Environmental Impact Assessment Review 56 (2016) 139–144

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

An energy and mortality impact assessment of the urban heat island in the US

Scott A. Lowe

Civil and Environmental Engineering Dept., Manhattan College, Riverdale, NY 10471, United States

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form 19 October 2015
Accepted 20 October 2015
Available online 31 October 2015

Keywords:
Urban heat island
Mortality impact energy impact
Heat related deaths
Cold related deaths

ABSTRACT

Increased summer energy use and increased summer heat related mortality are the two most cited detrimental impacts of the urban heat island (UHI). An assessment of these impacts was made that considered the annual impact of the UHI, not just the summer impact. It was found that in north of the US there was a net decrease in energy use from the UHI, as heating energy reductions were larger than the increase in cooling energy. In the south there was a net energy increase from the UHI. The impact of the UHI on heat related deaths was an estimated increase of 1.1 deaths per million people. The impact of the UHI on cold related deaths was an estimated decrease of 4.0 deaths per million people. These estimates are caveated by the acknowledgement that compounding factors influence mortality. Hypothermia related death rates were three times higher in rural areas than urban areas. This is surprising as the homeless population is usually considered the most at risk, yet they mostly live in urban areas.

1. Introduction

The urban heat island (UHI) effect has been known for 200 years. Luke Howard made temperature measurements in 1815 in and around London that not only identified the phenomenon but also most of the causes (Howard 1818). As identified by Howard the urban heat island effect raises the ambient air temperature compared to surrounding, less urbanized areas. The main contributor to the UHI is the extensive use of manmade materials (concrete and asphalt) that effectively store short wave radiation (Solecki et al. 2005; Rizwan et al. 2008; EPA (US Environmental Protection Agency) 2015a).

The detrimental impacts of the UHI are usually listed as (EPA (US Environmental Protection Agency) 2015b):

1. Increased energy consumption as cities use more electricity for cooling in summer.
2. Increased emissions of air pollutants and greenhouse gases associated with the above.
3. Increased mortality from heat related deaths in summer.

A less cited impact is the heating of stormwater runoff (EPA (US Environmental Protection Agency) 2015b). Warmer water has less dissolved oxygen and can impact temperature sensitive fish species.

It can be assumed that most if not all cities in the US are aware of the UHI. Many cities are developing or implementing plans to mitigate the UHI impact. For example, Hewitt et al. (2014) details the UHI mitigation strategies and results in 26 US cities. Some common approaches include reflective roofs; vegetated (green) roofs; porous pavement; shade trees and increasing urban vegetation in general.

Apart from projects specifically planned with the UHI in mind, numerous projects in a city will cite UHI reduction as a benefit. For example New York City has a large green infrastructure program whose main focus is on reducing Combined Sewer Overflows (CSO's) (NYC EP (New York City Environmental Protection) 2014). However most of the initiatives also act to reduce the UHI and this is cited as a benefit on the first page of the NYCEP report.

Assessment measures help guide the development of UHI strategies, and then help track their effectiveness once implemented. One problem with existing assessments of the UHI is that only detrimental effects are considered. Note that the list above considers only summer impacts, not winter or annual. An accurate assessment should at least cover an annual range.

This paper attempts to assess the UHI impact on an annual basis in the US. The list above basically falls into two categories: energy and mortality. Emissions are directly linked to energy use. The next section describes the energy calculation for New York City, and then this method is expanded to the US. Mortality impacts are addressed from both the heat and cold perspective.

2. Annual energy impact of the UHI on New York City

The urban heat island (UHI) in New York City has been studied extensively (e.g. Kirkpatrick and Shulman 1987; Childs and Raman 2005; Gaffin et al. 2008). The UHI typically has a diurnal signal and is stronger at night (EPA (US Environmental Protection Agency) 2015a). Gedzelman et al. (2003) analyzed a large amount of local data and

E-mail address: Scott.lowe@manhattan.edu.

http://dx.doi.org/10.1016/j.eiar.2015.10.004
0195-9255/

concluded an average value of the UHI was 3 °C in the winter (Dec, Jan., Feb) and 4 °C in the summer (Jun, July, Aug).

The long term monthly average temperatures for New York City Central Park are given in Table 1 (NOAA (National Oceanic and Atmospheric Administration) 2015). These values would include the UHI effect. Using monthly temperature the heating degree days (HDD) and cooling degree days (CDD) can be calculated. These are referenced from 18 °C. HDD is the (18 °C − monthly temperature) × (days in the month). If the monthly temperature is above 18 °C then CDD is calculated as (monthly temperature − 18 °C) × (days in the month). Based on these calculations there are 2460 heating degree days, and 609 cooling degree days.

It has been shown that energy consumption is highly correlated with heating and cooling degree days (Quayle and Diaz 1980; Le Comte and Warren 1981, Sailor and Muñoz 1997). Sivak (2008) also points out that there may be secondary variables that influence the need for heating and cooling, such as the differences in the tolerance for heat and cold, differential home insulation across the country and the energy efficiency of heating and cooling systems.

The last point in particular is worth paying attention to. If the efficiency of heating and cooling systems are compared using a coefficient of performance (COP), then cooling systems are typically more efficient (Sivak 2013). Based on new device efficiencies Sivak concluded that the energy impact of one HDD was twice that of one CDD.

However this ratio could change dramatically if other factors were considered. For example the efficiencies of systems are highly dependent on age and maintenance level, with cooling systems degrading more rapidly than heating (NREL (National Renewable Energy Laboratory) 2006). The reported efficiencies of new systems are based on standard calculations and vary widely in actual use (Stein and Meier 2000; Pérez-Lombard et al. 2009). The distribution efficiency of the system, as opposed to just the heating/cooling unit, is also a factor. A hydronic heating system is extremely efficient compared to losses in air ducts, for example (NREL (National Renewable Energy Laboratory) 2006).

So while it is probable that the energy related consumption of one HDD and one CDD are not the same, it is difficult to derive a realistic estimate of what the ratio should be. So for the analysis presented here the energy related consumption of one HDD and one CDD is assumed to be equal.

Table 2 shows the monthly average temperatures reduced by the values reported by Gedzelman et al. (2003). The heating and cooling degree days are then recomputed. The spring and fall use averages of the summer and winter UHI intensity values (i.e. 3.5 °C). Summer and winter generally represent the two extremes of the UHI (Schatz and Kucharik 2014) and studies have shown ~linear variations between the two (Gallo and Owen 1999).

The results from Tables 1 and 2 indicate the net energy effect of the UHI is a decrease in annual heating of 3068.9–2460.4 = 608.5 heating degree days. Conversely the UHI causes an increase in cooling requirements of 609–170.5 = 438.5 cooling degree days. This means there is an annual energy benefit of the UHI of 608.5 − 438.5 = 170°days.

This result is not unexpected for a city with the climate of New York, which has more months requiring heating than cooling. The official heating season is 8 months long, Oct. 1–May 31 (NYS (New York State) Division of Housing 2015).

Using this methodology the energy impact of the UHI across the US is assessed in the next section.

Table 1
Heating and cooling for NYC including UHI.

Month	Avg temp (°C)	Heating degree days	Cooling degree days
Jan	0.4	547.2	
Feb	1.8	453.6	
Mar	5.9	375.1	
Apr	11.3	201.0	
May	17.1	29.5	
June	22.0		120.0
July	25.2		221.7
Aug	24.4		196.9
Sept	20.4		70.5
Oct	14.2	117.8	
Nov	8.7	279.0	
Dec	3.3	457.3	
		2460.4 total	609.0 total

Table 2
Heating and cooling For NYC excluding UHI.

Month	Avg temp (°C)	Heating degree days	Cooling degree days
Jan	−2.7	475.9	
Feb	−1.2	470.4	
Mar	2.4	483.6	
Apr	7.8	306.0	
May	13.6	138.0	
June	18.0		0.0
July	21.2		97.6
Aug	20.4		72.9
Sept	16.9	34.5	
Oct	10.7	226.3	
Nov	5.2	384.0	
Dec	0.3	550.3	
		3068.9 total	170.5 total

3. Mapping energy impact of the UHI in the US

Remote sensing technology has enabled the estimation of the UHI in many cities in the US (Streutker 2002; Xian and Crane 2006; Yow and Carbone 2006; Yuan and Bauer 2007; Imhoff et al. 2010; Gallo and Xian 2014). In addition the EPA has compiled information on various cities (EPA (US Environmental Protection Agency) 2014).

Whether remote sensing is an accurate method to assess the UHI has been the subject of numerous papers. Many papers have concluded the validity of the method (for example Hu et al. 2014). Some papers have noted differences between measured air temperature and remote sensing results. For example Zhang et al. (2014) noted that although overall agreement was good, some particular situations were not (midday summer UHI for cities in forested areas, for example). Others have also noted the issues with observed air temperature measurements (for example Oke 1982; Stewart 2011). This further complicates the comparison of results. For the purposes of this paper the remote sensing estimates of the UHI are assumed to be accurate enough to complete the analysis presented.

Using the available UHI information and monthly NOAA temperature data, the annual energy impact of the UHI was computed for cities throughout the continental US. The same approach as above for New York City was utilized. Due to the large number of cities involved (42), it is not feasible to show all the individual tables in this paper. The spatial distribution of the cities considered is shown in Fig. 1. The results are summarized in Table 3. A city that would use less energy as a result of the UHI (e.g. New York City) is listed as positive UHI impact. A city that will use more energy as a result of the UHI is listed as negative UHI impact. In some cases the heating energy reductions and the cooling energy increases tend to offset each other. These cases are listed as neutral UHI impact.

The results indicate that cities in more northern areas will show a net energy benefit of the UHI, as a result of colder climates. Conversely cities in southern areas will be negatively impacted by the UHI as a result of their warmer climate. The results are mapped in Fig. 2. Also shown in Fig. 2 is an approximate location of the zero gain line — where there is neither a significant net energy gain nor loss.

Fig. 1. Spatial distribution of cities considered in the study. (Base map courtesy NationsOnline.org).

4. Health impacts of the UHI

Health impacts of the UHI encompass a huge range of consequences (Parsons 2014). For the purpose of this paper the discussion is confined to the most severe impact, human mortality.

The increase in heat related deaths due to the UHI has been well documented for several decades, beginning with Clarke and Bach (1971); Clarke (1972) and Buechley et al. (1972). Research into this area has been continual, and has increased in recent years as heat related deaths are often used as an impetus to develop strategies to mitigate the UHI (Dong et al. 2014; van der Hoeven and Wandl 2015; Sailor 2014).

Data on heat related deaths clearly indicate that most fatalities occur during heat waves (CDC (Centers for Disease Control and Prevention) 2013). It is also clear that the frequency and longevity of heat waves is exacerbated by the UHI (Tan et al. 2010; Laaidi et al. 2012).

Conversely the warming of cities in winter due to the UHI should lead to fewer deaths due to the effect of cold. This, however, does not

Table 3
Annual energy impact of the UHI in various US cities.

City	UHI impact	City	UHI impact	City	UHI impact
Albuquerque NM	Negative	Houston TX	Negative	Portland OR	Positive
Altanta GA	Neutral	Kansas City MO	Positive	Sacramento CA	Neutral
Austin TX	Negative	Los Angeles CA	Negative	Salt Lake City UT	Positive
Baltimore MD	Positive	Memphis TN	Neutral	San Antonio TX	Negative
Baton Rouge LA	Negative	Milwaukee WI	Positive	San Diego CA	Negative
Boston MA	Positive	Minneapolis MN	Positive	San Jose CA	Neutral
Charlotte NC	Neutral	New Orleans LA	Negative	Seattle WA	Positive
Chicago IL	Positive	New York NY	Positive	St Louis MO	Positive
Cleveland OH	Positive	Oklahoma City OK	Negative	St Paul MN	Positive
Columbus OH	Positive	Omaha NE	Positive	Tampa FL	Negative
Dallas TX	Negative	Orlando FL	Negative	Tucson AZ	Negative
Detroit MI	Positive	Philadelphia PA	Positive	Tulsa OK	Neutral
El Paso TX	Negative	Phoenix AZ	Negative	Washington DC	Positive
Fresno CA	Negative	Pittsburgh PA	Positive	Wichita KA	Positive

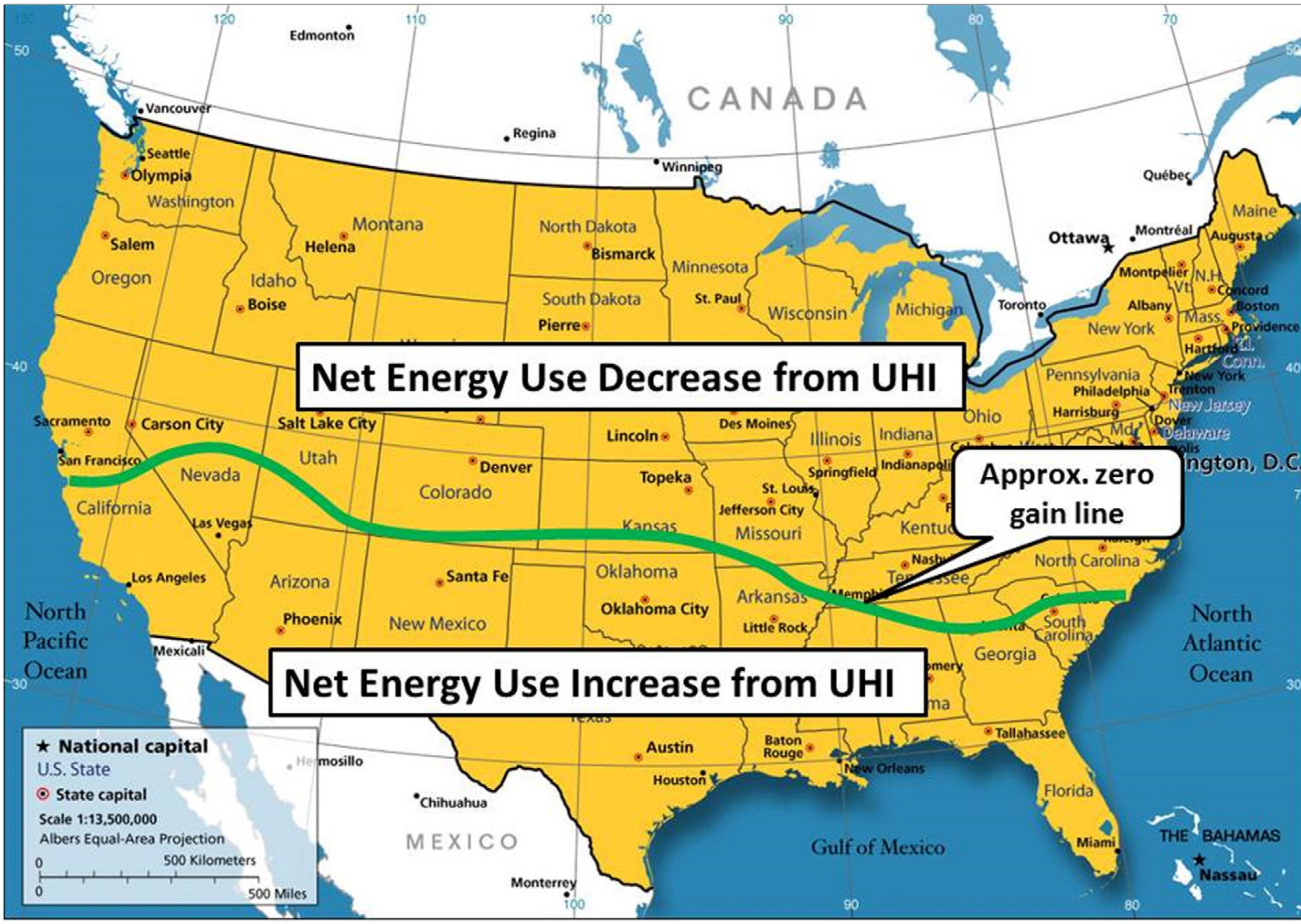

Fig. 2. Annual energy impact of the UHI. (Base map courtesy NationsOnline.org).

seem to have been the subject of any publications. This may not be surprising as it is obviously difficult to estimate how many fatalities did not occur due to the presence of the UHI.

The Centers for Disease Control and Prevention (CDC) recently released data on heat and cold related deaths in the US from 2006–2010 (Berko et al. 2014). The rise in deaths during heatwaves receives the most media attention, as the effect is the most dramatic and it is easy to correlate. However the number of cold related deaths is far greater. From 2006–2010 in the US there were 3332 heat related deaths and 6660 cold related deaths — almost exactly twice as many.

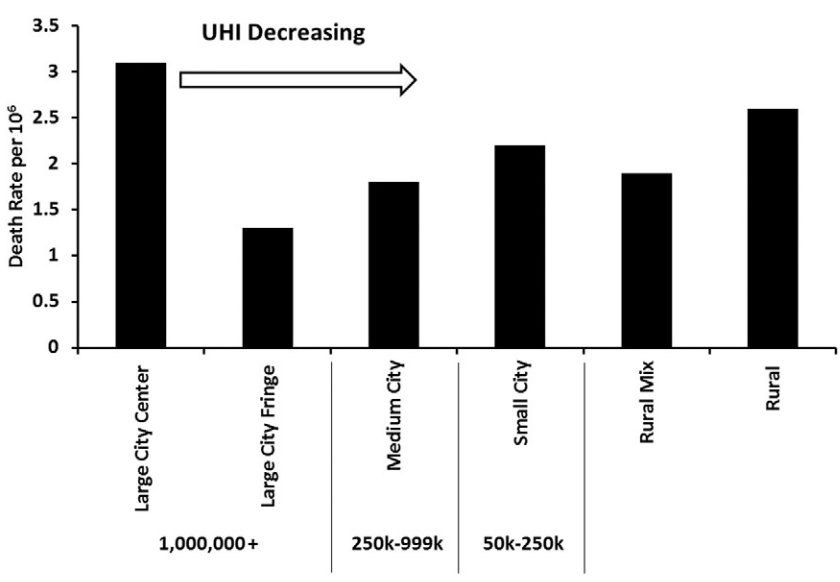

Fig. 3. US heat related deaths by urbanization level, 2006–2010.

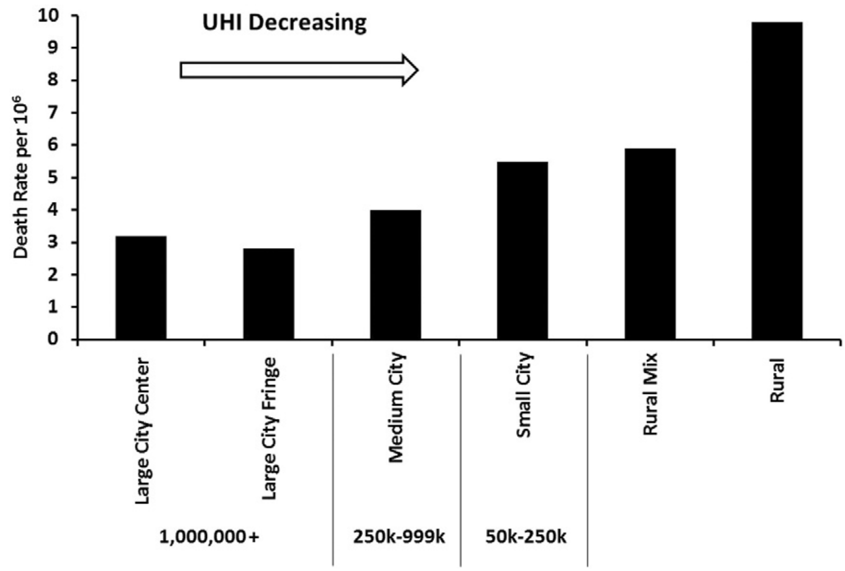

Fig. 4. US cold related deaths by urbanization level, 2006–2010.

The rate of heat related deaths by urbanization level is shown in Fig. 3 (Berko et al. 2014). The figure also notes the decreasing UHI trend. The highest death rate, 3.1 per 10^6 people, is in the most urban setting, "Large City Center", and this would also have the largest UHI (Oke 1973). After this the results are less definitive and the deaths rates actually increase with less urbanization. If the two large city categories were combined into one category, say "Large City", then there would be no relationship with the level of urbanization. The average rate of all the categories other than "Large City Center" is 2.0.

One possible conclusion is that the impact of the UHI is an increase in the death rate of $3.1–2.0 = 1.1$ people per million. The caveat here is that heat related mortality is related not just to temperature, but a host of other factors, the most significant being age. For example the CDC data set estimated the rate for the ">85 year old" age group was 150 times greater than for the "5–14 year old" age group.

The rate of cold related deaths by urbanization level is shown in Fig. 4. The figure also notes the decreasing UHI trend. Note that the rates are significantly higher than those for heat related deaths. Unlike Fig. 3 there is a consistent trend of rising death rate with decreasing urbanization level, and hence decreasing UHI. The average rate for the four urban categories (Large City Center to Small City) is 3.9. These areas would experience some level of UHI. The average rate for the two rural categories (rural mix and rural) is 7.9. These areas would experience no UHI.

As before, one possible conclusion is that the impact of the UHI is a decrease in the cold related death rate of $7.9 - 3.9 = 4.0$ deaths per million. Again there are many factors involved in cold related mortality that could have an influence.

Fig. 4 is also strikingly counter-intuitive in that it is commonly assumed that the homeless population is the most at risk during cold weather. Most of the homeless population in the US is found in highly urban areas (77%), while only 4% are found in highly rural areas (Henry and Sermons 2010). Over half the US homeless population lives in major cities. Based on this it would be expected that the most urban categorizes would have the largest mortality rates, whereas Fig. 4 shows the exact opposite.

5. Conclusions

This paper assessed the impact of the urban heat island (UHI) on annual energy consumption and mortality. A calculation for New York City showed how the UHI has a net impact of reducing energy use on an annual basis. The calculations showed energy savings from reduced heating requirements were greater than the extra energy used for cooling. This was not surprising given the climate of New York, where more months require heating than cooling.

This methodology was expanded to various cities in the US. The conclusion is that in northern areas with cold climates there is a net energy benefit from the UHI. Conversely southern, warmer areas use more energy as a result of the UHI. The results were mapped and showed the approximate location of the zero gain line across the US.

The increased mortality due to heat related deaths caused by the UHI was estimated at 1.1 per million people. This figure is caveated by the fact that heat related mortality is influenced by factors other than just temperature. The relationship between heat related mortality and level of urbanization, and hence UHI, was not well defined. Large city centers, which would have the highest UHI, did have the highest mortality. If the death rates for the two most urban categories were combined there would be no relationship between level of urbanization and the heat related death rate.

There are approximately twice as many cold related deaths in the US as heat related. The decrease in mortality from the UHI was estimated at 4.0 per million people. Again this figure is caveated by the realization that hypothermia related deaths are influenced by other factors beside temperature. In this case the level of urbanization and death rate showed a consistent trend — as urbanization decreased the death rate increased. The most rural areas had three times the death rate as the most urban areas.

The cold related deaths trend was the opposite of what would be expected if it is assumed that the homeless population is the most at risk during cold weather. Most of the homeless population is found in highly urban areas, and yet these had the lowest death rate.

References

Berko, J., Ingram, D.D., Saha, S., Parker, J.D., 2014. Deaths attributed to heat, cold, and other weather events in the United States, 2006–2010. Natl. Health Stat. Rep. 76, 1–16.

Buechley, R.W., Van Bruggen, J., Truppi, L.E., 1972. Heat island = death island? Environ. Res. 5 (1), 85–92.

CDC (Centers for Disease Control and Prevention), 2013. Heat illness and deaths — New York City, 2000–2011. Morb. Mortal. Wkly Rep. 62 (31), 617–621.

Childs, P.P., Raman, S., 2005. Observations and numerical simulations of urban heat island and sea breeze circulations over New York City. Pure Appl. Geophys. 162, 1955–1980.

Clarke, J.F., 1972. Some effects of the urban structure on heat mortality. Environ. Res. 5 (1), 93–104.

Clarke, J.F., Bach, W., 1971. Comparison of the comfort conditions in different urban and suburban microenvironments. Int. J. Biometeorol. 15 (1), 41–54.

Dong, W., Liu, Z., Zhang, L., Tang, Q., Liao, H., Li, X.E., 2014. Assessing heat health risk for sustainability in Beijing's urban heat island. Sustainability 6 (10), 7334–7357.
EPA (US Environmental Protection Agency), 2014. www.epa.gov/heatislands/resources/reports Accessed 10/19/14.
EPA (US Environmental Protection Agency), 2015a. Reducing urban heat islands: compendium of strategiesAvailable from www.epa.gov/heatisland/resources/compendium.htm Accessed 6/7/2015.
EPA (US Environmental Protection Agency), 2015b. www.epa.gov/heatisland Accessed 5/2/15.
Gaffin, S.R., Rosenzweig, C., Khanbilvardi, R., Parshall, L., Mahani, S., Glickman, H., Goldberg, R., Blake, R., Slosberg, R.B., Hillel, D., 2008. Variations in New York city's urban heat island strength over time and space. Theor. Appl. Climatol. 94, 1–11.
Gallo, K.P., Owen, T.W., 1999. Satellite-based adjustments for the urban heat island temperature bias. J. Appl. Meteorol. 38 (6), 806–813.
Gallo, K., Xian, G., 2014. Application of spatially gridded temperature and land cover data sets for urban heat island analysis. Urban Clim. 8, 1–10.
Gedzelman, S.D., Austin, S., Cermak, R., Stefano, N., Partridge, S., Quesenberry, S., Robinson, D.A., 2003. Mesoscale aspects of the urban heat island around New York City. Theor. Appl. Climatol. 75, 29–42.
Henry, M., Sermons, M.W., 2010. Geography of Homelessness. National Alliance to End Homelessness, Washington, DC.
Hewitt, V., Machres, E., Shickman, K., 2014. Cool policies for cool cities: best practices for mitigating urban heat islands in North American Cities. American Council for Energy Efficient Economy, Research Report.
Howard, L., 1818. The climate of London, deduced from Meteorological observations, made at different places in the neighbourhood of the metropolis. Originally published by Phillips and Yard, Lombard Street, London.
Hu, L., Brunsell, N.A., Monaghan, A.J., Barlage, M., Wilhelmi, O.V., 2014. How can we use MODIS land surface temperature to validate long-term urban model simulations? J. Geophys. Res. Atmos. 119 (6), 3185–3201.
Imhoff, M.L., Zhang, P., Wolfe, R.E., Bounoua, L., 2010. Remote sensing of the urban heat island effect across biomes in the continental USA. Remote Sens. Environ. 114 (3), 504–513.
Kirkpatrick, J.S., Shulman, M.D., 1987. A statistical evaluation of the New York City — Northern New Jersey urban heat island effect on summer daily minimum temperature. Nat. Weather Dig. 12 (1), 12–15.
Laaidi, M., Zeghnoun, A., Dousset, B., Bretin, P., Vandentorren, S., Giraudet, E., Beaudeau, P., 2012. The impact of heat islands on mortality in Paris during the August 2003 heat wave. Environ. Health Perspect. 120 (2), 254.
Le Comte, D.M., Warren, H.E., 1981. Modeling the impact of summer temperatures on national electricity consumption. J. Appl. Meteorol. 20 (12), 1415–1419.
NOAA (National Oceanic and Atmospheric Administration), 2015. www.ncdc.noaa.gov/climate-information/analyses/monthly-us-climate-reports Accessed 1/5/2015.
NREL (National Renewable Energy Laboratory), 2006. Building America Performance Analysis Procedures for Existing Homes. Research report NREL/TP-550-38238.
NYC EP (New York City Environmental Protection), 2014. NYC Green Infrastructure 2014 Annual Report.
NYS (New York State) Division of Housing, 2015. Fact sheet #15: Heat and Hot Water.
Oke, T.R., 1973. City size and the urban heat island. Atmos. Environ. 7, 769–779.
Oke, T.R., 1982. The energetic basis of the urban heat island. Q. J. R. Meteorol. Soc. 108 (455), 1–24.
Parsons, K.C., 2014. Human Thermal Environments: The Effect of Hot, Moderate and Cold Environments on Human Health, Comfort and Performance. 3rd Edition. Taylor and Francis Group, Boca Raton, Florida.
Pérez-Lombard, L., Ortiz, J., González, R., Maestre, I.R., 2009. A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes. Energy Build. 41 (3), 272–278.
Quayle, R.G., Diaz, H.F., 1980. Heating degree day data applied to residential heating energy consumption. J. Appl. Meteorol. 19 (3), 241–246.
Rizwan, A.M., Dennis, L.Y., Chunho, L.I.U., 2008. A review on the generation, determination and mitigation of urban heat island. J. Environ. Sci. 20 (1), 120–128.
Sailor, D.J., 2014. Risks of summertime extreme thermal conditions in buildings as a result of climate change and exacerbation of urban heat islands. Build. Environ. 78, 81–88.
Sailor, D.J., Muñoz, J.R., 1997. Sensitivity of electricity and natural gas consumption to climate in the USA—methodology and results for eight states. Energy 22 (10), 987–998.
Schatz, J., Kucharik, C.J., 2014. Seasonality of the urban heat island effect: patterns and drivers. AGU Fall Meeting, San Francisco, Dec 15–19.
Sivak, M., 2008. Where to live in the United States: combined energy demand for heating and cooling in the 50 largest metropolitan areas. Cities 25 (6), 396–398.
Sivak, M., 2013. Air conditioning versus heating: climate control is more energy demanding in Minneapolis than in Miami. Environ. Res. Lett. 8 (1), 014050.
Solecki, W.D., Rosenzweig, C., Parshall, L., Pope, G., Clark, M., Cox, J., Wiencke, M., 2005. Mitigation of the heat island effect in urban New Jersey. Glob. Environ. Chang. Part B Environ. Hazards 6 (1), 39–49.
Stein, J.R., Meier, A., 2000. Accuracy of home energy rating systems. Energy 25 (4), 339–354.
Stewart, I.D., 2011. A systematic review and scientific critique of methodology in modern urban heat island literature. Int. J. Climatol. 31 (2), 200–217.
Streutker, D.R., 2002. A remote sensing study of the urban heat island of Houston, Texas. Int. J. Remote Sens. 23 (13), 2595–2608.
Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A.J., Li, F., Chen, H., 2010. The urban heat island and its impact on heat waves and human health in Shanghai. Int. J. Biometeorol. 54 (1), 75–84.
van der Hoeven, F., Wandl, A., 2015. Amsterwarm: mapping the landuse, health and energy-efficiency implications of the Amsterdam urban heat island. Build. Serv. Eng. Res. Technol. 36 (1), 67–88.
Xian, G., Crane, M., 2006. An analysis of urban thermal characteristics and associated land cover in Tampa Bay and Las Vegas using Landsat satellite data. Remote Sens. Environ. 104 (2), 147–156.
Yow, D.M., Carbone, G.J., 2006. The urban heat island and local temperature variations in Orlando, Florida. Southeast. Geogr. 46 (2), 297–321.
Yuan, F., Bauer, M.E., 2007. Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. Remote Sens. Environ. 106 (3), 375–386.
Zhang, P., Bounoua, L., Imhoff, M.L., Wolfe, R.E., Thome, K., 2014. Comparison of MODIS land surface temperature and ari temperature over the continental USA meteorological stations. Can. J. Remote. Sens. 40 (2), 110–122.

Scott Lowe is a professor in the Civil & Environmental Engineering Department of Manhattan College in New York City. He teaches courses at the graduate and undergraduate level in a variety of areas, from fluid mechanics and hydraulic design, to green building design, air quality modeling and coastal engineering. His research interests mirror his teaching interests and are wide and varied. Dr. Lowe also works extensively in the environmental engineering consulting industry.