The Effect of Facades on Outdoor Microclimate

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CRC Urban Microclimates Workshop

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LOW CARBON LIVING CRC

UCR URBAN CLIMATES RESEARCH

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Acknowledgments

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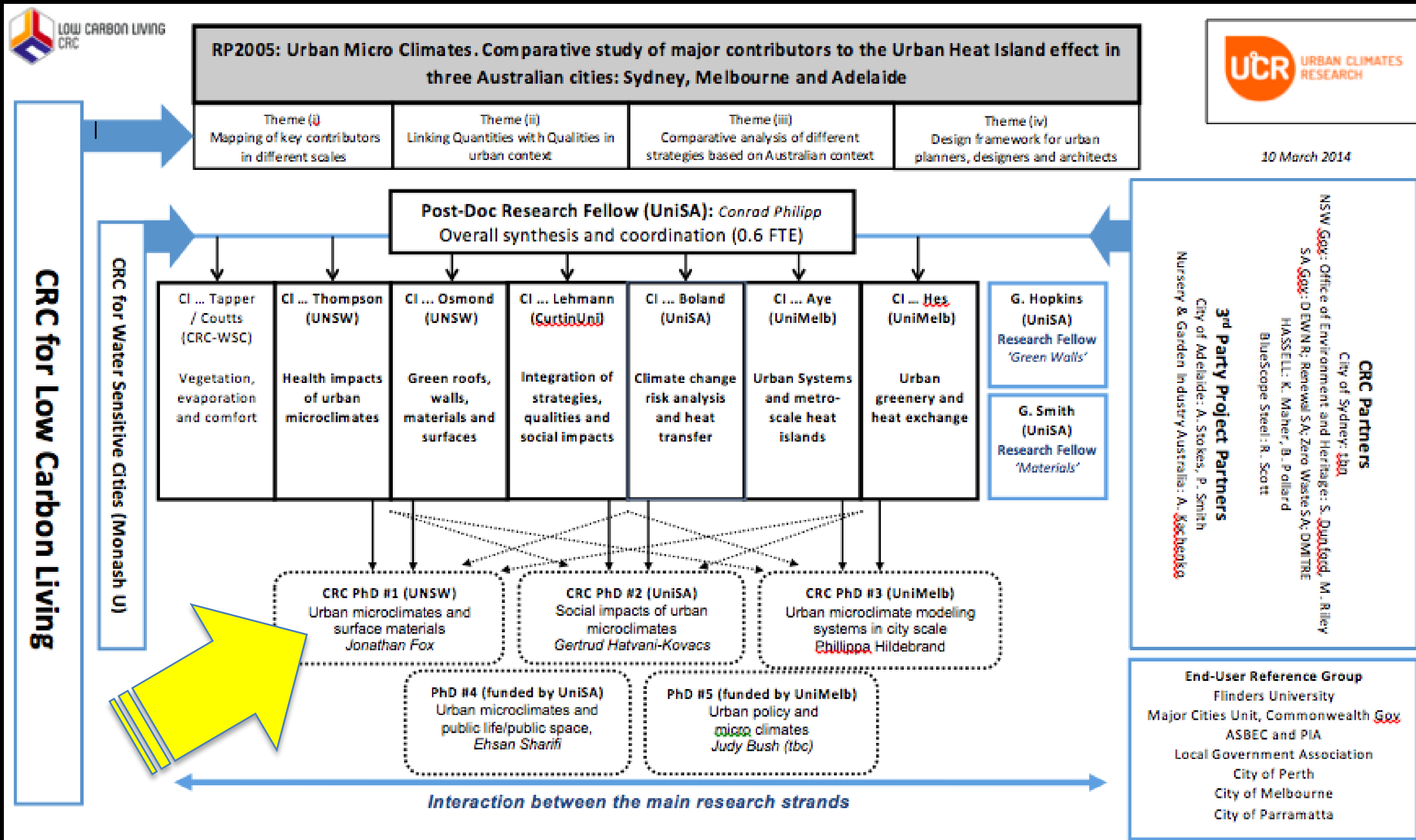
Relationship to RP2005 Institutions



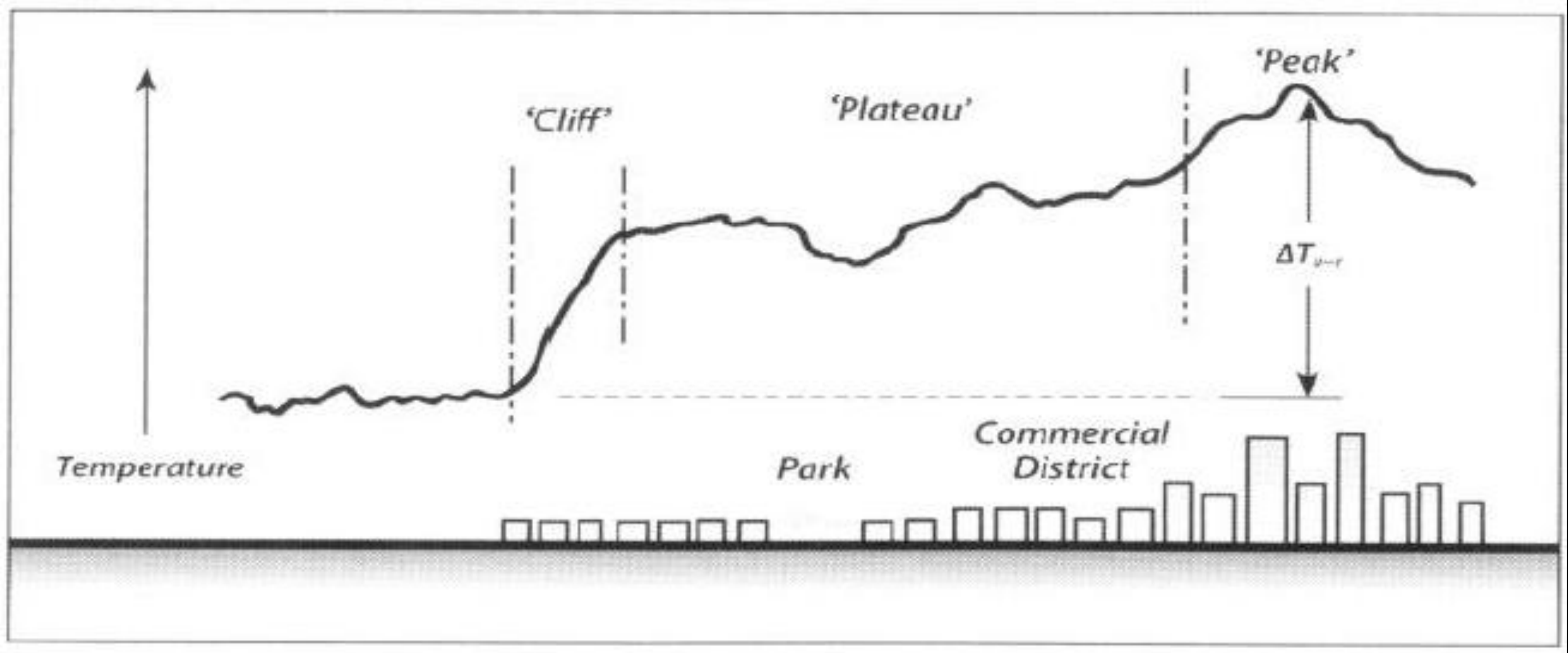
Research Context – Urbanisation

- More that 50% of global population now live in cities
- By 2050 urban dwellers will account for 89% of developed and 64% of less developed regions
- By 2050 in excess of 90% of Australia will be urban
- Urban areas are expected to absorb *all* the population growth over the next four decades + rural migration
- In 1970 only 2 “megacities”. By 2027 there will be 37

Source: UN-DESA (2012) World Urbanization Prospects 2011 Revision

Research Context – Cities and Heat

- Cities are typically hotter than their natural surroundings – **Urban Heat Island** (UHI) effect – nocturnal T_{air} differences up to 12°C



Source: Erell, Pearlmutter and Williamson 2011

Research Context – Cities and Heat

- **Surface** Heat Island (SHI) effect – hotter urban surfaces typically observed via satellite or aerial nadir remote sensors

Source: Michael Mobbs 2012 The Sustainable Communities Plan (thermal image of Chippendale recorded at 1:00 a.m. and 6:00 a.m. on 6 February 2009)

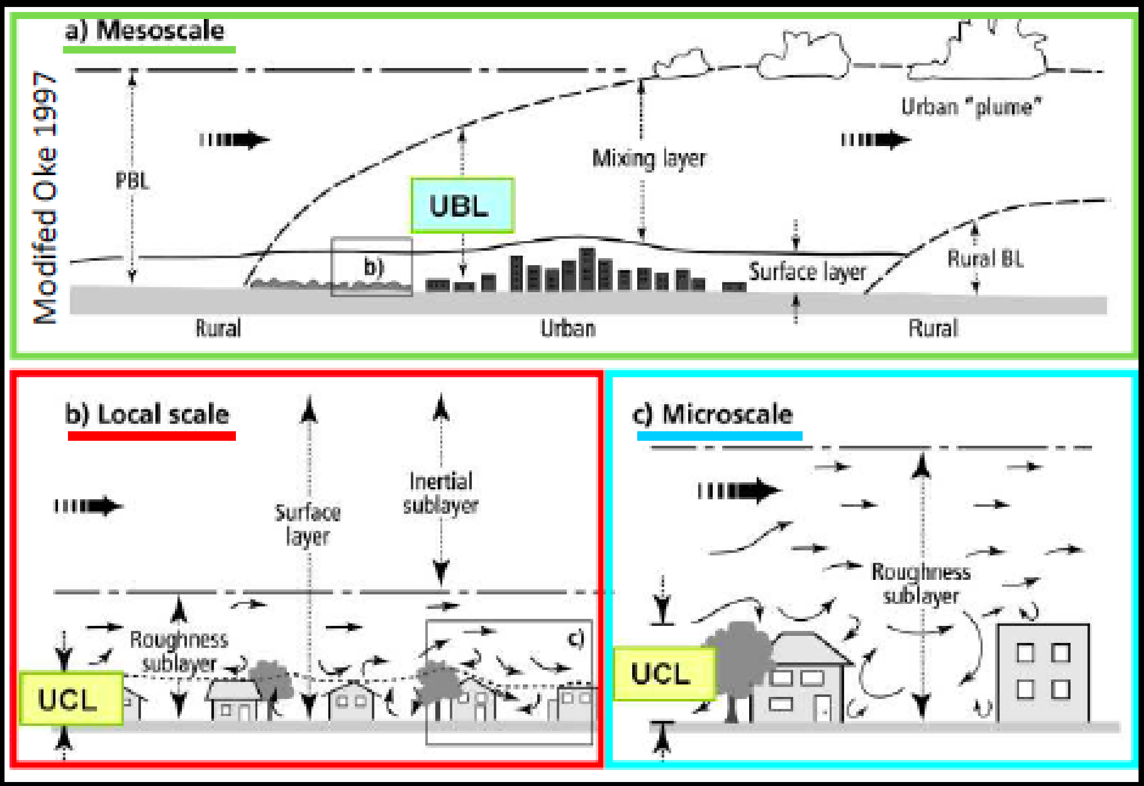
Cities and Heat - Implications

- Elevated urban heat increases vulnerability of urban inhabitants and infrastructure to climate change hazards – more frequent, longer and extreme heat waves
- Cooler cities endowed with an “adaptive surplus”
- Heat stress mortality – estimated 1100 deaths/year in AU
- Energy use in buildings – more cooling energy required
- Human thermal comfort – impacts for outdoor amenity and health

Source: Cleugh and Grimmond 2012; Grimmond et al 2010; Rosenzweig et al 2011; Saman et al 2013

Scales of Urban Climate

Cities modify atmospheric variables which define the climate at multiple spatial and temporal scales

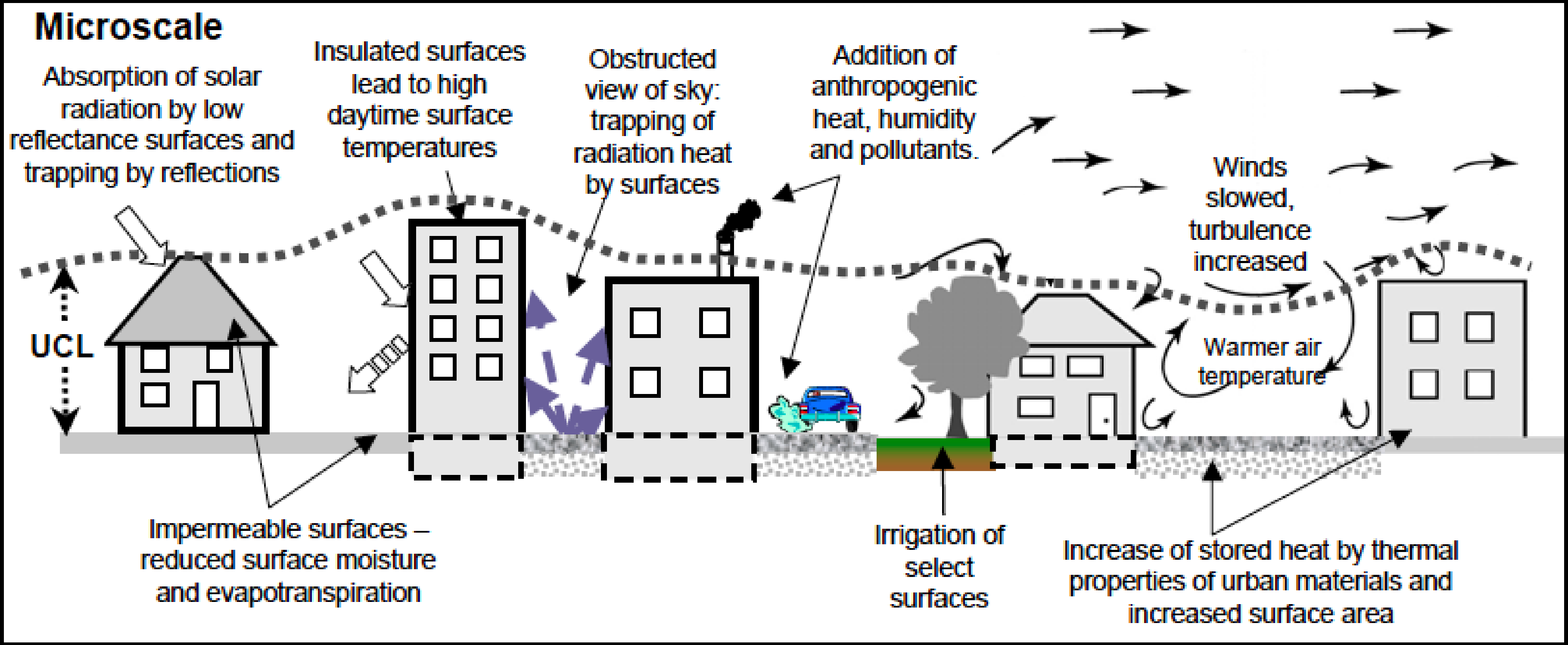


Source: Cleugh and Grimmond 2012

	Spatial Dimensions		
Units	Width (m)	Length (m)	Scale
Building	10	10	Micro
Canyon	30	300	
Block	500	500	Local
Land-use zone or neighbourhood	5000	5000	
City	> 25,000	> 25,000	Meso

Physical Basis for Urban Effects

Cities alter the *physical properties* of surfaces which in turn modify the fundamental *energy exchanges* that determine climate



Source: Voogt J, How Researchers Measure Urban Heat Islands - US EPA

Physical Basis for Urban Effects

"From a climatological perspective the surface is critically important"

Source: Voogt and Oke 1997, 1117

SURFACE ENERGY BALANCE

energy input = energy output + Δstored energy

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A$$

Source: Oke 1987

Urban *structure, cover and fabric* regulate the energy, moisture and momentum exchanges that determine urban climates

Source: Oke 2006

Hypotheses

If microclimate is dominated by the structure, cover and fabric of the city *then* microclimate may be intentionally modified by changes to urban form and materials

↓

If surface properties regulate the partitioning, magnitude and timing of energy exchanges between the atmosphere and discrete urban surfaces *then* intentional changes to surface properties will modify (the SEB which determines) microclimate

The Problem

Individual buildings are the "fundamental units to create the urban climate" (Cleugh and Grimmond 2012, 52)

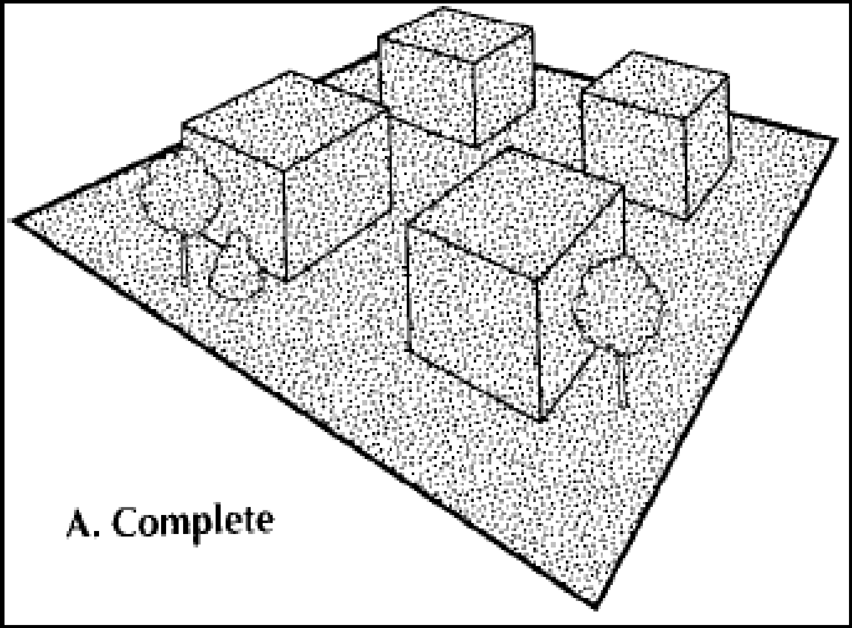
Generate dynamic microenvironments distinct from the aggregate climates represented in LCZs – *multiple UHIs*

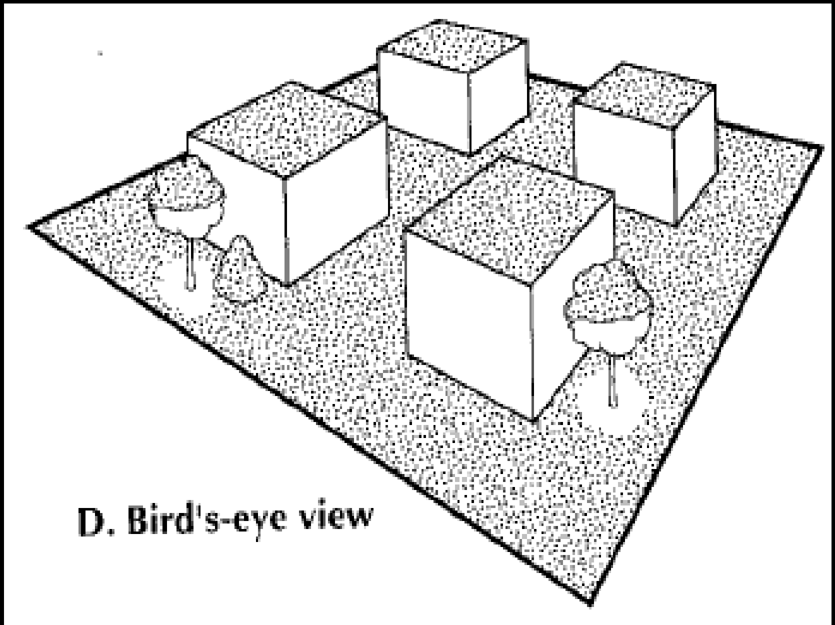
BUT Significant SEB processes – *the role of vertical surfaces in radiative and thermal partitioning* – remain UNRESOLVED, UNOBSERVED, UNEXPLORED and UNAPPLIED at the architectural scale

(Source: Arnfield 2003; Oke 2006; Voogt and Oke 2003)

Gaps in Application

Active VERTICAL surfaces are *underrepresented* – complex and heterogeneous (Soux, Voogt and Oke 2004)

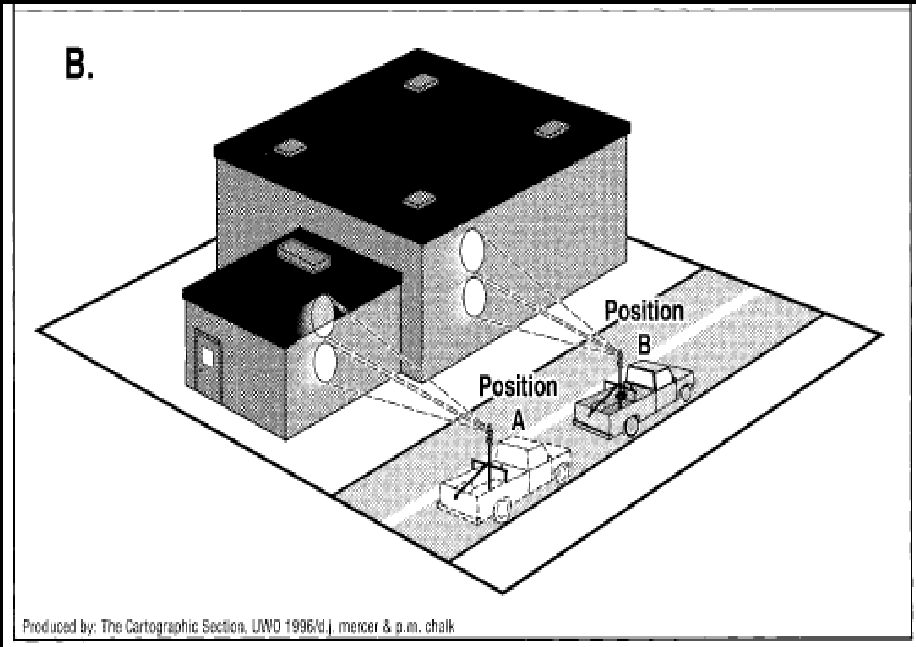




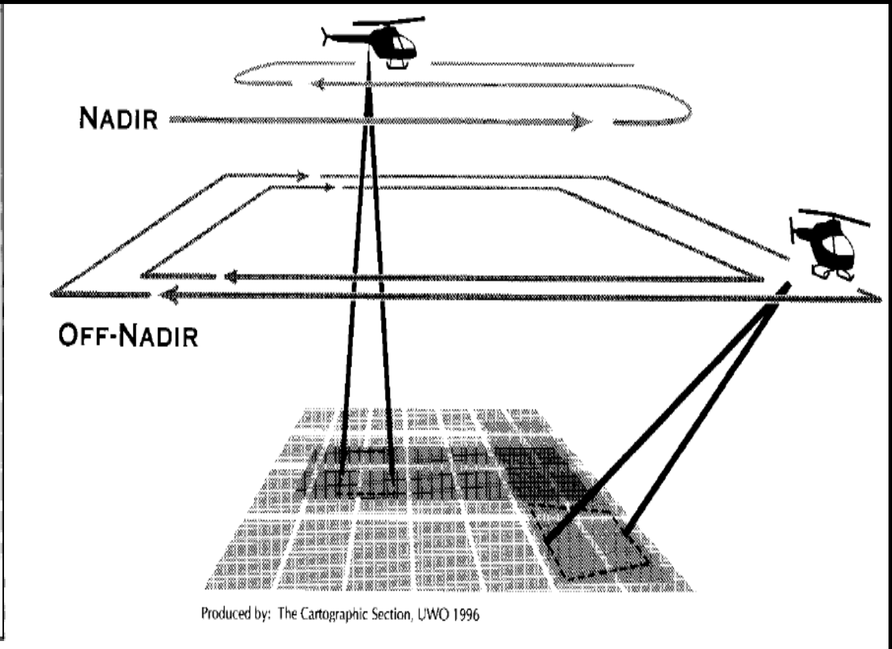
(Source: Voogt and Oke 1997)

Gaps in Observation

Active VERTICAL surfaces are *unobserved* by conventional nadir-sensing remote technologies (Voogt and Oke 2003)



(Source: Voogt and Oke 1998a)



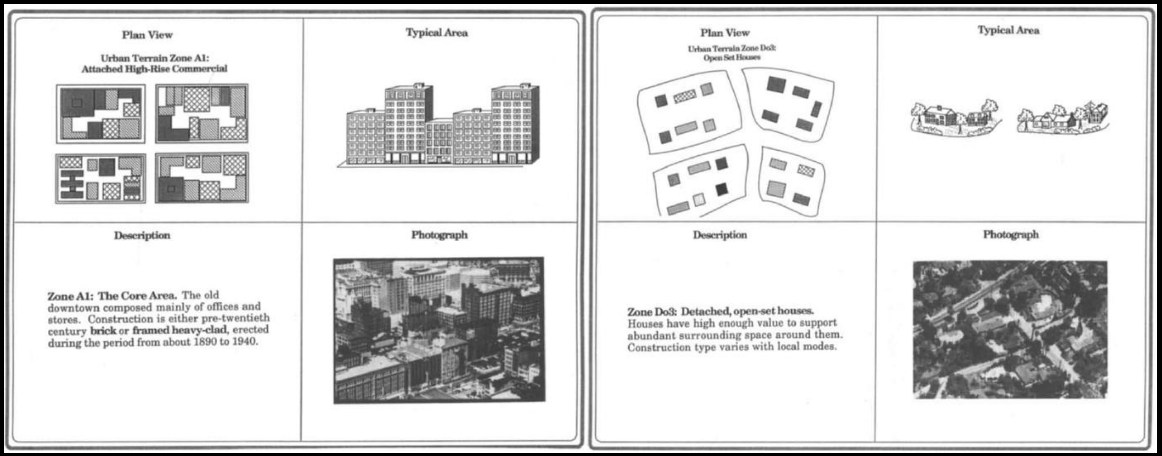
(Source: Voogt and Oke 1998b)

Significance of Vertical Surfaces

Aerial fraction of the complete urban surface: the *active surface area* is 3 x the plan area for urban cores

(Source: Roth, Oke and Emery 1989)

Proportion of walls relative to total 3-D surface area in contact with the atmosphere: walls in urban core account for 46.7% of total surface area (Source: Ellefsen 1990/91)

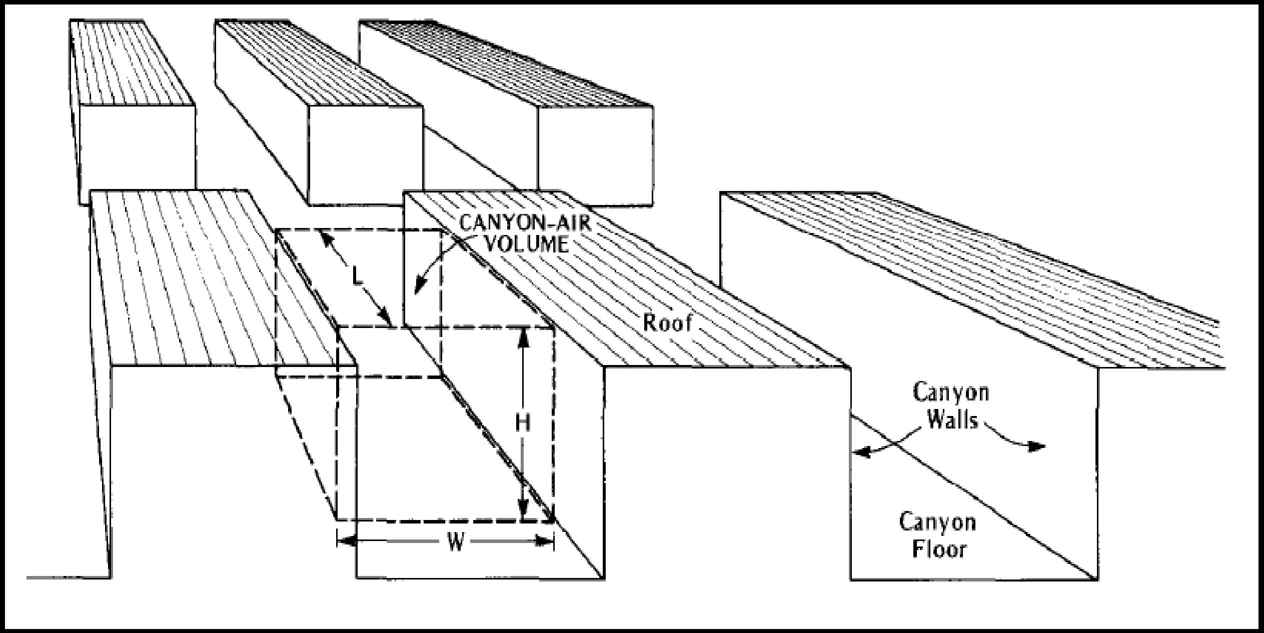


(Source: Ellefsen 1990/91)

Significance of Vertical Surfaces

Dry wall surfaces partition around 70-80% of their daytime energy into *sensible heat* and store 20-30%

Most active canyon surface changes with time – peak Q*

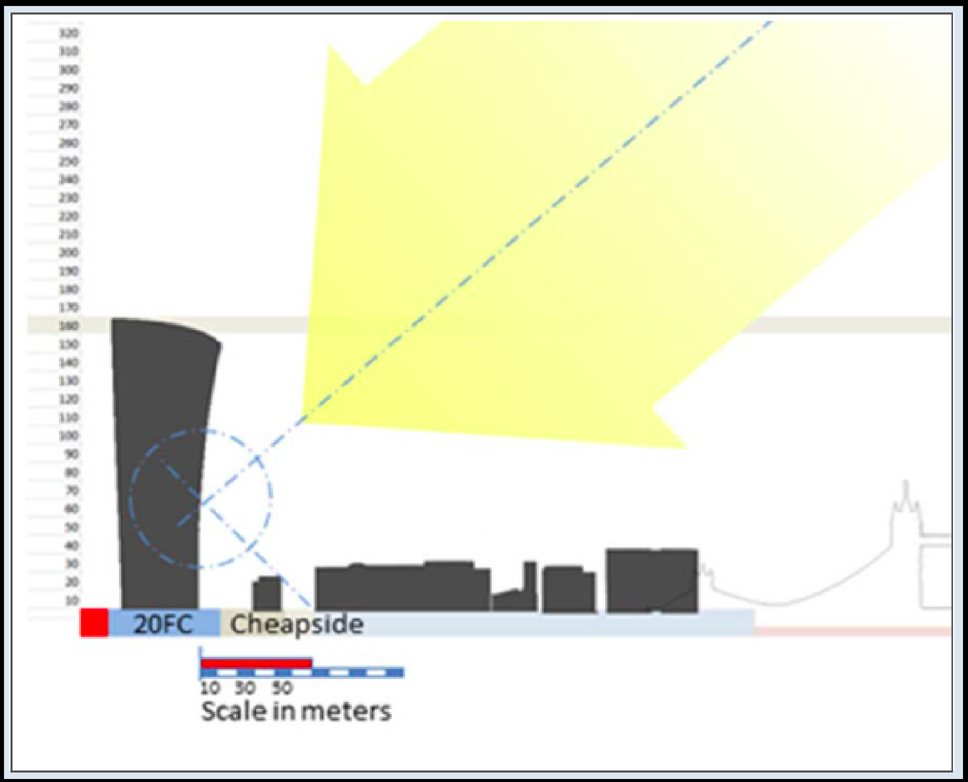


(Source: Nunez and Oke 1977)

Significance of Vertical Surfaces

"...reflected radiation caused parts of a nearby parked car to melt, peeled paint and cracked paving..." (Futcher and Mills 2013)

20 Fenchurch Street, London. Midday September 2013



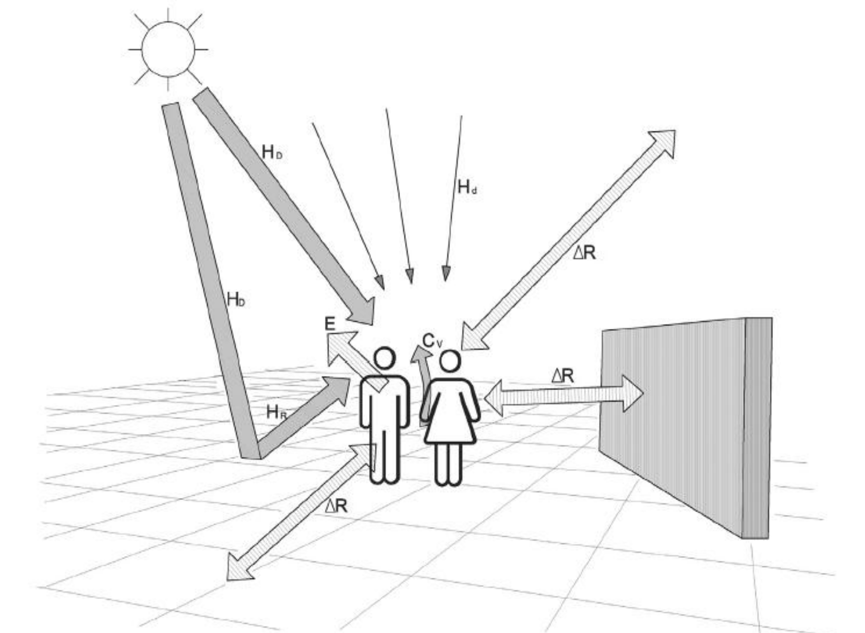
(Source: Futcher and Mills 2013)

Surface Material	Thermal property and behaviour
Glass facade	**Albedo** – typically low but *specularly reflective* at high angles of incidence (albedo: 0.08 – 0.52)

(Source: The Guardian, 5 September 2013)

Significance of Vertical Surfaces

Outdoor thermal comfort. Green facades



H_D : Direct solar radiation
H_d : Diffuse solar radiation
H_R : Reflected solar radiation
ΔR : Longwave radiation exchange with surrounding surfaces
C_V : Convection with air
E : Evaporation

Fig. 1. Diagram of the heat flow around people in an open space.

(Source: Gomez et al 2013)

(Source: Kontoleon and Eumorfopoulou 2010)

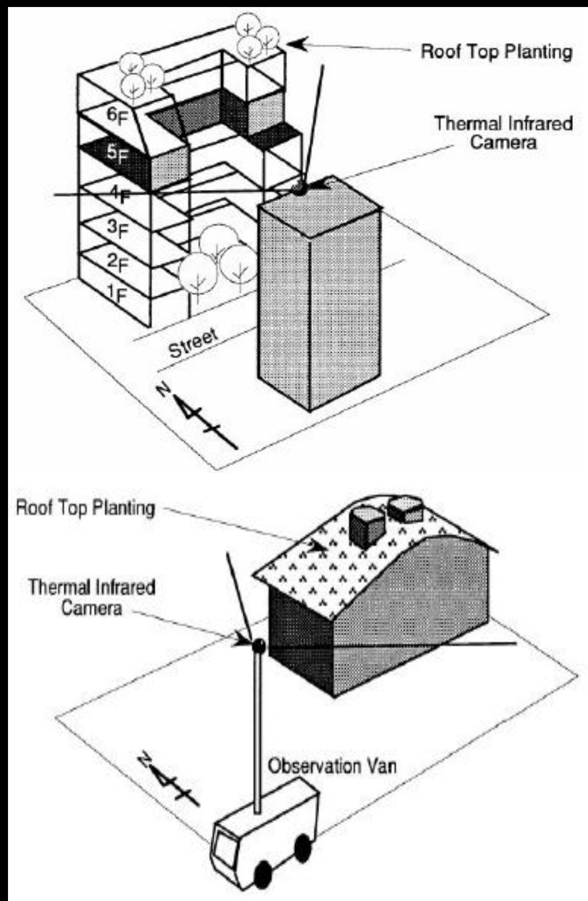
Vertical Surface Observations

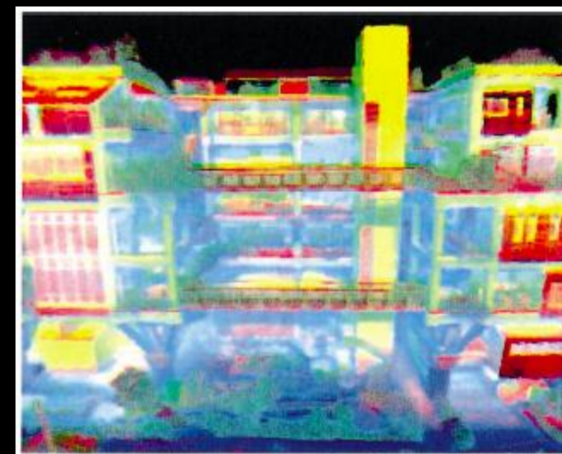
Lessons and Lacunae

Authors/date	Study purpose	Equipment	Lessons
Hoyana, Asano and Kanamaru 1999	Sensible heat flux from individual building facets	Pole-mounted and hand-held TIR camera	Façade classification; TST technique; observation times
Chudnovsky, Ben-Dor and Saaroni 2004	Temporal and spatial thermal behaviour of urban surfaces	Roof-mounted thermal video camera	Recording duration; observation times; non-transferability
Sham, Lo and Memon 2012; 2013	Nocturnal sensible heat transfer from walls	Laboratory and roof-mounted TIR camera	CSTM technique; issues with glass; emissivity and distance errors
Meier, Scherer and Richters 2010; Christen, Meier and Scherer 2012	Persistence effects on long-wave emissions; high-frequency surface temperature variations	Oblique-viewing, roof mounted TIR camera	GIS platform for analysis; calibrations; observation times for sensible/storage fluxes

Vertical Surface Observations

Lessons and Lacunae





(Source: Hoyano et al 1999)

Research Question(s)

What are the predictive relations between façade design and outdoor microclimate at the architectural scale?

Are there systematic patterns of surface temperature related to the structure, cover and fabric of building facades?

What are the modifiable surface properties and configurations of facades which causally and consistently dominate microclimate under typical climate conditions in characteristic urban and suburban locations in SAM?

Subordinate Research Domains

The scientific properties of materials and thermal characteristics

Observation and communication of architectural climatology

Classification, Definitions and Typology

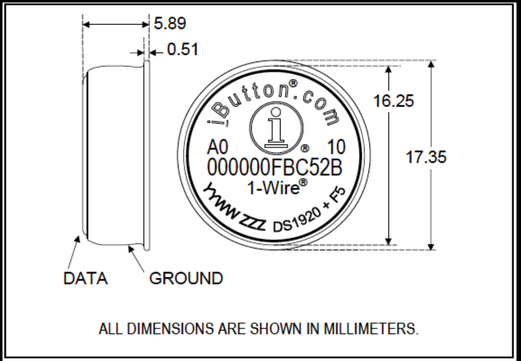
Research Variables

Dependent variables	*Equipment*	*Independent variables*		*Equipment or source*	*SEB term*	*Intervening variables*
Vertical surface temperature	TIR camera – FLIR B335	Vertical surface materiality	Albedo	Pyranometer(s) albedometer, net radiometer	Short-wave (solar) radiation	Canyon H/W ratio
Screen-height air temperature	Shielded digital logger		Emissivity	Blackbody temp., Stefan-Boltzmann eq. and tables	Long-wave radiation; Sensible (radiative) heat flux (Q_H)	Canyon sky-view factor (SVF)
Mean radiant temperature	38mm flat-grey globe thermometer		Thermal conductivity[1]	Heat flux plate(s); material tables; CSTM[8]	Storage heat flux (ΔQ_S)	Footpath and street albedo
			Density[1]			
			Specific heat[1]			
		Façade orientation		Cadastral		
		Vegetation	System[2]	Digital camera, elevation models and species data; in-situ obs.	Latent heat flux (Q_E)	Street trees (height and spacing)
			Percentage Wall Cover[3]			
			Depth[4]			Canyon vegetated fraction
			Species; plant parameters[5]			
		Air velocity and direction		Anemometer	Sensible (convective) heat flux (Q_H)	Point-source heat emissions
		Solar geometry		Solar charts		
		Façade parameters	Facade height[6]	Digital camera, elevation models and digital 3-D models		
			Facade length[6]			
			Window/wall area ratio			
			Wall type(s)[7]			
		Relative humidity		Digital logger		
		Street surface temperature		IR thermopile array		

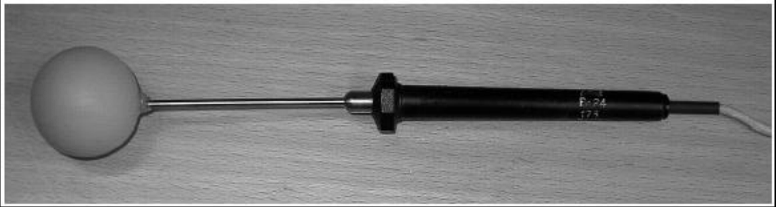
Data Acquisition

Dependent variables	*Equipment*
Vertical surface temperature	TIR camera – FLIR B335
Screen-height air temperature	Shielded digital logger
Mean radiant temperature	38mm flat-grey globe thermometer

(Source: FLIR)



(Source: Maxim Integrated Products 2014)



(Source: Thorsson et al 2007)

Experimental Design

Experimental Design
Data Collection - Methods and Protocols
Calibration and Testing
Data Analysis - Software Platforms
Façade Classification System
Pilot Study
Review of Experimental Design
Final Site Selection

Climatology of Facades

Thermophysical Properties	Climate Variables

Relations between variables

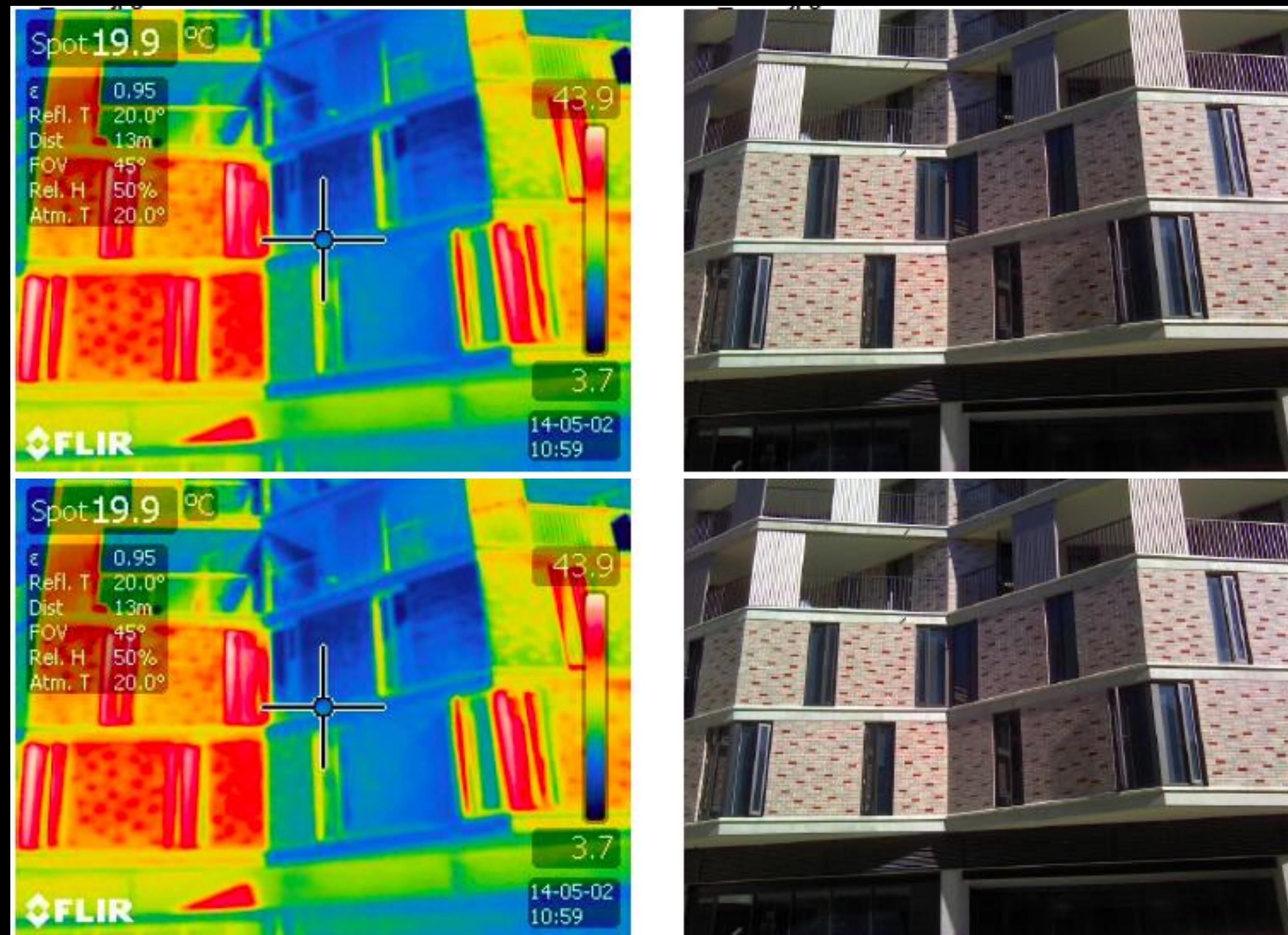
Statistical modeling, spatial unit and data collection	GIS data management, visualisation and analysis

Vertical Surface Thermal Typology (VeSTT)

Input: TIR image + meteorological data	**Output**: thermal classification

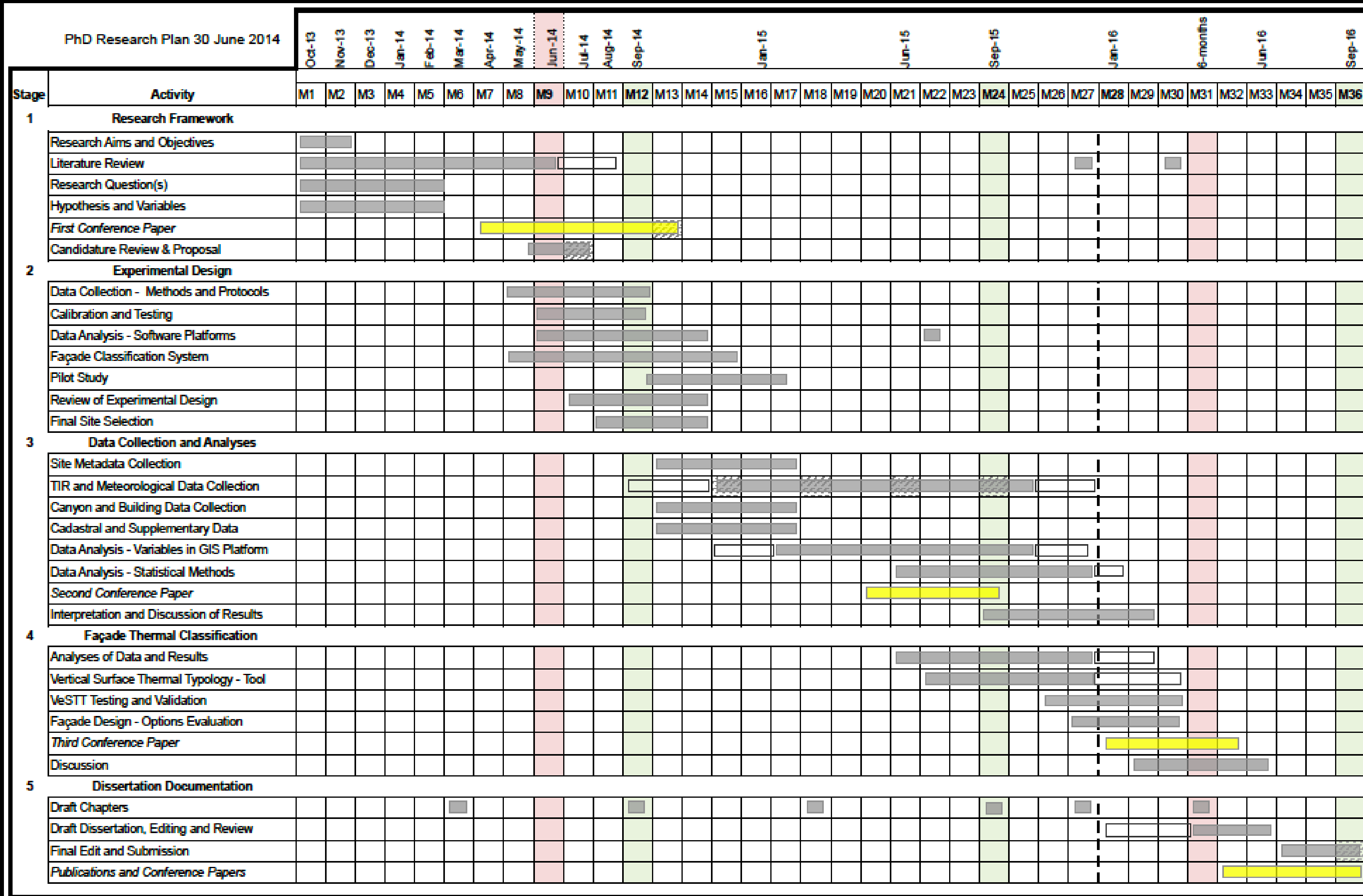
Pilot Study

(Source: BatesSmart Pty Ltd)



(Source: Jonathan Fox)

Research Completion Plan



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Thank You!

References

Arnfield A. J., 2003, “Two Decades Of Urban Climate Research: A Review Of Turbulence, Exchanges Of Energy And Water, And The Urban Heat Island”, International Journal of Climatology 23:1-26.

Cleugh H.A. and Grimmond C.S.B., 2012, “Urban Climates and Global Climate Change”, in Henderson–Sellers A. & Mc Guffie K. (eds.), The Future of the World’s Climate, Elsevier, Chapter 3: 47-76.

Ellefsen R., 1990/91, “Mapping and measuring buildings in the canopy boundary layer in ten U.S. cities”, Energy and Buildings 16(3-4): 1025-1049.

Erell E., D. Pearlmutter and Williamson T., 2011, Urban Microclimate - Designing the Spaces Between Buildings, London, Earthscan.

Gómez F., Cueva A.P., Valcuende M. and Matzarakis A., 2013, ”Research on ecological design to enhance comfort in open spaces of a city (Valencia, Spain). Utility of the physiological equivalent temperature (PET)”, Ecological Engineering 57:27– 39.

Grimmond et al, 2010, “Climate and More Sustainable Cities: Climate Information for Improved Planning and Management of Cities (Producers/Capabilities Perspective).” Procedia Environmental Sciences 1: 247-274.

Futcher K and Mills G., 2013, “No building is an energy island: the cautionary tale of the Fryscraper”, IAUC Urban Climate News 49.

Hoyano A., Asano K., and Kanamaru T., 1999, “Analysis of the sensible heat flux from the exterior surface of buildings using time sequential thermography”, Atmospheric Environment 33:3941-3951.

Kontoleon, K.J. and E.A. Eumorfopoulou. 2010. “The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone”, Building and Environment 45 (5): 1287-1303.

Mobbs M., 2012, The sustainable communities plan, from: http://theplan.sustainablehouse.com.au.

Nunez M. and Oke T. R., 1976, “Long-wave radiative flux divergence and nocturnal cooling of the urban atmosphere”, Boundary-Layer Meteorology 10: 121-135.

Oke T.R., 1984, “Towards a prescription for the greater use of climatic principles in settlement planning”, Energy and Buildings 7:1–10.

Oke T.R., 1987, Boundary Layer Climates, 2nd edition, Methuen, London .

Oke T.R., 2006, “Towards a better scientific communication in urban climate”, Theoretical and Applied Climatology 84:179-190.

Rosenzweig C., Solecki B., Hammer S. and Mehrota S., 2011, “Climate Change and Cities”: First Assessment Report of the Urban Climate Change Research Network”, Cambridge University Press, Cambridge.

Roth M, Oke T.R. and Emery W.J., 1989, “Satellite-derived urban heat islands from three coastal cities and the utilization of such data”, Urban Climatology, International Journal of Remote Sensing 10(11): 1699-1720.

Thorsson S., Lindberg F., Eliasson I. and Holmer B., 2007, “Different methods for estimating the mean radiant temperature in an outdoor urban setting”, International Journal of Climatology 27:1983-1993.

Voogt J. A. and Oke T. R., 1997, "Complete Urban Surface Temperatures”, Journal of Applied Meteorology, 36: 1117-1132.

Voogt J. A. and Oke T. R., 1998a, “Radiometric Temperatures of Urban Canyon Walls Obtained from Vehicle Traverses”, Theoretical and Applied Climatology, 60:199–217.

Voogt J. A. and Oke T. R., 1998b, "Effects of urban surface geometry on remotely-sensed surface temperature”, International Journal of Remote Sensing 19(5): 895-920.

Voogt J. A. and Oke T. R., 2003, "Thermal remote sensing of urban climates", Remote Sensing of Environment 86(3): 370-384.

UNDESA (United Nations Department of Economic and Social Affairs), 2012, *World Urbanization Prospects: The 2011 Revision, Highlights*, United Nations, New York,