Planning for the Urban Heat Island in Adelaide:

Are urban heat island and urban cool island effects detrimental or are they beneficial?

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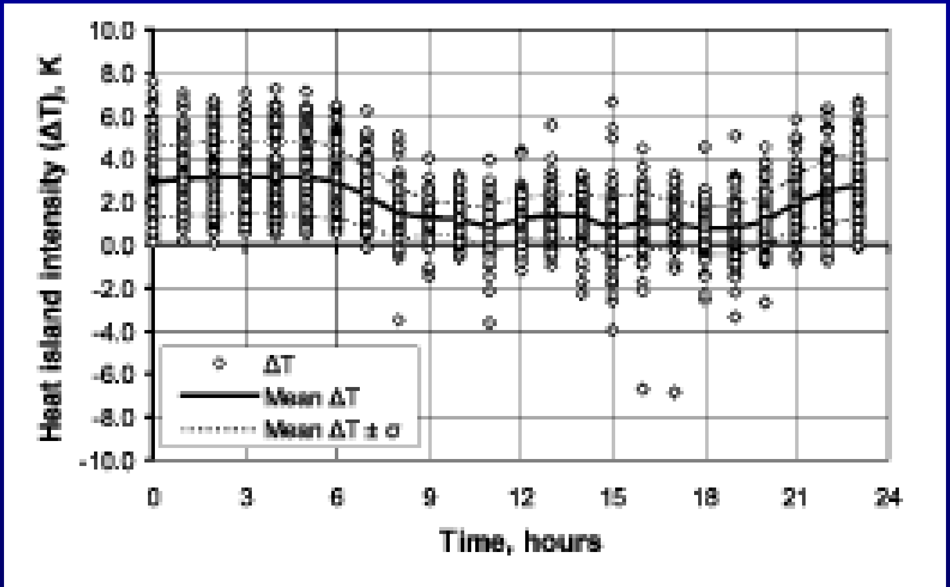
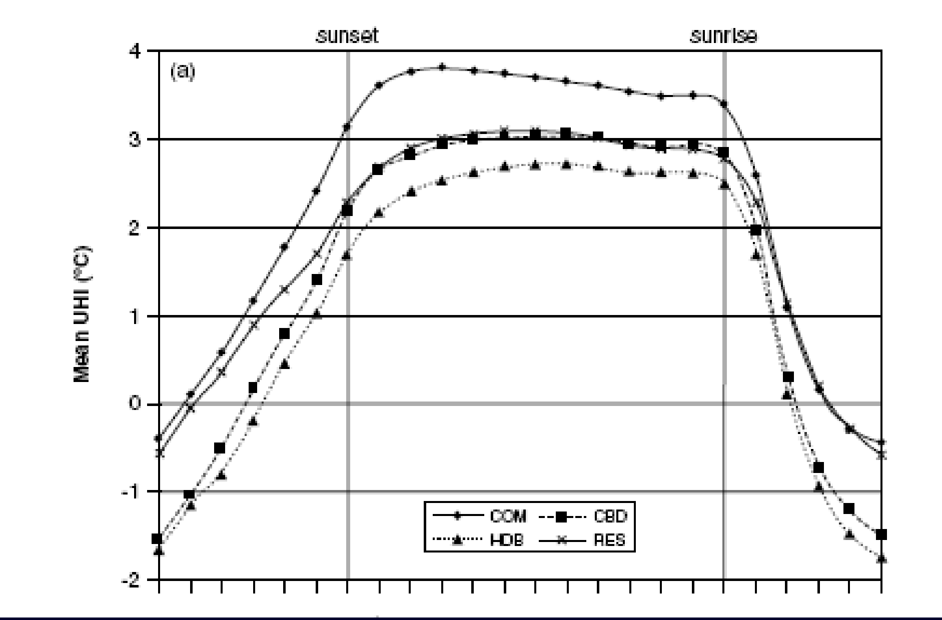
The urban microclimate
Difference between surrounding “rural” and urban areas caused by:

- Radiation exchange (solar, long wave)
- Wind
- Extent and type of vegetation
- Materials (thermal properties, water absorption)
- Anthropogenic heat release

What has been observed …….



London UHI Intensity Summer



Singapore UHI Intensity

Is there an “urban climate”?

1) 2 degrees
2) 4 degrees
3) 9 degrees
4) 12 degrees

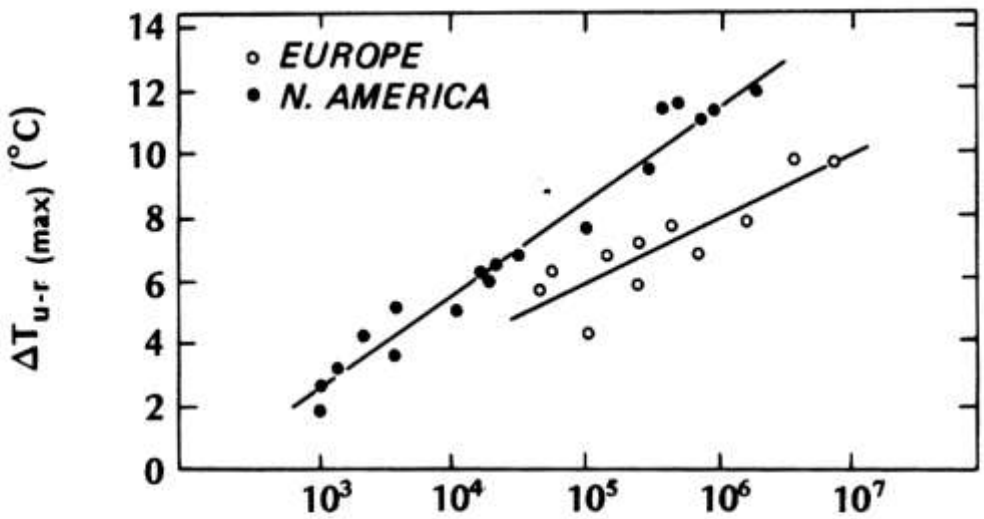
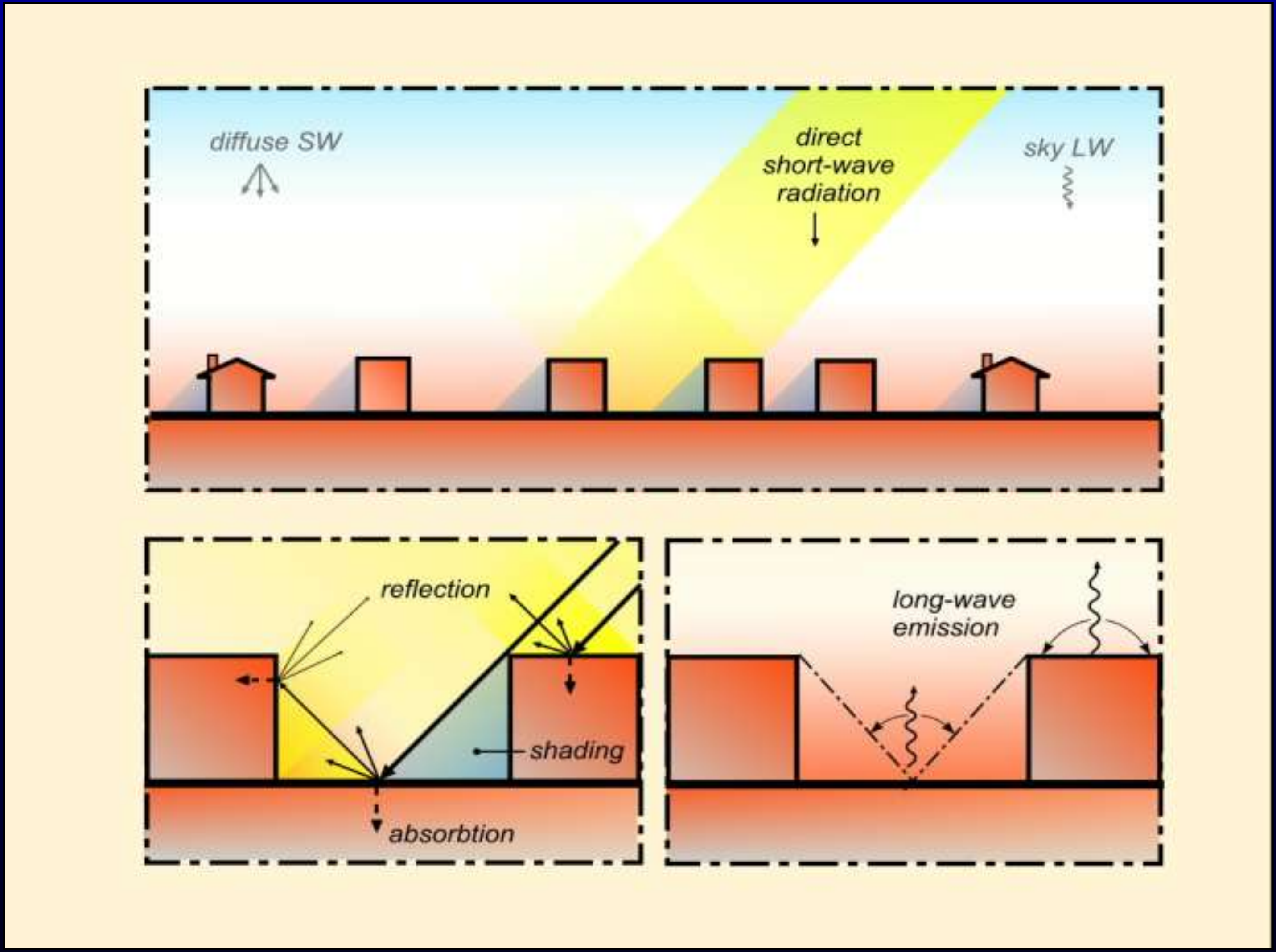


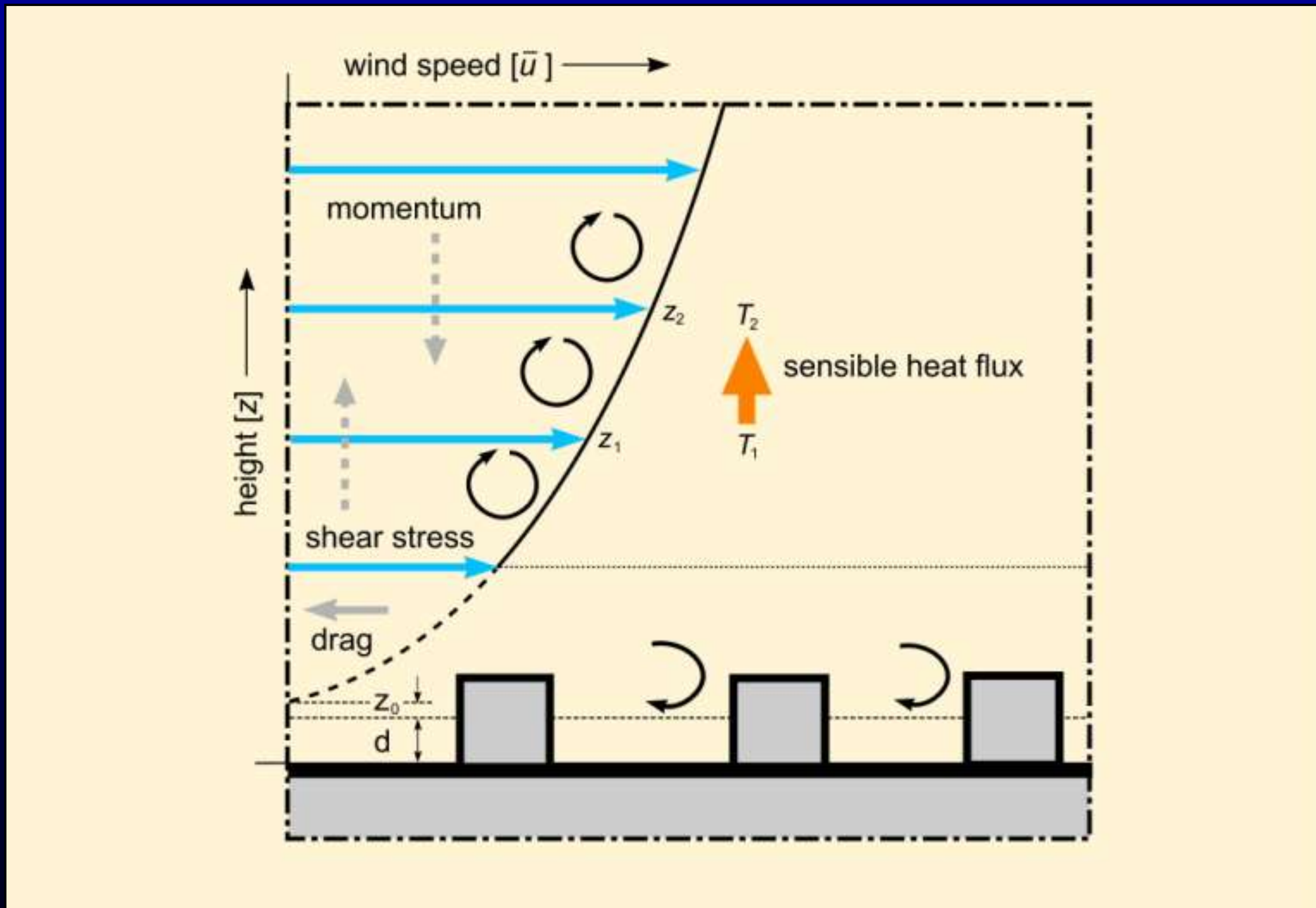
Figure 8.15 Relation between maximum observed heat island intensity ($\Delta T_{u-r(max)}$) and population (P) for North American and European settlements (modified after Oke, 1973).

Question : *What is the maximum temperature difference between the center of Adelaide and the surrounding areas?*

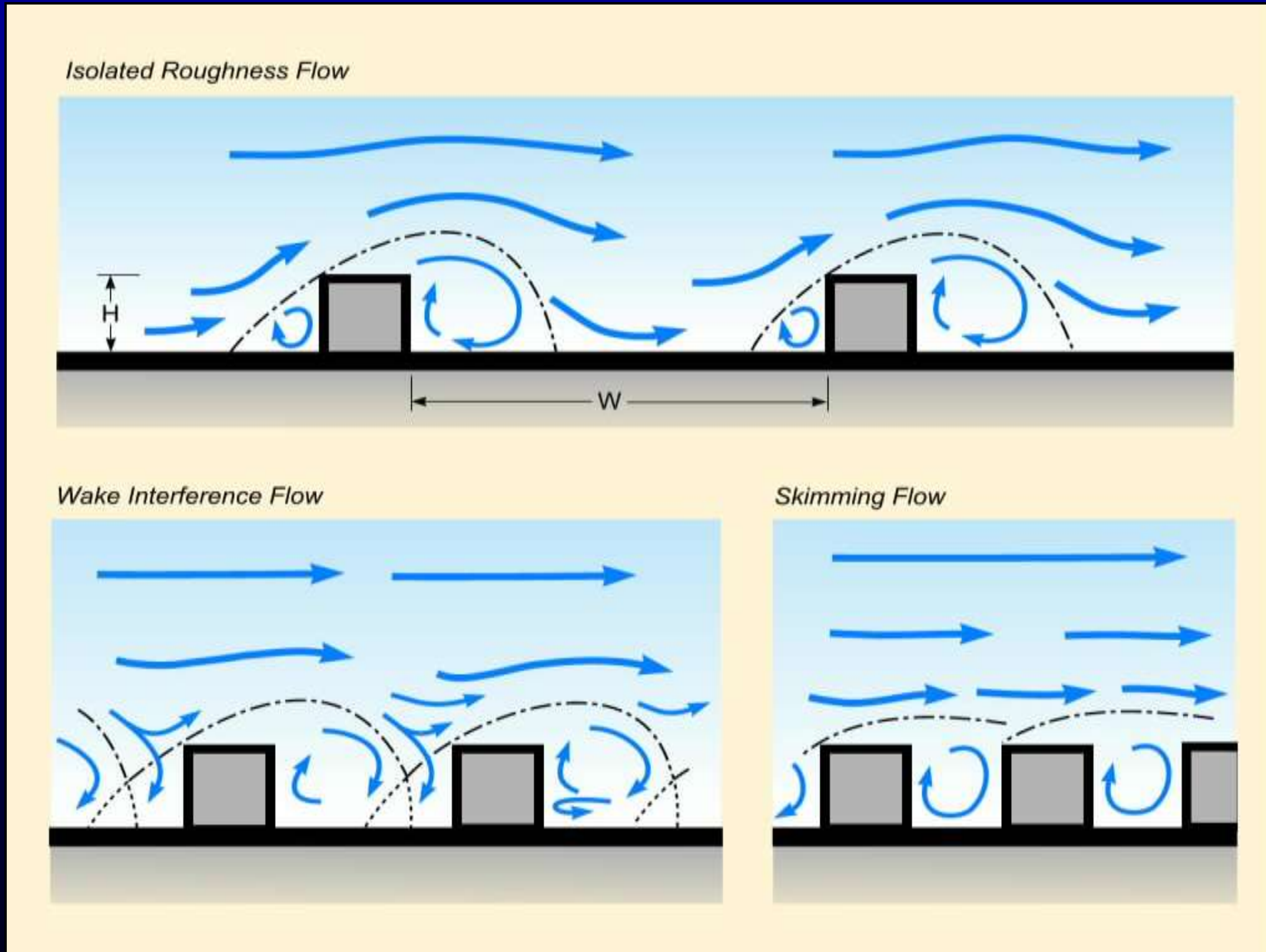
The radiation balance of the city



Turbulent heat exchange in the urban boundary layer



Air flow around groups of buildings



Anthropogenic heat

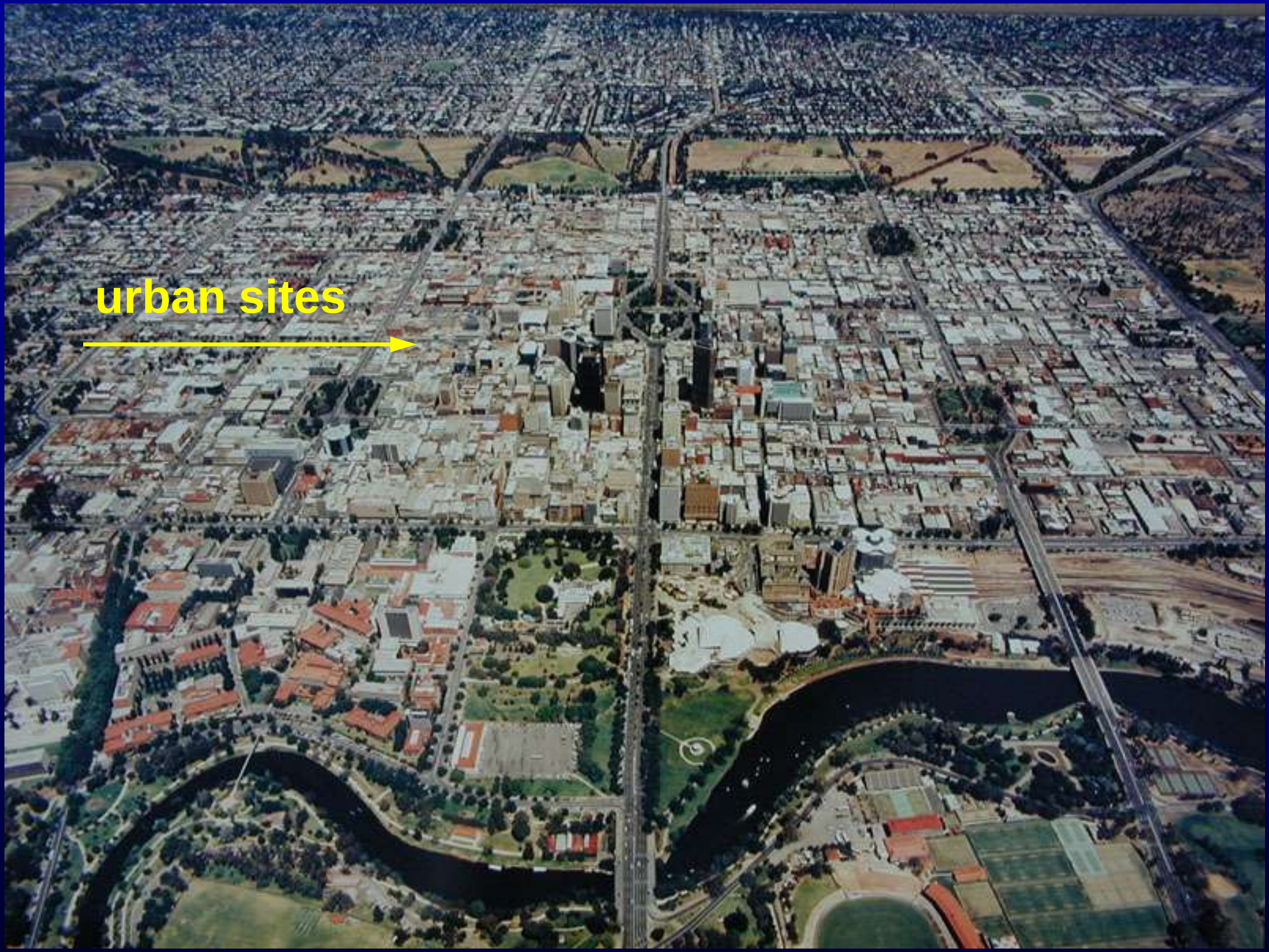
Table 8.1 Average anthropogenic heat release (Q_F) from selected urban areas

Urban area	Year	Period	Population ($\times 10^6$)	Population density (persons km^{-2})	Per capita energy use ($MJ \times 10^3$)	Q_F ($W\ m^{-2}$)	Q^* ($W\ m^{-2}$)
Manhattan (40°N)	1967	Year	1·7	28,810	128	117	93
		Summer				40	
		Winter				198	
Montréal (45°N)	1961	Year	1·1	14,102	221	99	52
		Summer				57	92
		Winter				153	13
Budapest (47°N)	1970	Year	1·3	11,500	118	43	46
		Summer				32	100
		Winter				51	−8
Sheffield (53°N)	1952	Year	0·5	10,420	58	19	56
West Berlin (52°N)	1967	Year	2·3	9,830	67	21	57
Vancouver (49°N)	1970	Year	0·6	5,360	112	19	57
		Summer				15	107
		Winter				23	6
Hong Kong (22°N)	1971	Year	3·9	3,730	34	4	~110
Singapore (1°N)	1972	Year	2·1	3,700	25	3	~110
Los Angeles (34°N)	1965–70	Year	7·0	2,000	331	21	108
Fairbanks (64°N)	1965–70	Year	0·03	810	740	19	18

Sources: Oke, 1974; Kalma and Byrne, 1975.

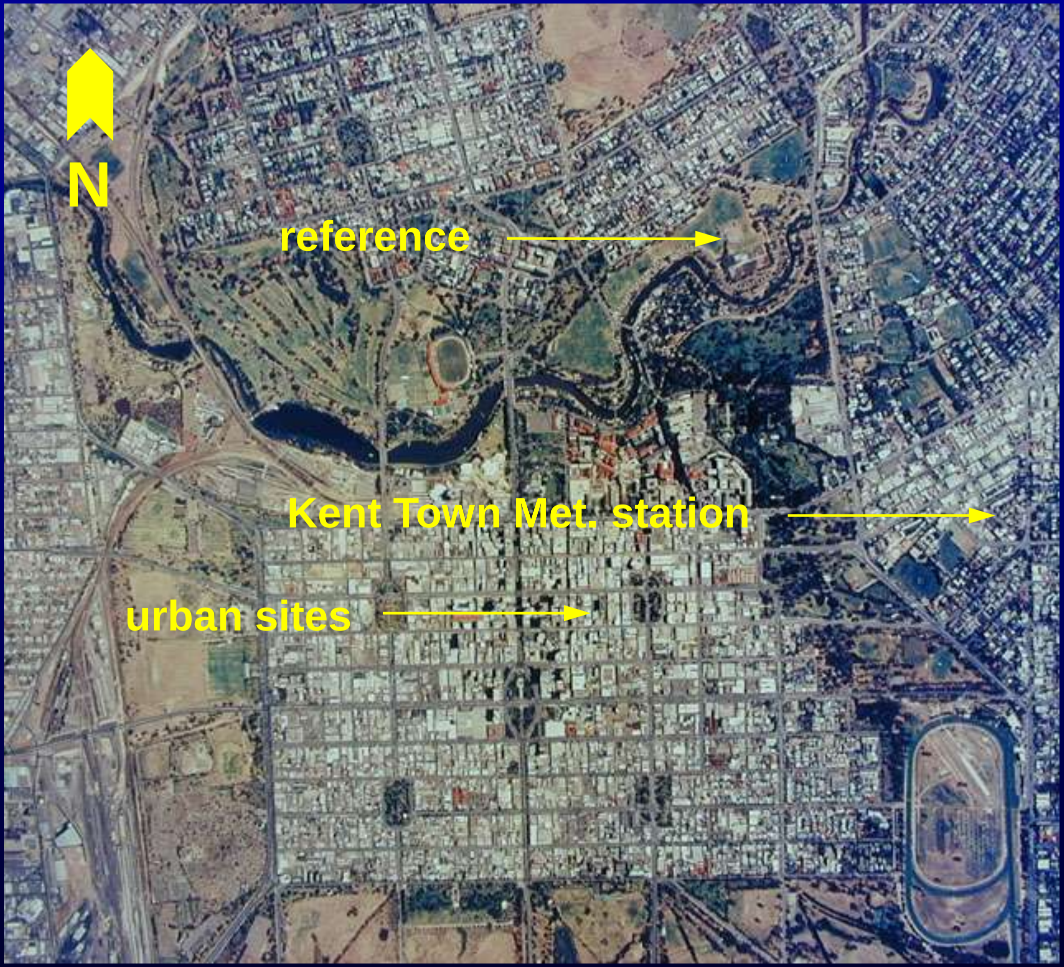
Question: *Where is heat ejected from buildings in a cold climate? In a hot climate?*

Study Location …



Aerial photo of central Adelaide from north

Location(s)

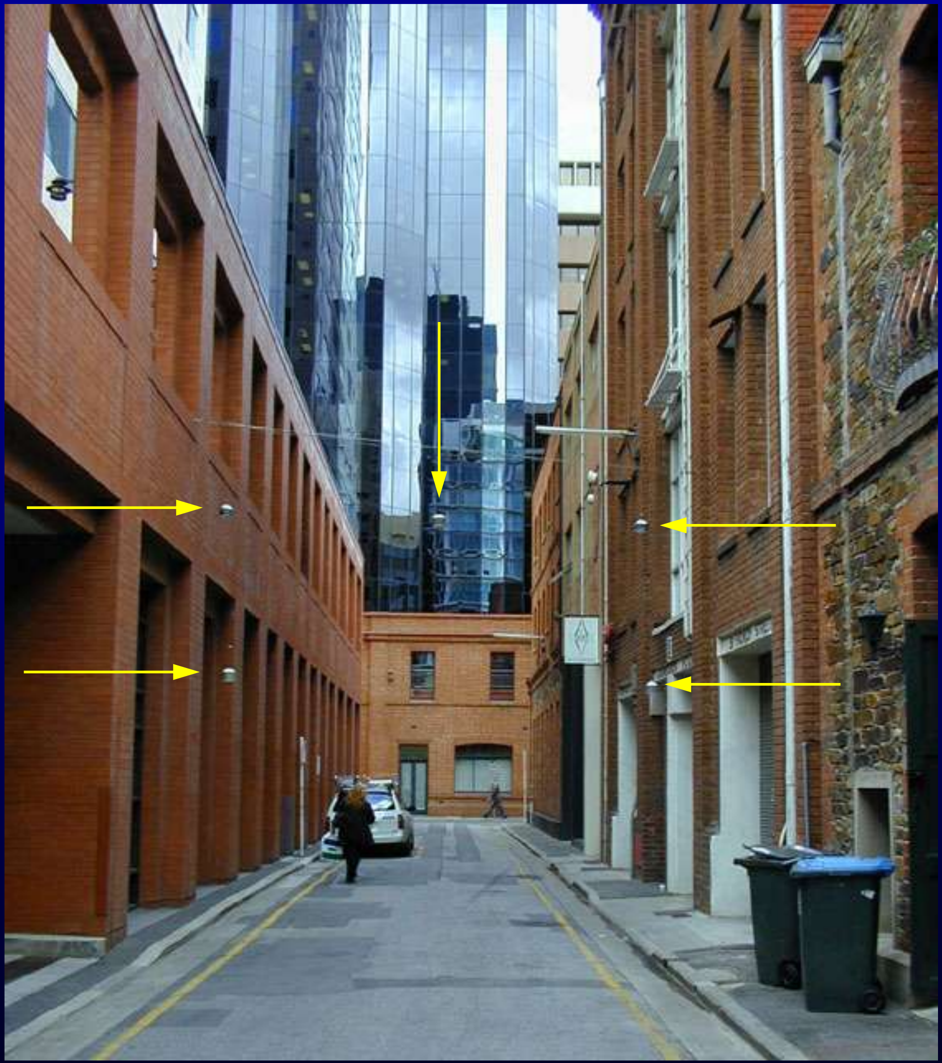


Aerial photo of Adelaide showing monitoring sites

Urban Site - North-south canyon

Chesser street, looking north

Urban Site - East-west canyon



French street, looking east

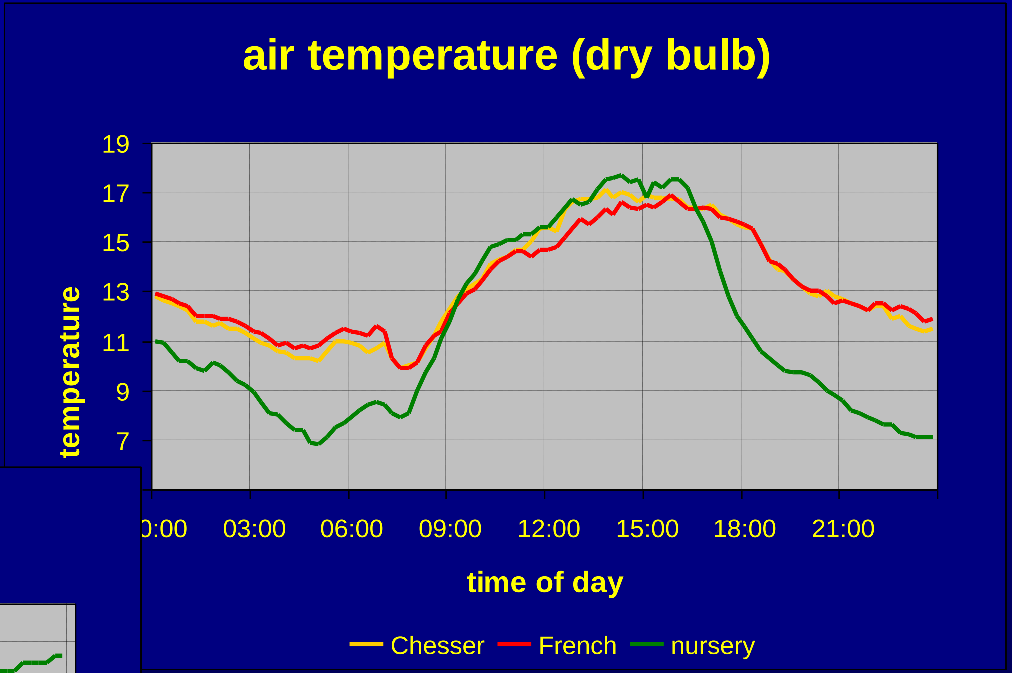
Reference site - 1

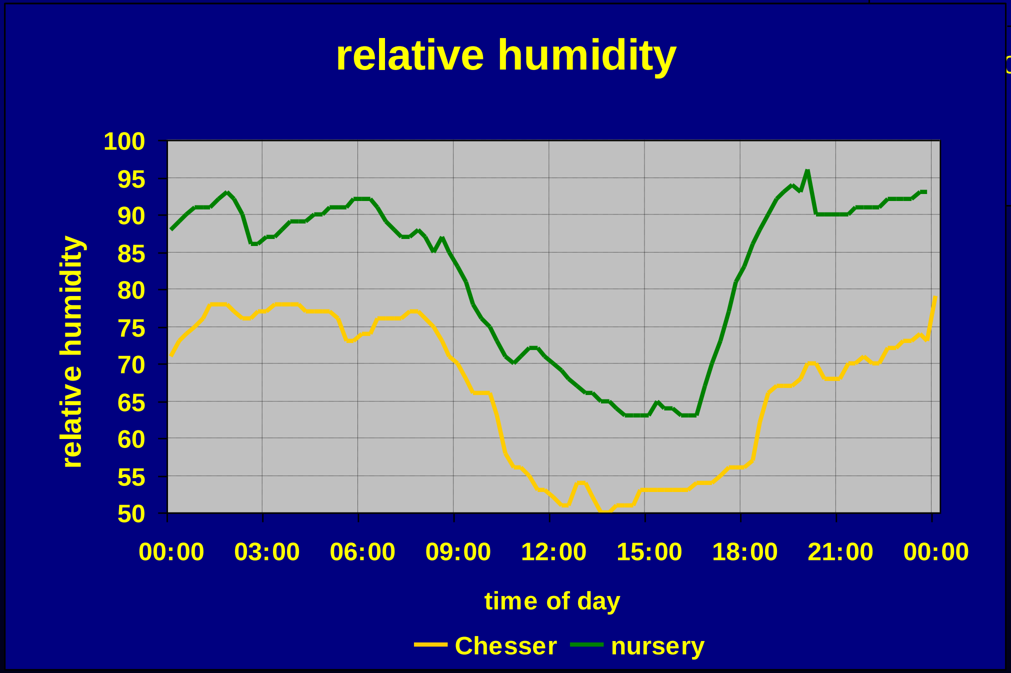
The reference site: Adelaide city nursery

Reference site - 2

The BoM weather station, Kent Town

… this is what we found (May 22, 2000)





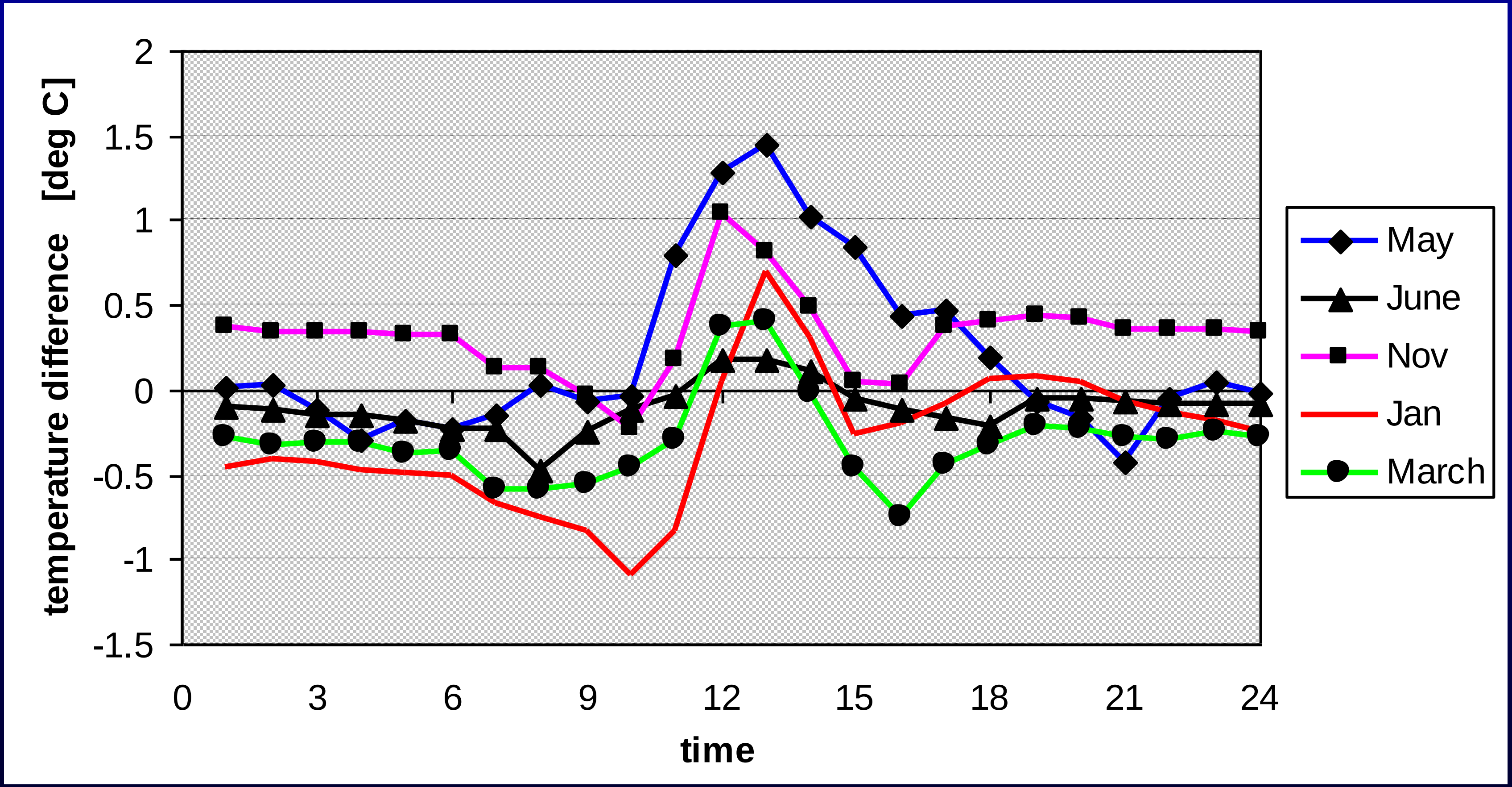
Seasonal variations in the intensity of the nocturnal urban heat island

month	no. of days	urban - Kent Town intensity of UHI [deg C]			no. of days	urban - nursery intensity of UHI [deg C]		
		min	avg	max		min	avg	max
May 2000	21	2.2	3.9	6.1	21	1.8	5.1	8.9
June 2000	30	1.3	3.6	6.7	30	1.4	4.8	8.7
November 2000	30	0.6	2.1	4.0	0			
January 2001	26	1.9	4.8	8.6	26	1.7	4.7	8.5
March 2001	27	1.3	3.4	6.6	27	1.2	4.9	9.4
ensemble	**134**	**0.6**	**3.5**	**8.6**	**104**	**1.2**	**4.8**	**9.4**

Seasonal variations in the intensity of the daytime urban cool island

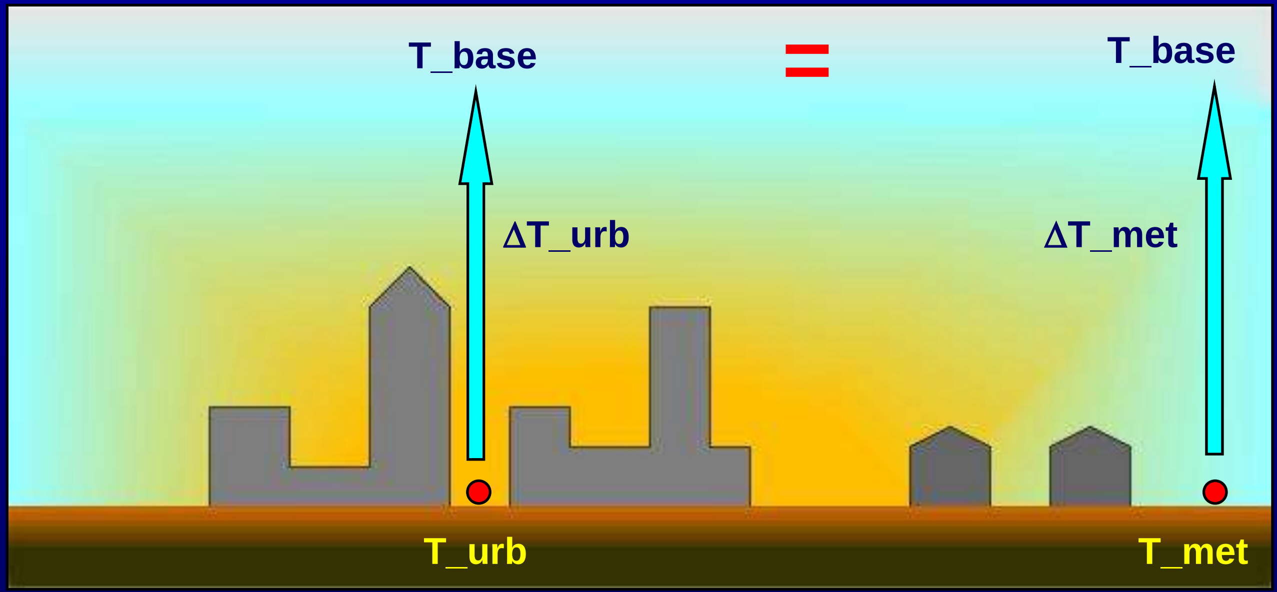
month	no. of days	urban - Kent Town intensity of UCI [deg C]			no. of days	urban - nursery intensity of UCI [deg C]		
		min	avg	max		min	avg	max
May 2000	21	-0.4	-1.1	-2.2	21	0.1	-0.9	-2.8
June 2000	30	0.7	-0.4	-1.6	30	0.7	0.1	-0.8
November 2000	30	-0.3	-1.8	-3.8	0			
January 2001	26	-1.5	-2.4	-3.8	26	-1.5	-3.4	-6.0
March 2001	27	0.6	-1.5	-3.4	27	0.5	-1.8	-3.1
ensemble	**134**	**0.7**	**-1.4**	**-3.8**	**104**	**0.7**	**-1.5**	**-6.0**

Differences in air temperature between north-south (Chesser St.) and east-west (French St.) urban canyons



Curves represent average hourly differentials for each month. Positive values indicate Chesser Street was warmer

Development of *CAT* prediction model



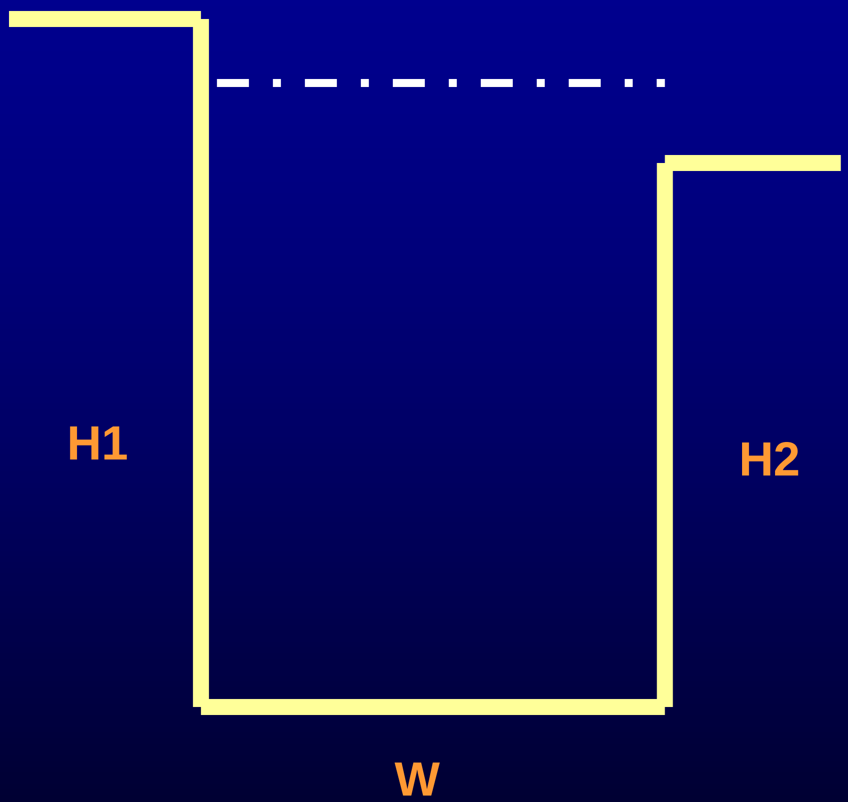
$$T_a(t)_{met} = T_{base}(t) + \Delta T\,(t)_m$$

$$T_a(t)_{urb} = T_{base}(t) + \Delta T\,(t)_{urb}$$

$$T_a(t)_{base} = T_{met}(t) - \Delta T\,(t)_{met}$$

$$T_a(t)_{urb} = T_{base}(t) + \Delta T\,(t)_{urb}$$

The urban street canyon



The basic unit

A semi infinite canyon, defined by its 2-D section: width (W) and height of two sides (H1 and H2).

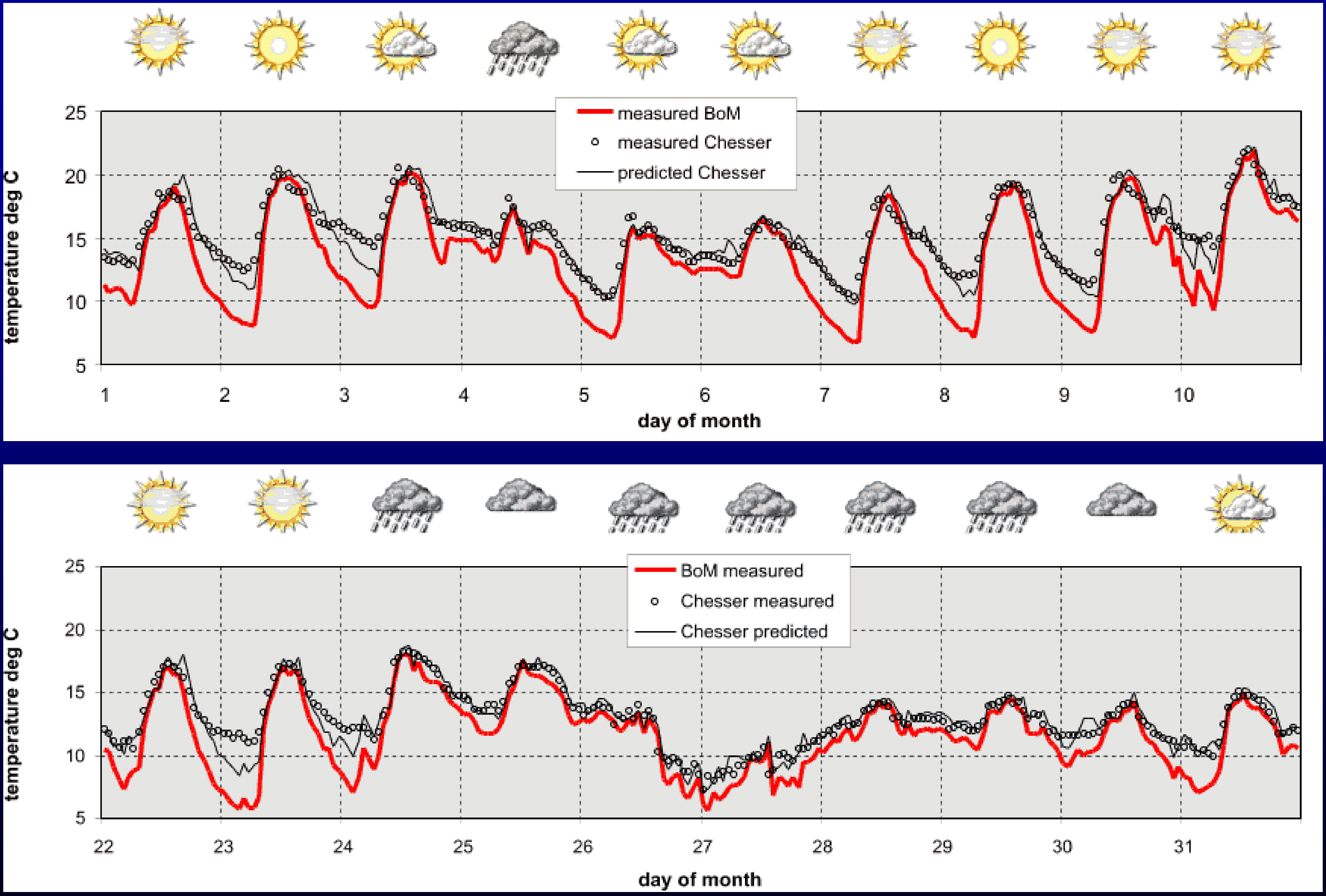
Assumption

While each surface may be exposed to different conditions, the enclosed volume of air is well-mixed and has uniform properties (specifically – air temperature).

Methodology

Compute energy balance for canyon air, and rate of mixing with above-canopy air.

How good are predictions ?



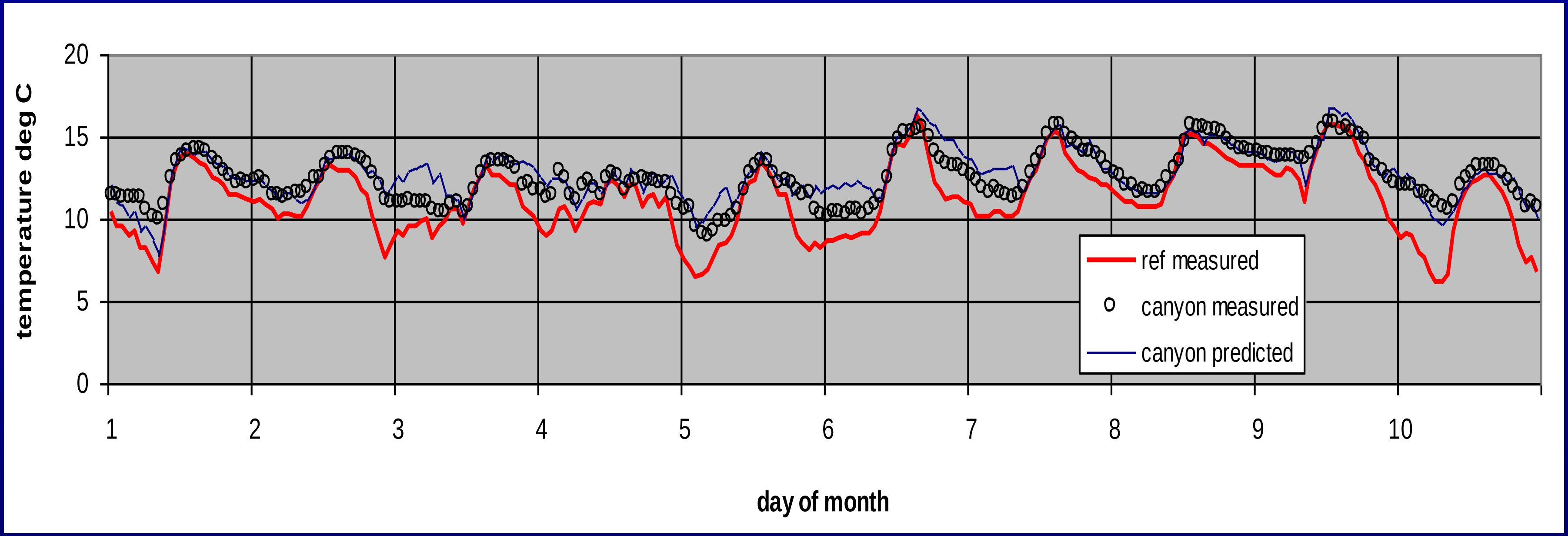
Comparison of observations and predictions – Adelaide, May 2000

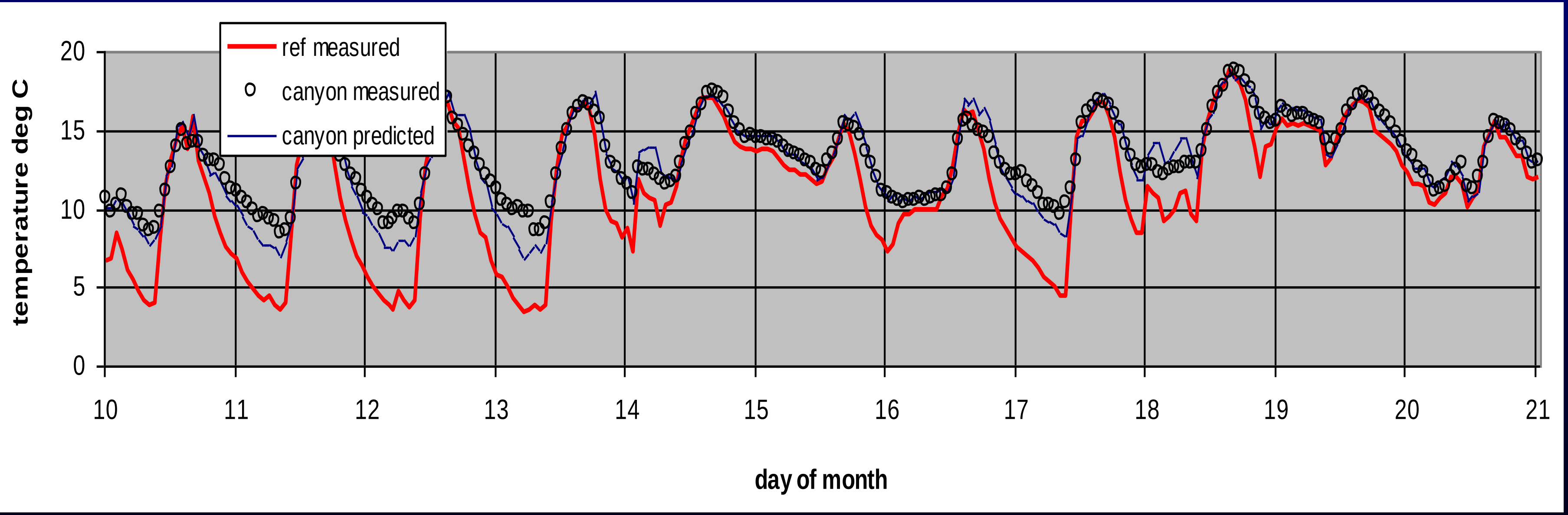
How good are predictions ?

	BoM (observed)	urban observed	urban predicted
Absolute monthly min	5.6	7.3	6.5
Mean monthly	13.0	14.6	14.6
Absolute monthly max	22.0	22.0	22.0
Mean daily minimum	8.2	9.5	9.6
Mean daily maximum	17.7	19.0	19.2

Comparison of observations and predictions – averages, May 2000

How good are predictions ?





Comparison of observations and predictions – Goteberg Sweden, June 2002

CAT Applications

- Provision of site-specific temperature data for use in building thermal simulation software.
- Evaluation of changes to the micro-climatic conditions at specific urban locations as a result of proposed changes such as new construction.
- Evaluation of the micro-climatic effects of proposed planning regulations concerning land use and building density in new or existing urban development.
- Use as a research tool for examining various urban configurations in terms of their effect on pedestrians and on consumption of energy in buildings.

Case Study

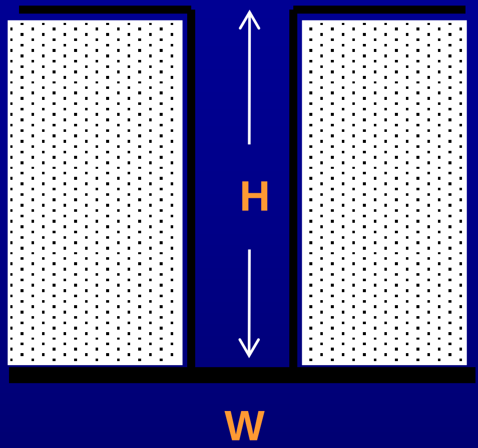
- Office building
- 1430 m2
- Ext wall: precast concrete, concrete roof, double glazed low-e
- 15 L/sec per person ventilation
- 15 W/m2 lighting and appliances
- VAV HVAC system
- Thermostat settings:
  - Summer: 24 – 26 deg (Occ – Unocc.)
  - Winter: 21 deg
- Assumed: surrounded by buildings with the same height 4.5 m away except in front of the main façade/entry.
- Canyon runs east west, and north south

Simulated with ENERWIN-EC:

- Hourly thermal/energy simulation program
- Taking into account hourly weather, building geometry, envelope properties, internal loads and operations, HVAC operations
- Predicting hourly, monthly, and annual heating and cooling loads, energy end uses, energy costs, thermal comfort.

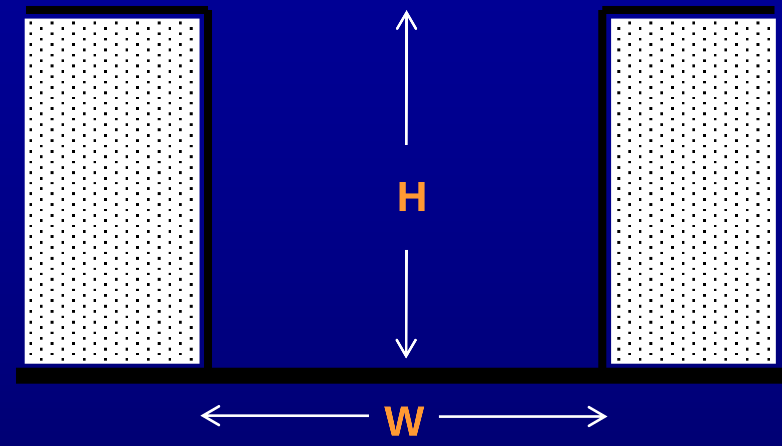
Canyon Ratios

H/W = 4

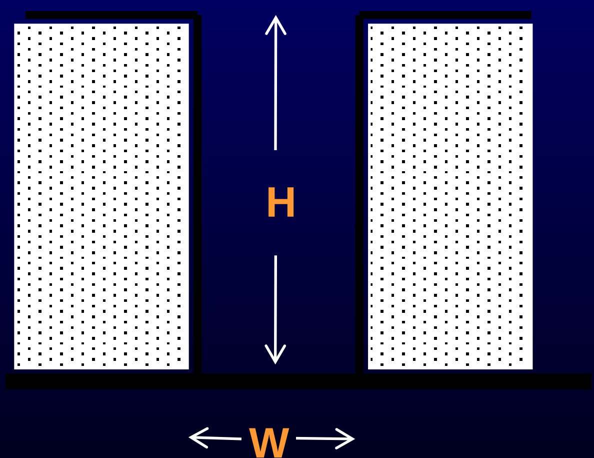


H = 14 m

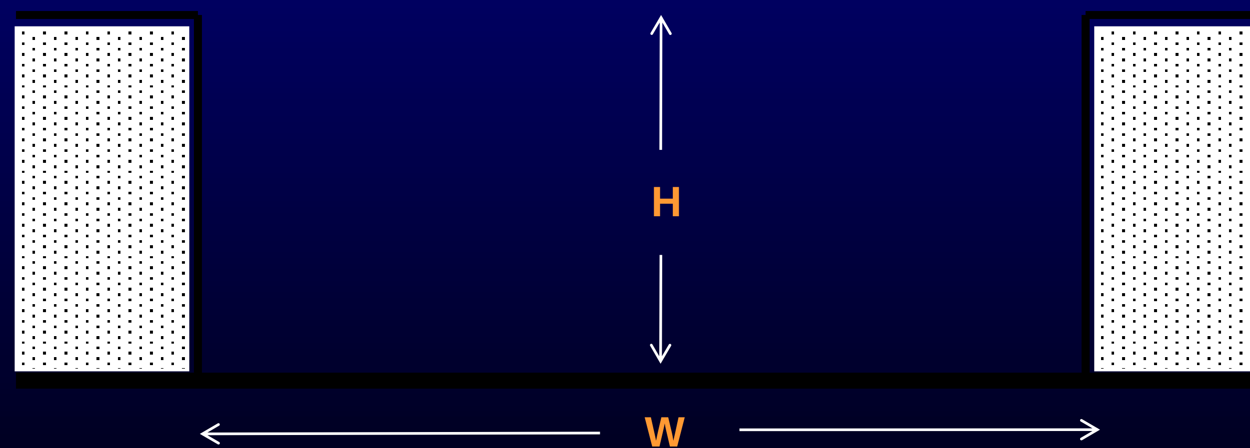
H/W = 1



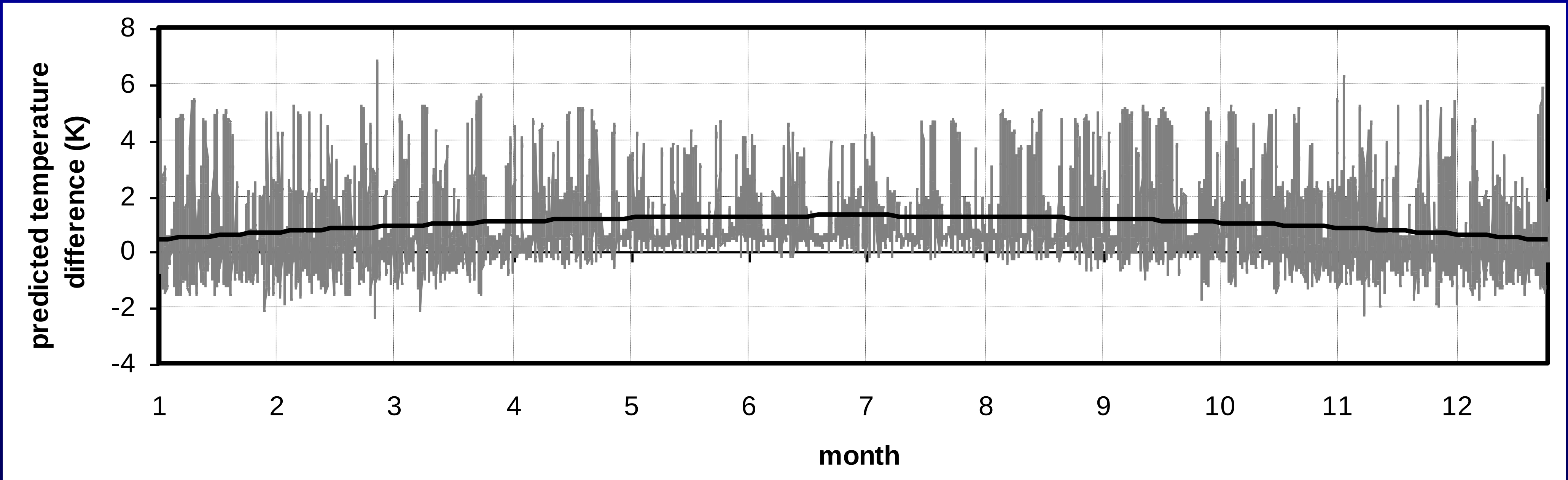
H/W = 2



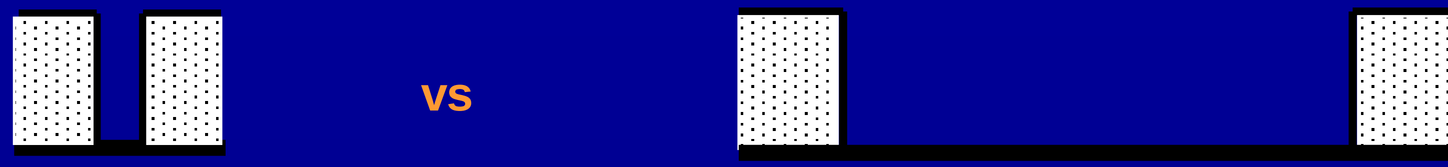
H/W = 0.5



And H/W = 0.25



Seasonal pattern of the intra-urban heat island of Adelaide simulated by CAT from RMY, for a street canyon with H/W=1.
Negative values indicate the street is cooler than Reference data.
The time series trend is represented by a thick black line.

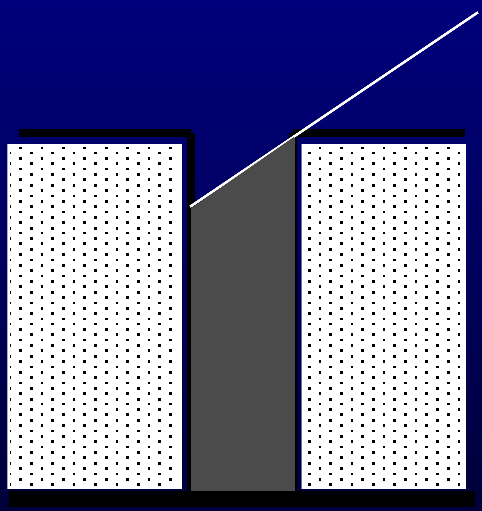


- Anthropogenic heat input varied for each canyon width , eg:
  - Narrow street canyon (H/W = 4.0) – 54 Wm^{-2}
  - Wide street canyon (H/W = 0.25) – 12 Wm^{-2}.

- A clear inverse correlation between canyon width and heat island intensity, i.e:
  - Narrow street canyon (H/W=4.0) – 5.9 K
  - Wide street canyon (H/W = 0.25) – 3.1 K

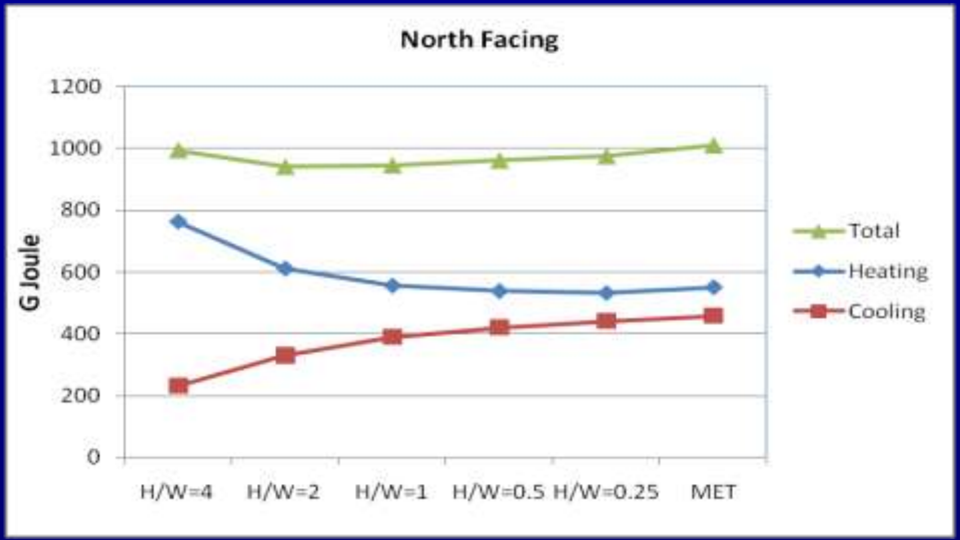
- In summer there is more development of nocturnal heat islands and daytime cool islands.

Average annual energy budget for heating and cooling for different street canyon configurations

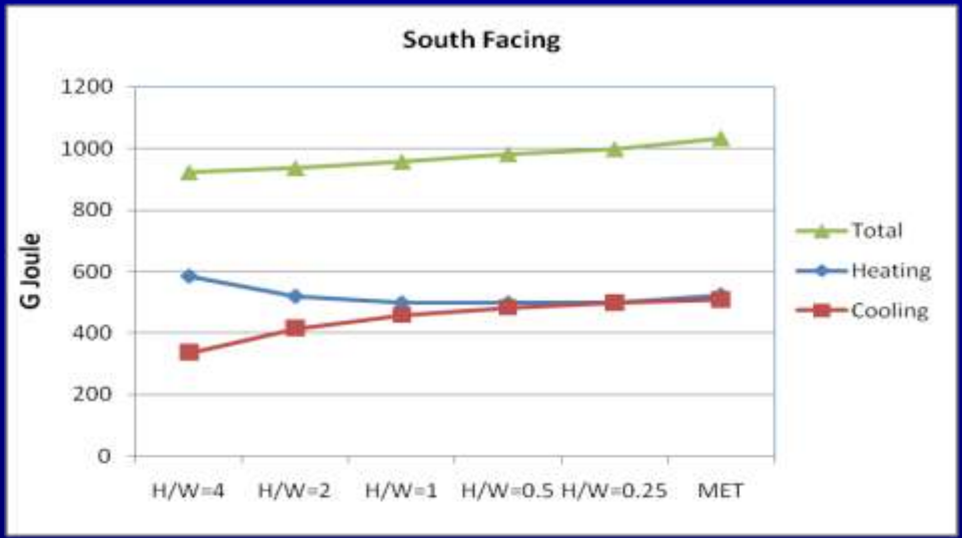


H/W	heating (GJ)	cooling (GJ)	total (GJ)
4	666	285	951
2	550	407	957
1	508	480	988
0.5	500	522	1022
0.25	498	546	1044

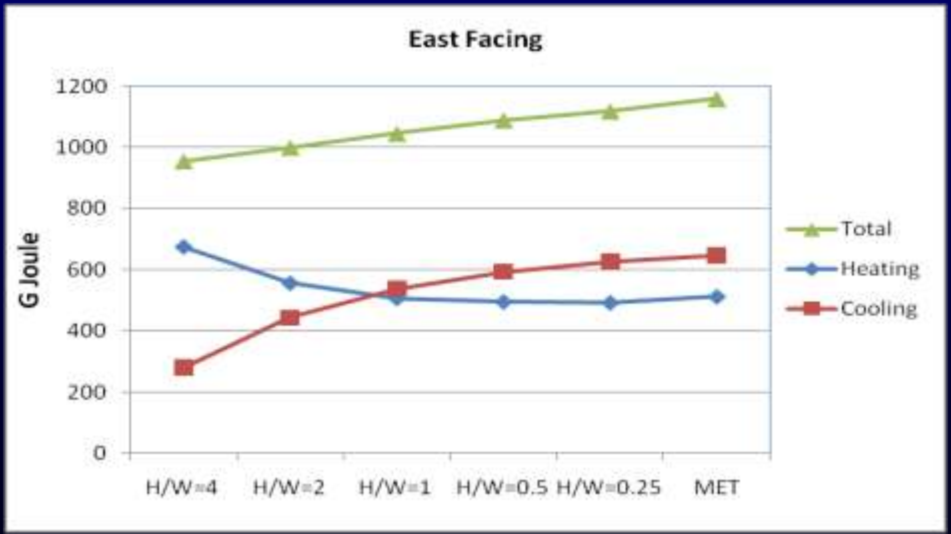
Predicted Annual Heating and Cooling Loads



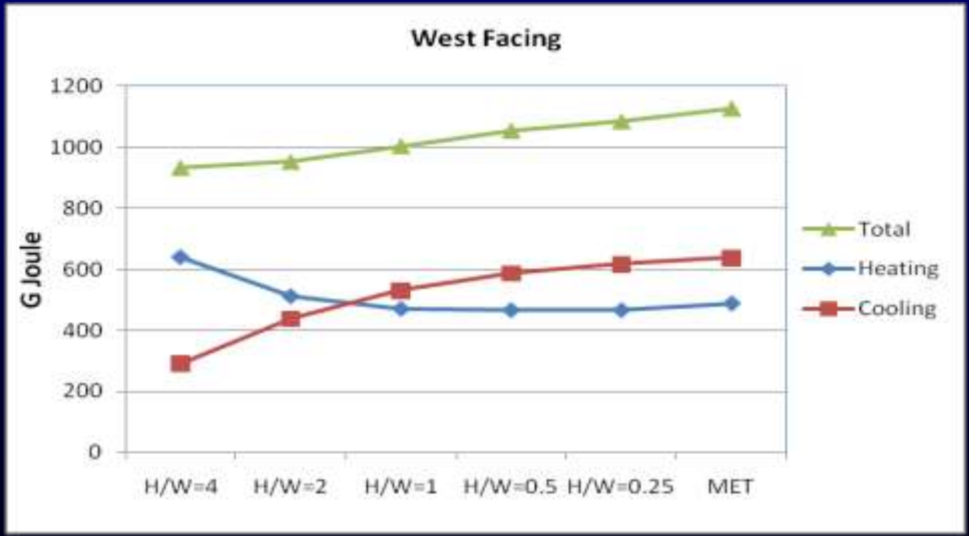
Narrow → Wide



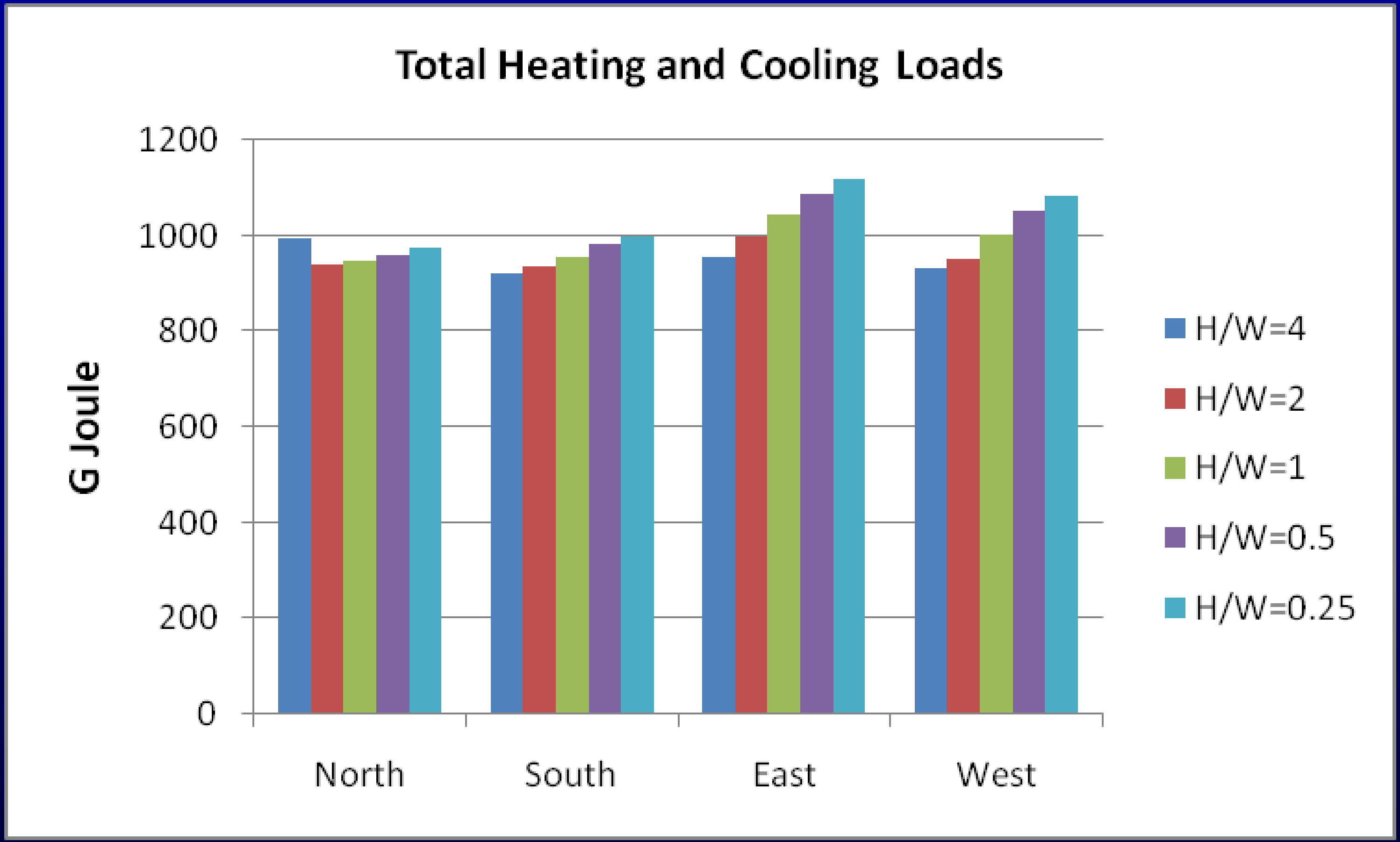
Narrow → Wide



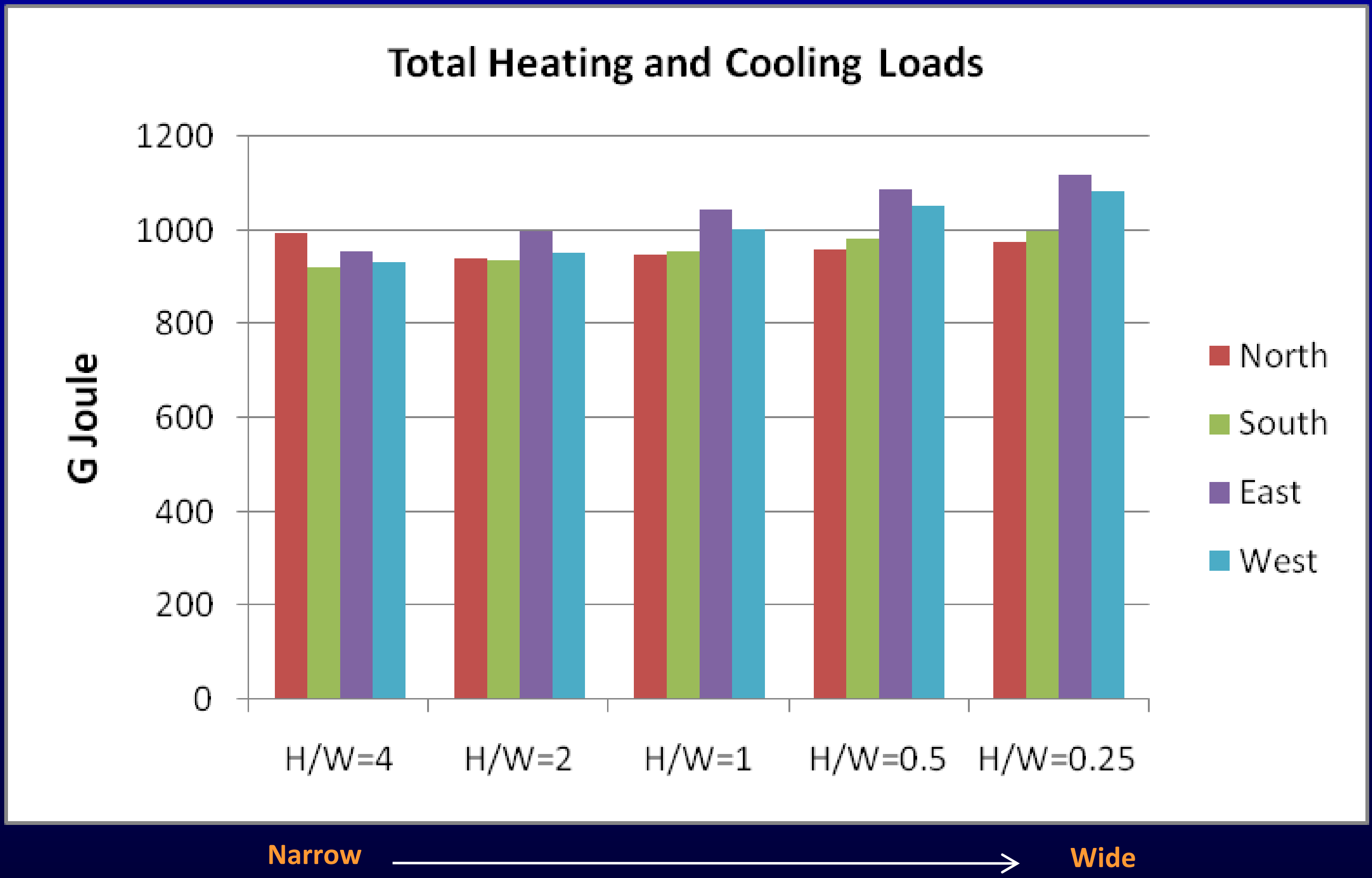
Narrow → Wide



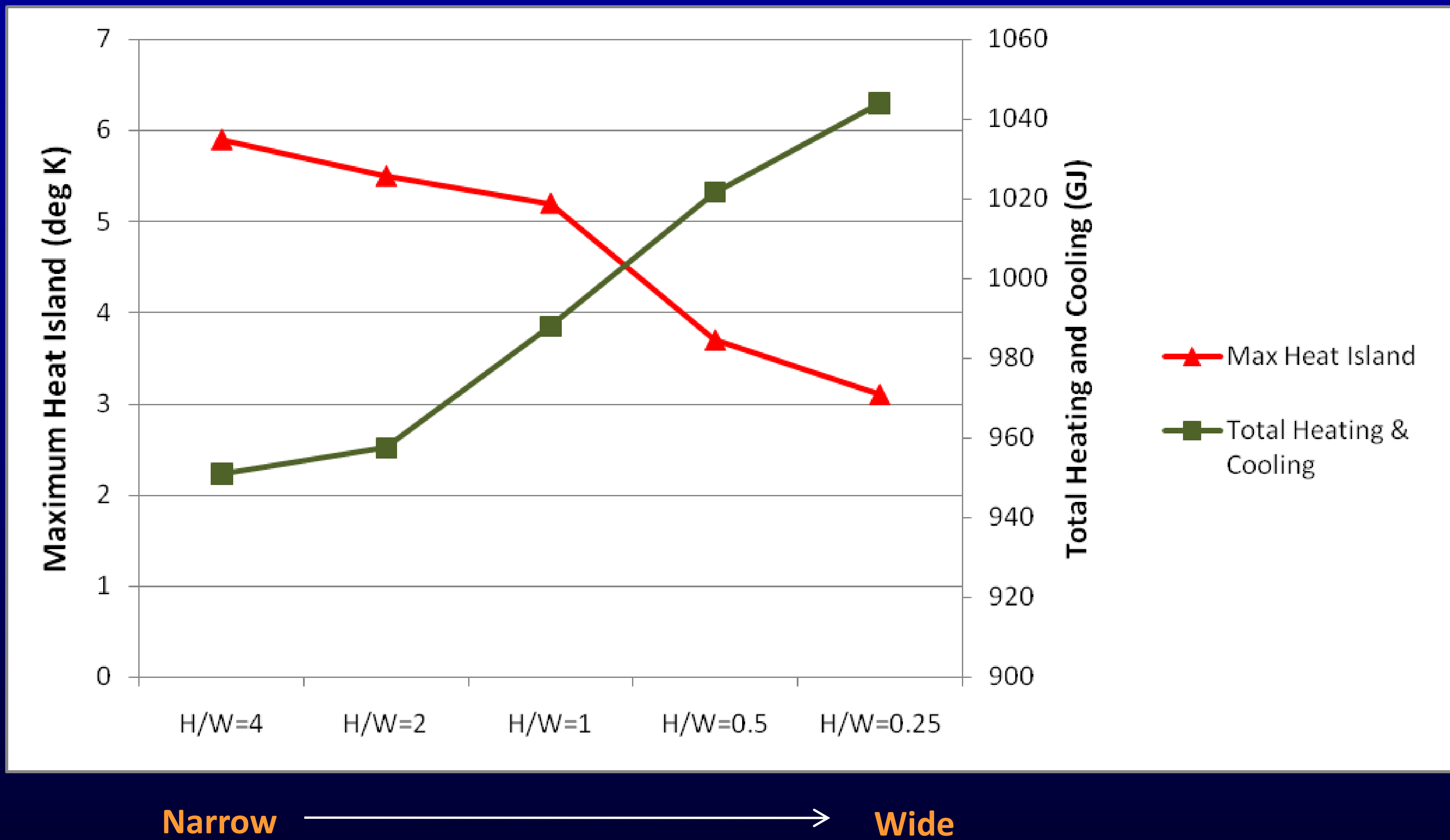
Narrow → Wide



→ In general denser building configurations could in fact reduce energy use



→ Performance of east/west facing buildings could be similar to North-South facing buildings in denser building planning



Maximum Heat Island (deg K)
Total Heating and Cooling (GJ)
0
1
2
3
4
5
6
7
900
920
940
960
980
1000
1020
1040
1060
H/W=4
H/W=2
H/W=1
H/W=0.5
H/W=0.25
Max Heat Island
Total Heating & Cooling
Narrow
Wide

Summary

In Adelaide:

- Results show that denser development produces higher UHI and also greater UCI;
- The net effect could potentially result in a reduction in total heating and cooling energy use;
- Further research along the lines presented here (and including the anticipated effects of climate change) could inform planning controls;
- Possible further research may include:
  - Analysing the effect of different building heights in various street width
  - Analysing the impact of various exterior surfaces including green walls and green roofs

Thank you!