy and Buildings 36 (2004) 1181-1189	Shinsuke Kato, Ryozo Ooka, Yasuyuki Shiraishi
031	Development of a numerical simulation system toward comprehensive assessments of urban warming countermeasures including their impacts upon the urban buildings energy-demands	Yukihiro Kikegawa	Global Environment Laboratory, Fuji Research Institute Corp, Tokyo, Japan	Applied Energy	Applied Energy 76 (2003) 449-466	Yutaka Genchi, Hiroshi Yoshikado, Hiroaki Kondo
032	Effects of Vegetation on Urban Climate and Buildings	F. Wilmers	University of Hannover, Institute for Meteorology and Climatology, Germany	Energy and Buildings	Energy and Buildings, Volume 15-16, Pages 507-514, 1990/91	
033	Energy effects of heat-island reduction strategies in Toronto, Canada	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Energy	Energy, Volume 29, Page 191-210, 2004	S. Konopacki
034	Evolution of Cool Roof Standards in the US	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Advances in Building Energy Research	Advances in Building Energy Research, 2008, Volume 2, Pages 1-32	Ronnen Levinson
035	Global cooling: increasing world-wide urban albedos to offset CO2	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Climatic Change	Climatic Change, Volume 95, Joint Issue 3-4, May-June 2009	S. Menon, A. Rosenfeld
036	Global temperature change and its uncertainties since 1861	CK Folland	Met Office, Hadley Centre, Exeter, UK			N. A. Rayner, S. J. Brown, T. M. Smith, S. S. P. Shen, D. E. Parker, I. Macadam, P. D. Jones, R. N. Jones, N. Nicholls and D. M. H. Sexton
037	Guidelines for Heat Island Control Measures	unknown	Bureau of the Environment, Tokyo Metropolitan Government		Tel: 03-5321-1111 Ext: 42-723, 725	

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					Direct in: 03-5388-3563, 3567 Fax: 03-5388-1380	
038	Impact of anthropogenic heat on urban climate in Tokyo	Toshiaki Ichinose	Center for Global Environment Research, National Institute for Environmental Studies, Tsukuba, Japan	Atmospheric Environment	Atmospheric Environment 33 (1999) 3897-3909	Kazuhiro Shimodozono, Keisuke Hanaki
039	Impacts of vegetation on residential heating and cooling	E Gregory McPherson	University of Arizona, Department of Landscape Architecture, USA	Energy and Buildings	Energy and Buildings 12 (1988) 41-51	Lee Herrington, Gordon Heisler
040	Incorporating built environment factors into climate change mitigation strategies for Seoul, South Korea: A sustainable urban systems framework	J.H. Jo	Arizona State University, School of Sustainability, Tempe, AZ, USA	Habitat International	Habitat International, Volume 33, Pages 267-275, 2009	J.S. Golden, S.W. Shin
041	Indirect carbon reduction by residential vegetation and planting strategies in Chicago, USA	H.-K Jo	Kangwon National University, Division of Architecture and Landscape Architecture, College of Engineering, South Korea	Journal of Environmental Management	Journal of Environmental Management (2001) 61, 165-177	E G McPherson
042	Influence of tree cover on summertime surface energy balance fluxes, San Gabriel Valley, Los Angeles	CSB Grimmond	Indiana University, Climate and Meteorology Program, Department of Geography, Indiana, USA	Climate Research	Climate Research Vol. 6: 45-57, 1996	Catherine Souch, Mark Hubble
043	Intraurban Differences of Surface Energy Fluxes in a Central European City	B Offerle	Indiana University at Bloomington	Journal of Applied Meteorology and Climatology	Volume 45, page 125, 2006	CSB Grimmond, K Fortuniak, W Pawlak
044	Investigating the Surface Energy Balance in Urban Areas - Recent Advances and Future Needs	M Piringer	Central Institute for Meteorology and Geodynamics, Vienna, Austria	Water, Air and Soil Pollution	Water, Air and Soil Pollution: Focus 2: 1-16, 2002	C. S. B. Grimmond, S.M. Joffre, P.Mestayer, D. R.Middleton, M.W. Rotach, A. Baklanov, K. De Ridder, J. Ferreira, E. Guilloteau, A. Karppinen, A. Martilli, V. Masson and M. Tombrou
045	Japanese Experience of Technology and Policy for Urban Heat-Island Mitigating	Akashi Mochida	Tohoku University, Department of Architecture & Building Science	None	None	

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046	Measured Impact of Neighbourhood Tree Cover on Microclimate	David J Sailor	Lawrence Berkeley Laboratory, Energy & Environment Division		LBL-32419	Leo Rainer, Hashem Akbari
047	Measures to Mitigate Urban Heat Islands	Yoshika Yamamoto	Environment and Energy Research Unit, Science and Technology Foresight Center	Science & Technology Trends	Quarterly Review No. 18 / January 2006. 6	
048	Mesoscale meteorological and air quality impacts of increased urban albedo and vegetation	Haider Taha	Lawrence Berkeley National Laboratory, Heat Island Group	Energy and Buildings	Energy and Buildings 25 (1997) 169-177	Sharon Douglas, Jay Haney
049	Meso-urban meteorological and photochemical modeling of heat island mitigation	Haider Taha	Altostratus Inc, Martinez, CA, USA	Atmospheric Environment	Atmospheric Environment 42 (2008) 8795-8809	
050	Meteorological and air quality impacts of heat island mitigation measures in three US cities	Haider Taha	Lawrence Berkeley National Laboratory, Heat Island Group		LBNL-44222	Sheng-chieh Chang, Hashem Akbari
051	Meteorological and air quality modeling to further examine the effects of urban heat island mitigation measures on several cities in the northeastern US	A Belle Hudischewskyj	ICF Consulting		SYSAPP-01-001	Sharon G Douglas, Jeffrey R Lundgren
052	Microclimatic modeling of the urban thermal environment of Singapore to mitigate urban heat island	Rajagopalan Priyadarsini	Deakin University, School of Architecture and Building, Australia	Solar Energy	Solar Energy 82 (2008) 727–745	Wong Nyuk Hien, Cheong Kok Wai David
053	Mitigating New York City's Heat Island with urban forestry, living roofs, and light surfaces	Cynthia Rosenweig	Columbia University, New York		J3.2	William Solecki, Lily Parshall, Stuart Gaffin, Barry Lynn, Richard Goldberg, Jennifer Cox, Sara Hodges
054	Mitigating temperature increases in high lot density sub-tropical residential developments	DA Luxmoore	Queensland University of Technology, School of Engineering, Brisbane, Australia	Energy and Buildings	Energy and Buildings 37 (2005) 1212-1224	MTR Jayasinghe, Mahen Mahendran,

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055	Mitigating the urban heat island with green roof infrastructure	Brad Bass	University of Toronto, Adaptation and Research Group, Environment Canada, Institute for Environmental Studies			Scott Krayenhoff, Alberto Martilli, Roland Stull
056	Mitigating Urban Heat Island effects with water and energy sensitive urban designs	Anthony Brazel	Arizona State University, School of Geographical Studies, Tempe		J7.3	Patricia Gober, Susanne Grossman Clarke, Soe Myint, Ray Quay, A. Q. Miller, S. Rossi and Sue Grimmond
057	Mitigating urban heat island: Possibility and effect of reducing anthropogenic heat emission from vehicles and buildings	Tsuyoshi Kinouchi	Public Works Research Institute, Tsukuba, Japan		6.7	Junichi Yoshitani
058	Mitigation of the heat island effect in urban New Jersey	William D Solecki	City University of New York, Department of Geography, Hunter College,	Environmental Hazards	Environmental Hazards 6 (2005) 39-49	Cynthia Rosenzweig, Lily Parshall, Greg Pope, Maria Clark, Jennifer Cox, Mary Wiencke
059	Mitigation of urban heat island: Meteorology, energy, and air quality impacts	Haider Taha	Lawrence Berkeley National Laboratory, Heat Island Group	Architectural Institute of Japan	J. Archit. Plann. Environ. Eng., AIJ, No. 529, 69-76, Mat., 2000	Alan Meier, Weijun Gao, Toshio Ojima
060	Mitigation of Urban Heat Islands - Recent progress and future prospects	David J Sailor	Portland State University, Portland, Oregon, USA	None		Eva Wang, Niko Dietsch, David Hitchcock, Dale Quattrochi, Hashem Akbari
061	Mitigation of urban heat islands: materials, utility programs, updates	Arthur Rosenfeld	Lawrence Berkeley National Laboratory, Heat Island Group	Energy and Buildings	Energy and Buildings, Volume 22, Page 255-265, 1995	H. Akbari, S. Bretz, B. L. Fishman, D. M. Kurn, D. Sailor, H. Taha
062	Modeling and Simulation of the Tokyo Urban Heat Island.	T.S. Saitoh	Tohoku University, Department of Aeronautics and Space Engineering, Sendal, Japan	Atmospheric Environment	Atmospheric Environment, Volume 30, Issue 20, Pages 3431-3442, 1996	T. Shimada, H. Hoshi
063	Modeling the impacts of increased urban vegetation on ozone air quality in the south	Haider Taha	Lawrence Berkeley National Laboratory, Heat Island Group	Atmospheric Environment	Atmospheric Environment Vol. 30, No, 20, pp. 3423-	

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064	Modeling the impacts of large-scale albedo changes on ozone air quality in the south coast air basin	Haider Taha	Lawrence Berkeley National Laboratory, Heat Island Group	Atmospheric Environment	Atmospheric Environment Vol. 31, No, 11, pp. 1667-1676, 1997	
065	Numerical Study on the Effect of Buildings on Temperature Variation in Urban and Suburban Areas in Tokyo	Takayki Tokairin	National Institute of Advanced Industrial Science and Technology (AIST) Japan	Journal of the Meteorological Society of Japan	Journal of the Meteorological Society of Japan, Vol. 84, No. 5, pp. 921-937, 2006	Hiroaki Kondo, Hiroshi Yoshikado, Yutaka Genchi, Tomohiko Ihara
066	Painting the Town White - and Green	Arthur Rosenfeld	Lawrence Berkeley National Laboratory, Heat Island Group	MIT's Technology Review	Feb/March 1997	J Romm, H Akbari, A Lloyd
067	Passive Cooling of Outdoor Urban Spaces: The Role of Materials	M Santamouris	University of Athens, Group Building Environmental Studies, Section Applied Physics, Physics Department, Greece	Solar Energy	Solar Energy 77 (2004) 231-249	L Doulos, I Livada
068	Paving Materials for Heat Island Mitigation	Melvin Pomerantz	Lawrence Berkeley National Laboratory, Heat Island Group		LBL-38074	H. Akbari, A Chen, H Taha, AH Rosenfeld
069	Potential energy savings in buildings by an urban tree planting program in California	E Gregory McPherson	USDA Forest Service, California, USA	Urban Forestry & Urban Greening	Urban for Urban Green 2 (2003) 073-086	James Simpson
070	Potentials of urban heat island mitigation	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group		International Conference "Passive and Low Energy Cooling for the Built Environment" May 2005, Santorini, Greece	
071	Practical Issues for using solar reflective materials to mitigate urban heat islands	Sarah Bretz	Lawrence Berkeley National Laboratory, Energy Analysis Program	Atmospheric Environment	Atmospheric Environment Vol. 32. No. 1 pp. 95 101. 1998	H Akbari, A Rosenfeld
072	Preliminary survey of the solar reflectance of cool roofing materials	Paul Berdahl	Lawrence Berkeley National Laboratory, Heat Island Group	Energy and Buildings	Energy and Buildings 25 (1997) 149-158	Sarah E Bretz

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073	Reducing Urban Heat Islands: Compendium of Strategies - Cool Pavements	Eva Wong	US Environmental Protection Agency, Climate Protection Partnership, Office of Atmospheric Programs			Bruce Ferguson, Kim Fisher, Jay Golden, Lisa Hair, Liv Haselbach, David Hitchcock, Kamil Kaloush, Mel Pomerantz, Nam Tran, and Don Waye.
074	Reducing Urban Heat Islands: Compendium of Strategies - Cool Roofs	Eva Wong	US Environmental Protection Agency, Climate Protection Partnership, Office of Atmospheric Programs			Gregory Chin, Andre Desjarlais, Maury Estes, David Hitchcock, Megan Lewis, Danny Parker, Joyce Rosenthal, Lorraine Ross, Steve Ryan, Rachel Schmeltz, Peter Turnbull, and Barry Zalph
075	Reducing Urban Heat Islands: Compendium of Strategies - Green Roofs	Eva Wong	US Environmental Protection Agency, Climate Protection Partnership, Office of Atmospheric Programs			Ryan Bell, Robert Berghage, Hitesh Doshi, Robert Goo, David Hitchcock, Megan Lewis, Tom Liptan, Karen Liu, Greg McPherson, Dave Nowak, Steven Peck, Katrin Scholz-Barth, Jeff Sonne, Benjamin Taube, Linda Velazquez, Kathy Wolf, Jim Yarbrough, and Barry Zalph
076	Reducing Urban Heat Islands: Compendium of Strategies - Heat Island Reduction Activities	Eva Wong	US Environmental Protection Agency, Climate Protection Partnership, Office of Atmospheric Programs			David Cole, Nikolaas Dietsch, Gary Gero, David Hitchcock, Megan Lewis, Julie Magee, Misha Sarkovich, Jim Yarbrough, and Barry Zalph

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077	Reducing Urban Heat Islands: Compendium of Strategies - Trees and Vegetation	Eva Wong	US Environmental Protection Agency, Climate Protection Partnership, Office of Atmospheric Programs			Ryan Bell, David Cole, Ben DeAngelo, Lynn Desaultes, Ed Dickerhoff, Maury Estes, Gordon Heisler, David Hitchcock, Kim Klunich, Cheryl Kollin, Megan Lewis, Julie Magee, Greg McPherson, Dave Nowak, Philip Rodbell, Joyce Rosenthal, Misha Sarkovich, Kathy Wolf, Jim Yarbrough, and Barry Zalph.
078	Reducing Urban Heat Islands: Compendium of Strategies - Urban Heat Island Basics	Eva Wong	US Environmental Protection Agency, Climate Protection Partnership, Office of Atmospheric Programs			Hashem Akbari, Ryan Bell, Tony Brazel, David Cole, Maury Estes, Gordon Heisler, David Hitchcock, Brenda Johnson, Megan Lewis, Greg McPherson, Tim Oke, Danny Parker, Alan Perrin, Joyce Rosenthal, David Sailor, Jason Samenow, Haider Taha, James Voogt, Darrell Winner, Kathy Wolf, and Barry Zalph.
079	Residential Cooling Loads and the Urban Heat Island - the Effects of Albedo	Haider Taha	Lawrence Berkeley Laboratory, University of California	Building and Environment	Building and Buildings, Vol, 23, No. 4, pp. 271-283, 1988.	Hashem Akbari, Arthur Rosenfeld, Joe Huang
080	Shade trees reduce building energy use and CO2 emissions from power plants	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Environmental Pollution	Environmental Pollution, Volume 116, Page 119-126, 2002	

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081	Strategic Plan for Urban Heat Island Mitigation in the Houston Area	David Hitchcock	Houston Advanced Research Center, The Woodlands, Texas USA		International Workshop on Countermeasures to Urban Heat Islands. Tokyo, Japan. 3-4 August 2006	
082	Study of green areas and urban heat island in a tropical city	Nyuk Hien Wong	National University of Singapore, Department of Building, School of Design and Environment	Habitat International	Habitat International 29 (2005) 547–558	Chen Yu
083	Study of thermal performance of extensive rooftop greenergy systems in the tropical climate	Wong Nyuk Hien	National University of Singapore, Department of Building, School of Design and Environment	Building and Environment	Building and Environment 42 (2007) 25–54	Tan Puay Yok, Chen Yu
084	Study on mitigation measures for outdoor thermal environment on present urban blocks in Tokyo using coupled simulation	Hong Chen	University of Science & Technology, School of Architecture and Urban Planning, Huazhong, China	Building and Environment	Building and Environment 44 (2009) 2290-2299	Ryozo Ooka, Hong Huang, Takashi Tsuchiya
085	Study on optimum design method for pleasant outdoor thermal environment using genetic algorithms (GA) and coupled simulation of convection, radiation and conduction	Hong Chen	University of Tokyo, Institute of Industrial Science, Japan	Building and Environment	Building and Environment 43 (2008) 18-30	Ryozo Ooka, Shinsuke Kato
086	Study on the urban heat island mitigation effect achieved by converting to grass-covered parks	Hideki Takebayashi	Kobe University, Department of Architecture, Graduate School of Engineering, Japan	Solar Energy	solar energy 83 (2009) 1211-1223	Masakazu Moriyama
087	Surface heat budget on green roof and high reflection roof for mitigation of urban heat island	Hideki Takebayashi	Kobe University, Department of Architecture, Graduate School of Engineering, Japan	Building and Environment	Building and Environment 42 (2007) 2971-2979	Masakazu Moriyama
088	The Potential for Reducing Urban Air Temperatures and Energy Consumption Through Vegetative Cooling	Dan Kurn	Lawrence Berkeley Laboratory, Energy & Environment Division		LBL-35320	S Bretz, B Huang, H Akbari

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089	The potential of Urban Heat Island mitigation to alleviate heat related mortality: Methodological overview and preliminary modeling results for Philadelphia	David J Sailor	Tulane University, New Orleans, Louisiana, USA		7.1	Laurence S Kalkstein, Eva Wong
090	The summer thermal behaviour of ''skin" materials for vertical surfaces in Athens, Greece as a decisive parameter for their selection.	F. Bougiatioti	National Technical University of Athens, School of Architecture, Department of Architectural Technology, Athens, Greece	Solar Energy	Solar Energy, Volume 83, Pages 582–598, 2009	E. Evangelinos, G. Poulakos, E. Zacharopoulos
091	The Urban Heat Island Mitigation Impact Screening Tool (MIST)	David J Sailor	Portland State University, Portland, Oregon, USA		Modeling Study for the US Environmental Protection Agency (EPA)	Nikolaas Dietsch
092	Urban Climates and heat islands: albedo, evapotranspiration, and anthropogenic heat	Haider Taha	Lawrence Berkeley National Laboratory, Energy and Environment Division	Energy and Buildings	Energy and Buildings, 25 (1997) 99-103	
093	Urban Climate Modeling, Heat Island Mitigation and Local Knowledge: Co-producing Science for Urban Policy	Lily Parshall	Columbia University, New York		J7.2	Jason Corburn
094	Urban form and climate change, balancing adaptation and mitigation in the US and Australia	Elisabeth M Hamin	University of Massachusetts, Landscape Architecture and Regional Planning, USA	Habitat International	Habitat International 33 (2009) 238-245	Nicole Gurran
095	Urban Heat Island Characteristics in London during Winter	Maria Kolokotroni	Brunel University, Mechanical Engineering, School of Engineering and Design, UK	Solar Energy	Solar Energy 83 (2009) 1668-1682	Renganathan Giridharan
096	Urban Heat Island Intensity in London: An Investigation of the Impact of Physical Characteristics on Changes in Outdoor Air Temperature during Summer	Maria Kolokotroni	Brunel University, Mechanical Engineering, School of Engineering and Design, UK	Solar Energy	Solar Energy 82 (2008) 986-998	Renganathan Giridharan, Assoc Editor M Santamouris

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097	Urban Heat Island: Spatial analysis, assessment and measuring mitigation in cities of extreme dry weather.	Jorge Villanueva Solis	Autonomous University of Baja California (UABC)			Francisco Raúl Venegas Cardoso, Onofre Rafael García Cueto
098	Urban Heat Islands and Climate Change - Melbourne, Australia	CJG (Jon) Morris	The University of Melbourne, School of Earth Sciences, Victoria, Australia			
099	Urban Heat Islands and Environmental Impact	S. S. Devi	Andhra University, Visakhapatnam, India		Mitigation of Urban Heat Islands (Joint with 6th Symposium on the Urban Environment and Forum on Managing our Physical and Natural Resources), January 2006	
100	Urban Heat Islands in Small Towns - Deniliquin, Australia	CJG (Jon) Morris	The University of Melbourne, School of Earth Sciences, Victoria, Australia			
101	Urban Heat Islands: A Climate Change Adaptation Strategy For Montreal	Chee F Chan	McGill University School of Urban Planning, The Climate Change Action Partnership		McGill URBP 624	Julia Lebedeva, Jose Otero, Gregory Richardson
102	Urban Sprawl and air quality in large US cities	Brian Stone Jr	Georgia Institute of Technology, City and Regional Planning Program, College of Architecture, Atlanta USA	Journal of Environmental Management	Journal of Environmental Management 86 (2008) 688-698	
103	Urban Sprawl and Climate Change: A Statistical Exploration of Cause and Effect, with Policy Options for the EU	István László Bart	European Commission, DG Environment, Bruxelles, Belgium	Land Use Policy	Land Use Policy (2009), doi:10.1016/j.landusepol.2009.03.003	
104	Urban Surface Modification as a Potential Ozone Air-Quality Improvement Strategy in California: A Mesoscale Modelling Study	Haider Taha	Altostratus Inc, Martinez, CA, USA	Boundary-Layer Meteorology	Boundary-Layer Meteorol (2008) 127:219-239	

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105	Urban Surfaces and Heat Island Mitigation Potentials	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Journal of the Human Environment System	Paper LBNL 747E	Leanna Shea Rose
106	Urban thermal environment measurements and numerical simulation for an actual complex urban area covering a large district heating and cooling system in summer	Hong Huang	University of Tokyo, Institute of Industrial Science, Japan	Atmospheric Environment	Atmospheric Environment 39 (2005) 6362-6375	Ryozo Ooka, Shinsuke Kato
107	Urban Warming trends in several large Asian cities over the last 100 years	Kumi Kataoka	University of Tsukuba, Japan	Science of the Total Environment	Science of the Total Environment 407 (2009) 3112-3119	Futoshi Matsumoto, Toshiaki Ichinose, Makoto Taniguchi
108	Urbanization and global environmental change: local effects of urban warming	Sue Grimmond	King's College London, Environmental Monitoring and Modelling Group, Department of Geography, UK	The Royal Geographical Society	Cities and Global Environmental Change, p83	
109	Vegetation as a climatic component in the design of an urban street. An empirical model for predicting the cooling effect of urban green areas with trees.	L. Shashua-Bar	Technion-Israel Institute of Technology, Faculty of Architecture and Town Planning, Haifa, Israel	Energy and Buildings	Energy and Buildings, Volume 31, Page 221–235, 2000	M.E. Hoffman
110	White Roofs Cool the World, Directly Offset CO2 and Delay Global Warming	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group		Research Highlights, LBNL Heat Island Group, November 10 2008	Arthur Rosenfeld
111	Yearlong evaluation of urban heat island countermeasures from the viewpoints of thermal environment mitigation and urban energy conservation	Yukihiro Kikegawa	Global Environment Laboratory, Fuji Research Institute Corp, Tokyo, Japan		P3.1	Yutaka Genchib, Hiroaki Kondob, and Yukitaka Ohashic
112	Energy saving potentials and air quality benefits of urban heat island mitigation	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	None	None	
113	Cooling Energy Savings Potential of Reflective Roofs for Residential & Commercial	H. Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Energy	Energy, Volume 24, pp381-407, 1999	S.Konopacki, M.Pomerantz

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114	City size and the urban heat island	Tim Oke	University of British Columbia, Department of Geography, Vancouver	Atmospheric Environment	1973, Vol 7 pp 769-779	
115	Turbulent heat fluxes in urban areas: Observations and a local-scale urban meteorological parameterization scheme (LUMPS)	Sue Grimmond	Indiana University, Department of Geography	Journal of Applied Meteorology and Climatology	Vol 41, p 792	Tim Oke
116	Some studies on the Earth's surface conditions relating to the urban heat island	Shuji Yamashita	Tokyo Gakugei University	Energy and Buildings	Energy and Buildings, 15 - 16 (1990/91) 279-288	Kiyoshi Sekine
117	Epidemiologic study of mortality during the Summer 2003 heat wave in Italy	Susanna Conti	National Centre of Epidemiology, Italian National Institute of Health	Environmental Research	Environmental Research 98 (2005) 390-399	Paola Meli, Giada Minelli, Renata Solimini, Virilia Toccaceli, Monica Vichi, Carmen Beltrano, Luigi Perini
118	On relationships between heat island and sky view factor in the cities of Tama River Basin, Japan	Shuji Yamashita	Tokyo Gakugei University	Atmospheric Environment	Atmospheric Environment Vol 20 No 4 pp 681-686	Kiyoshi Sekine, Masahiro Shoda, Kohji Yamashita, Yoshio Hara
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130	Extreme weather and climate events and public health responses: Health impacts of the 2003 heat-wave in France	Pascal Empereur-Bissonnet		World Health Organisation, Report Feb 2004		
131	Estimating the mortality effect of the July 2006 California heat wave	Bart D Ostro	California Environmental Protection Agency	Environmental Research	Environmental Research 109 (2009) 614-619	Lindsey Roth, Rochelle Green, Rupa Basu

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134	Effects of composition and exposure on the solar reflectance of portland cement concrete	Ronnen Levinson	Lawrence Berkeley National Laboratory, Heat Island Group	Concrete Research	Cement and concrete research 32 (2002) 1679-1698	Hashem Akbari
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140	Suspended particulate matter and its relation to the urban climate in Dar es Salaam, Tanzania	P Jonsson	Goteborg University, Sweden	Atmospheric Environment	38 (2004) 4175-4181	C Bennet, I Eliasson, E Selin Lindgren
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156	Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits	Corrie Clark	University of Michigan			Peter Adrians, F Brian Talbot
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171	Energy and peak power savings potential of radiant cooling systems in US commercial buildings	Corina Stetiu				
172	Impact of Climate Change – An Economic Perspective	KS Lam	Hong Kong Polytechnic University			
173	Urbanization and warming of Phoenix (Arizona, USA): Impacts, feedbacks and mitigation	Lawrence Baker	University of Minnesota	Urban Ecosystems	6: 183-203, 2002	Brazel, Selover, Martin, McIntyre, Steiner, Nelson, Musacchio
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181	Cool Cars Standards and Test Procedures		California Air Resources Board		Public Workshop, March 12, 2009	
182	Impact of rapid urban growth on heat and moisture islands in Pune City, India	Vrishali Deosthali	University of Pune, India	Atmospheric Environment	34 (2000) 2745-2754	
183	Assessment of Urban Heat Island Intensities over Delhi	Manju Mohan	Indian Institute of Technology (Centre for Atmospheric Sciences), Delhi, India		The seventh International Conference on Urban Cliamte 29 June - 3 July 2009, Yokohama, Japan	Yukihiro Kikegawa, BR Gurjar, Shweta Bhati, Anurag Kandya, Koichi Ogawa
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189	Planning for Climate Change			Journal of the American Planning Association	Spring 2009, Vol 75 No 2	
190	Technology Assessment of Greenhouse Gas and Carbon Emissions Management Strategic Planning Tools - Localized Strategic Planning	Augusta Systems	Augusta Systems		Report Number AS-NETL-50113-3-FR	Michelle L Varga, Janet M Wood, Patrick R Esposito II, C David Locke, Carrie Pancake
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194	Report on the Benefits and Costs of Green Roof Technology for the City of Toronto	Hitesh Doshi	Ryerson University		City of Toronto and Ontario Centres of Excellence, Earth and Environmental Technologies (OCE-Etech)	Dr Doug Banting, Dr James Li, Dr Paul Mmissios, Angela Au, Beth Anne Currie, Michael Verrati
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200	Promotion of Cool Roofs in the EU - The Cool Roofs Project	Afroditi Synnefa	University of Athens, Group Building Environmental Studies, Section Applied Physics, Physics Department, Greece	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Mat Santamouris, Denia Kolokotsa
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206	Development of a green roof environmental monitoring and meteorological network in New York City	Stuart Gaffin	Columbia University, New York	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Reza Khanbilvardi, Cynthia Rosenzweig
207	SMUD Shade Tree and Cool Roof Programs: Case Study in Mitigating the Urban Heat Island Effects	Misha Sarkovich	Sacramento Municipal Utility District, Sacramento, California	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	
208	The Climate-Adapted Design for the Humid-Hot Region - Case Study on the University Library in the Lingnan Region	Fang Xiaoshan	South China University of Technology, College of Architecture	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Song Zhenyu
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210	Outline of the Policy Framework to Reduce Urban Heat Island Effects		Government of Japan, Ministry of the Environment, Inter-Ministry Coordination Committee to Mitigate Urban Heat Island			
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223	Effect of the Evaporative Cooling Techniques by Spraying Mist Water on Reducing Urban Heat Flux and Saving Energy in Apartment House	Daisuke Narumi	Osaka University, Japan	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Kentaro Shigematsu, Yoshiyuki Shimoda
224	Development of empirical models for an estate level air temperature prediction in Singapore	Steve Kardinal Jusuf	National University of Singapore	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Wong Nyuk Hien
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226	Study on Characteristics of Solar Radiation in the Geometrically Complex Urban Spaces by Using a Spetroradiometer	Yasunobu Ashie	NILIM Tsukuba, Japan	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Daisuke Itoh
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229	Evaporation Performance Analysis for Water Retentive Material Based on Outdoor Heat Budget and Transport Properties	S.Kinoshita	Osaka Prefecture University, Japan	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	A.Yoshida andN.Okuno
230	Reduction of Urban Heat Island Effect through Harvest of Heat Energy from Asphalt Pavements	Rajib B. Mallick	Worcester Polytechnic Institutem Civil and Environmental Engineering, USA	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Bao-Liang Chen and Shankha Bhowmick
231	Research on Urban Heat Island and Energy Saving Design Based on Climate Regulation	Zhuang Yu	University of Science and Technology Wuhan, China	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Hui Zhang
232	National Research Project on Kaze-no-michi for City Planning: Creation of Ventilation Paths of Cool Sea Breeze in Tokyo	Koji Kagiya	National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba, Ibaraki, Japan	Second International Conference on Countermeasures to Urban Heat Islands	September 19 - 23 2009	Yasunobu Ashie
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235	Analyzing the land cover of an urban environment using high-resolution orthophotos	Hashem Akbari	Lawrence Berkeley National Laboratory, Heat Island Group	Landscape and Urban Planning	Landscape and Urban Planning 63 (2003) 1-14	L.Shea Rose and Haider Taha
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