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INADVERTENT URBAN-CLIMATE EMITTERS: Internal-Combustion Engines and Air-Conditioners

This paper considers aspects of the **urban heat island** phenomenon from the viewpoint of *thermal pollution* unwittingly and inadvertently emitted to the urban atmosphere, most specifically in this instance, from internal-combustion engine vehicles and air-conditioners. Urban design aspects of the UHI are also briefly elaborated. In sum: effects of thermal emissions are considered, specific causes revisited, and a set of potential remedial actions described.

Invisible thermal emissions from a range of urban sources impacting together affect the ecology of urban climates. These inadvertent emissions become visible under infra-red photography - a technique which can also empirically measure radiant heat temperatures emanating from anything (at any spot on the IR image). Thus, the aim of utilizing nocturnal IR imagery is to expose the sources of this stealthy influence on the urban heat load and energy budget. The cameras are highly sophisticated and accurate machines (and very expensive, even to hire), but I have had the use of one for a few nights in Sydney, and some of these images are included here (albeit reduced to black and white, for publication purposes).

The detrimental consequences of urban heat island situations are now well known, ranging from exacerbating regional, local and micro-climatic weather extremes, to a range of serious health issues and, of course, implicating the consumption of scarce energy resources and resulting in the emission of greenhouse gases when city buildings are cooled with air-conditioners using fossil-fuelled electrical power. Greenhouse gases are widely assumed to be the '*cause*' of global warming and subsequent climate-change extremes. However, in fact, it is the heat they absorb which is the active catalyst that changes the climate. The gases in themselves, without the heat, are climatically innocuous. A paradigm shift in our environmental consciousness and sustainability efforts from *energy to heat* is thus crucially necessary, since we are principally focused on only half of the equation. Moreover, energy equations in themselves are also vexed and convoluted by vested interests and national priorities while heat is a waste product which nobody wants. If the **thermal pollution itself** is acted upon, the climate warming potential of the gases could be immediately reduced, given the above understanding. Remove or reduce the heat, thus and, logically, weather disequilibrium should respond positively.

The principle rationale for undertaking this mini-expose here arises from the ubiquitous reality of cities being *the* primary source of thermal pollution. It is only logical that cities should be the major contributors to global warming of the troposphere – those 11-kilometers of atmosphere directly above us where the weather is manufactured. Cities simultaneously emit heat *and* thermally-activated climate-changing $CO_{2\text{-}e}$ gases in an unholy alliance; and any local action taken to cool them is also likely to mitigate global climate extremes.

Currently, in the professional practice of architectural and urban design there is scant regard given to the thermal pollution of the urban atmosphere. The focus is squarely (fairly?) on energy: efficiency; integrated renewables; climate-appropriate passive-solar design to sustainably manage heat-gain/heat-loss transactions in all building typologies. Urban climatologists, meanwhile, seem to revel in mathematically modeling complex urban settings. But ask practicing urban designers if the UHI or these climatic simulations are part of their considerations, and the answer is mostly a resounding no. Yet, the urban climate, this invisible parameter, is possibly *the most important factor* to consider in any sustainable and habitable urban design process.

Recognition of these specific invisible but potent thermal polluters could or in any event should influence decisions made regarding the design and use of cities. The two pollutant sources highlighted for discussion here are subject to complex psycho-social and economic aspects which cannot be addressed here. With regard to internal combustion vehicles the fact that they are *hot* is the issue. Similarly, the utility of mechanical cooling systems for buildings implicates thermal comfort and acclimatization and cultural aspects, and much more, but the fact that buildings eject heat into the urban atmosphere is at issue here. Generically, there are at least three salient eco-logical design aspects which could moderate UHI conditions: naturally cooled buildings, greening of streets and urban squares, and the urban geometry of pedestrian prioritization – in particular, organic street grids.

The urban heat island phenomenon is inevitable and ubiquitous – wherever there is a city this effect is produced. Solar radiation and thermal mass are inextricably symbiotic; there is no escape from this relationship, and irrespective of the amount of urban mass it will exert disruptive pressures on micro-climatic and ultimately local and regional weather systems. In effect, every city creates its own climate. The materials in buildings and the urban infrastructure absorb solar radiation and anthropogenic heat generated by urban lifestyles and energy use, and in conjunction with the loss of natural thermal sinks (trees especially) cause the temperature of urban air domes to range up to 10^{o}C warmer than the surrounding countryside (www.NASA) – up to 16^{o}C warmer in Athens (Santamouris, 2001).

This heat, absorbed by the greenhouse gases present in the urban atmosphere, influences a wide range of ecological parameters: temperature *experienced*, first and foremost. We are thermodynamic beings, acclimatized to particular conditions but sensitive like thermometers to the slightest change in temperature - our moods, comfort, performance and health affected in turn. Heat-waves are silent killers, particularly of the more vulnerable segments of populations: the elderly and very young, and the poor or just poorly housed and millions of slum dwellers who cannot find cool shelter. Heat-waves are more humanly destructive than other urban calamities, floods and hurricanes included. Thirty-five thousand people died in a short unusually hot period on the most sophisticated of all continents, Europe, in the summer of 2003. Moreover, recently French researchers discovered that during that heat-wave parched forests and grasslands emitted huge quantities of carbon dioxide (Ciais *et al*, 2005). Furthermore, it is not widely appreciated that air pollution in cities is exacerbated by both heat and sunlight, the toxicity of the photochemical ozone being intensified *ie* the VOCs revving up in effect and having more potent affects than on an average winter's day (www.LBL).

But this is not all - rainfall and wind movement patterns are also relentlessly impacted upon, seriously disturbing the urban and regional climate in a multitude of ways. Precipitation intensity is disturbed, and thunderstorms, hail and violent winds are all exacerbated (Eliasson, 1996; Bornstein & Lin, 1999; Burian *et al*, 2004), even downwind of urban hotspots. Humidity, cloud-cover, fog and snow are also impacted. Recent simulations of Sydney's urbanization and deforestation impacts on the weather also indicate that the biggest storms form over the CBD (SMH, Oct 2005) – *ie* where thermal mass concentrations are greatest.

At the end of the scale of UHI human-factor impacts is thermal comfort, another underestimated but major force in our lives. Both indoors and in city streets and urban squares, comfort makes up a large component of our livability and habitability experiences, or put simply: our ability to enjoy the environment. Moreover, when people come out onto the streets and linger there, there is little loitering - people making other people feel safer by their happy presence. Even at this extreme of possible interactions, thus, heat has an affect on lifestyle and experience.

If these are some of the consequences and symptoms of the UHI, the *causes* of this phenomenon are also multiple, and only very few aspects will be posited here, starting with the unavoidable solar irradiation which falls on the earth and is absorbed, stored and emitted by the 'thermal mass of materials' in the built environment. The mass, emissivity, albedo and reflectivity characteristics of each material vary enormously. Obviously, black is hot and has a very high emissivity rate, but these relationships are complex since although white is cool and has a high albedo white paint has a high emissivity. But generally speaking, green and blue are cool, and the inclusion or removal of each of these (as vegetation and water) can have an enormous impact on UHI intensity.

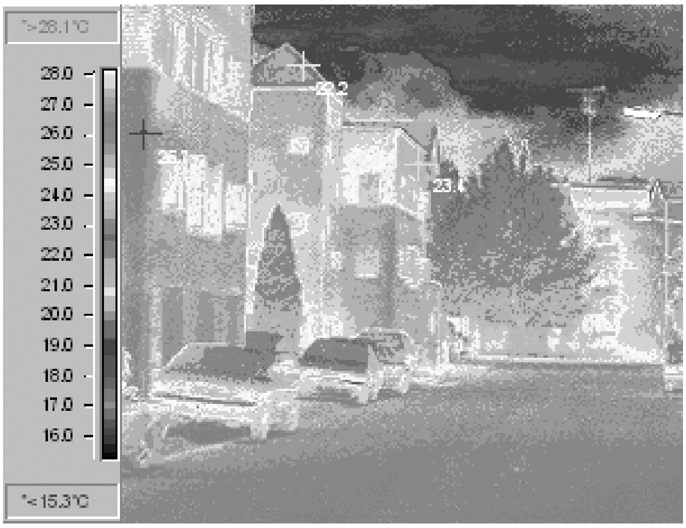
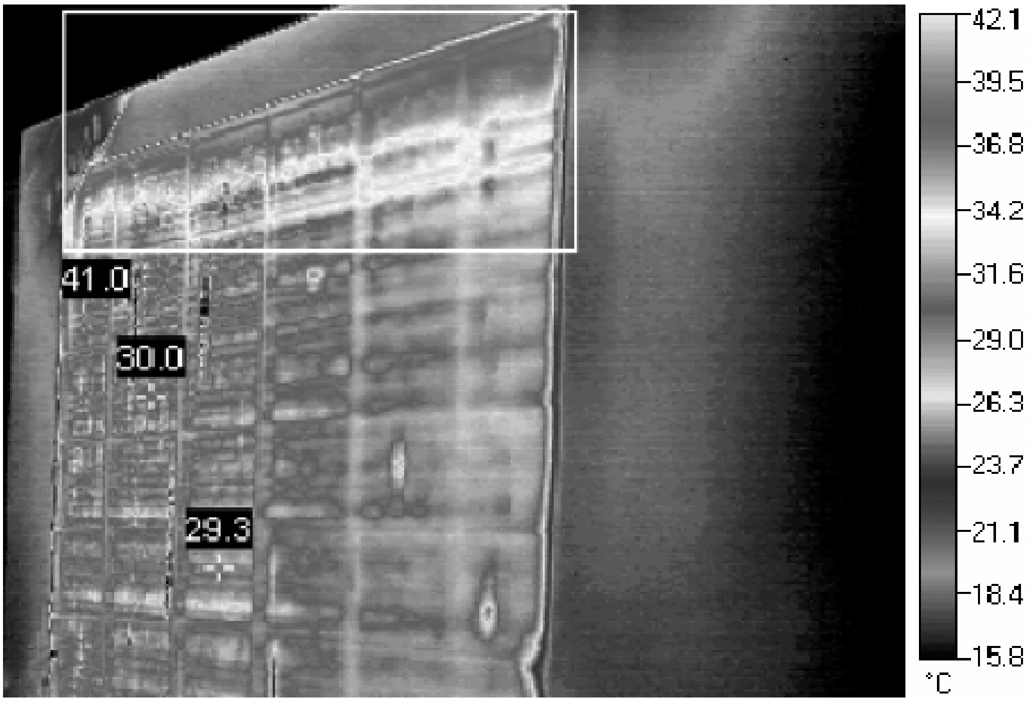


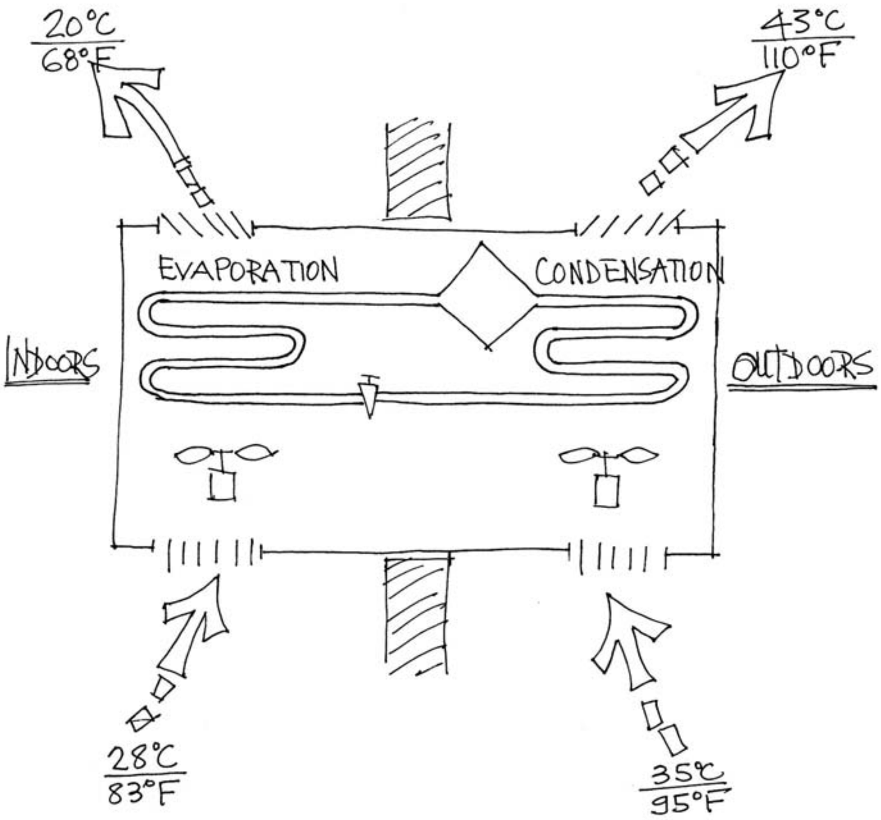
Fig. 1: In the thermal image above, taken at 10pm on a summer's night, the grey colour of the road and the base of the buildings indicate thermal radiation around 26^{o}C (deep red in the IR image). The deeper gray of parked cars and the two trees (green in the IR image) indicate radiation emitted at around 22^{o}C. The cars have given off their heat to the ambient air, while the trees are 'trapped' in the mini-canyon – working hard to be cool. The black night sky is even cooler, around 18^{o}C. [1]

[1] NOTE: All thermal images have of necessity been reduced to black and white for purposes of this paper. All images in this paper: Author

Added to this omnipresent material element of the built environment is the anthropogenic factor: the urban ecology of lifestyle. We spend the vast majority of our time inside buildings, residential, work-related and commercial - frequently packed with heat-emitting electrical devices. Indoor climates thus generate high levels of incidental heat, not the least of which is sourced from humans themselves who pulsate internally at 37^{o}C and emit metabolic heat to the environment in the 30^{o}C range by sweating, breathing and just being energetic. In order to make these environments comfortable in warm conditions and climates this heat is extracted, via air-conditioners if natural ventilation is unavailable, and ejected outdoors into the urban air – where it exacerbates the heat island, requiring even more cooling energy and pumping out even more fossil-fuel emissions in a vicious cycle .

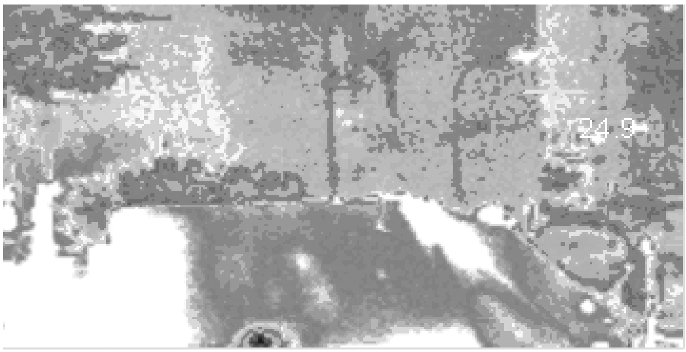
Figs. 2, 3 & 4: Hot moist air ejected from shopping centre air-conditioning exhaust on rooftop in Sydney; one example of sets of outlets on thousands of New York office buildings; hundreds of individual units in one Hong Kong residential building.

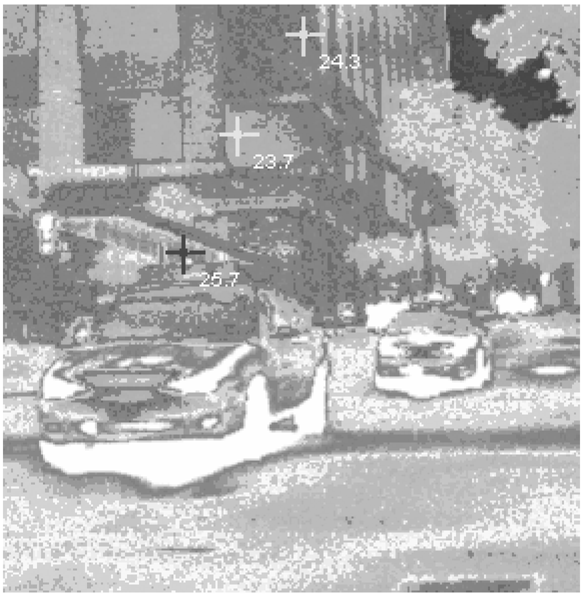




Figs. 5 & 6: Thermal image of individual air-conditioner in cooling mode, ejecting hot air to the urban air; and internal mechanism of refrigerative system indicating how hot air is removed from the inside of the building but not eliminated, being simply transferred to the outside air.

We have also ingeniously (or disingenuously, ultimately) invented an engine to drive our vehicles which explodes internally in order to function and thus constantly gives off masses of heat, from burning-hot exhaust pipes too. These vehicles also travel on hot tires along thermally dense and mostly black macadamized roads; and together interact as positive feedback thus further saturating the urban air with heat and the greenhouse gases to absorb it.





Figs 7 & 8: In the thermal images above 'white' heat is being emitted from the internal combustion engines of a rear-engine bus and two taxis @ around 50^{o}C (motors), 59^{o}C (exhausts) and 46^{o}C (tires) - measured *at midnight* in Sydney city in summer. Even the buildings are still hot.

Currently there is discussion about petrol/electric hybrids, and taxis in NYC and other US cities are converting to this system. However, the dual mechanisms driving the vehicles are still heat-emitting, albeit less greenhouse gases are emitted. Similarly, hydrogen fuel-cell driven vehicles rely on the explosive power of the hydrogen, even if only water is emitted at the tail-pipe. The urban thermal pollutant impact of millions upon millions of vehicles is not considered in these equations; yet as a source of anthropogenic heat they are unparalleled. Considered holistically, this is a further convincing argument for pedestrianisation.

Which brings us to a brief consideration of urban form associated with the UHI phenomenon. The architectural composition of cities unavoidably involves *urban canyons* which thermally exaggerate the absorption of heat, particularly during the daylight hours, which is then re-emitted to the urban atmosphere when the night sky is cooler. In particular, high-rise, high thermal-mass canyons magnify the impact of the built environment on urban climate by trapping heat (Arnfield *et al*, 1999; Santamouris, 2001; *inter alia*) and reducing long-wave heat loss - or cooling potential (Oke, 1982).

Alternatively, 'skyview' (night-sky access), 'roughness' (urban configuration variability), light-weight and high reflectivity/albedo materials (Akbari *et al,* 1990) and 'nodal' low-pressure configurations (like urban squares) exert a cooling potential, limiting heat build-up or allowing for the escape or transfer of heat. If, however, this heat is simply relocated in the *urban canopy* not much has been achieved for UHI cooling, albeit beneficial for cooling energy consumption in buildings and urban comfort at street level. Only if the heat is removed to the urban boundary layer (*ie* above the building rooftops) can it can be transported away downwind from that urban setting itself. Otherwise, this is not much different to air conditioning, which also takes heat from one place and transports it to another, but still remains within the urban framework.

Often ignored but fundamentally implicated is the design of the urban street grid itself. It is posited that orthogonal (90^o angled) high-rise canyon grids exacerbate urban climate extremes – by unnaturally channeling winds and concentrating heat – while organic/cellular grids should act to moderate extremes by dispersing weather conditions and emulating the roughness of natural conditions more closely. Moreover, incidentally, critically, linear grids favour the use of vehicles. Organic matrices, on the other hand, discourage their use and, rather, encourage either subterranean mass transit, or nimble-footed light rail systems, or best of all, walking and cycling – the coolest and most benign of all modes. If then cities accommodated walking people first, in other words: prioritized pedestrianisation, and integrated paths and urban squares and parks and converted hot roads for cars into greened streets for people, one can readily imagine the benign influence on heat island concentrations.

Such compact, organic grid, medium-density medium-rise models already exist - all over the European continent. The concept is millennia old; and still proving livable, even for cities ten-million strong, like Paris, which epitomes this urban resolution (see over). Inevitably, these cities also have UHIs and their local geographic conditions will enhance or moderate the intensity of its occurrence, but they incorporate elements which militate against heat accumulation - their grid-canyon configuration in the first instance. Their sustainability potential will also inevitably be related to the extent that greenery is integrated (trees in particular). To this end such compact cities could benefit from re-integrating greenery removed by horizontal sprawl into courtyards, urban squares, streets, parking lots and pocket parks, as well as into and where feasible onto buildings. Compact cities need not be denuded of greenery at all if considered holistically. Vegetation and trees in particular naturally cool the environment by evapo-transpiration, and on an average sunny summer day the average temperature of walls can be reduced by 15^oC through shading with trees and/or shrubs (Givoni, 1991; 1998). Stormwater evaporating from porous paving could do much the same (Kinouchi & Kanda, 1998).

The carbon dioxide removed from the air by a tree requires no further elaboration here, now common knowledge – it is the carbon sink basis of Kyoto Protocol carbon trading negotiations.

Fig. 9: Paris epitome: compact, organic-grid, humane-scale, medium-density, medium-rise, culturally-sensitive architecture, and pedestrian-prioritized streets (even tree and water cooling, here).

In Conclusion, it seems unfortunate in the extreme that the mega-massive iconic high-rise urban model now being disgorged undigested all over the emerging world is not being appreciated for its UHI weather-distorting capacity. Many of these nations are located in the vicinity of tropic of cancer<>capricorn latitudes, intrinsically hot cities, now further impacted by global warming *and* massive urban heat islands, and car-addicted to boot. How much more relevant could it be than to neutralize the thermal pollution factor here?

Perhaps infra red imagery is one method to help expose the many inadvertent and invisible heat emitters in the urban environment, cars and air conditioners and building materials, and all electrical energy-consuming appliances, *inter alia*. Even varying urban configurations and their thermal signatures could be detected, and compared.

Generally, it appears that sufficient focus is not being put on the removal and/or even transformation of waste heat in the urban environment, but this represents a potent opportunity to have an immediate and substantial impact on the warming of the urban and global climates.

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