Urban heat island, climate change and impact on ventilation for cooling

Maria Kolokotroni

School of Engineering and Design,

Brunel University

What is the difference between cities and countryside?

Urban Pollution:
air, thermal, noise

Thermal pollution causes:

- Heat capacity & conductivity
- Solar absorptivity
- Sky factor
- Wind speed
- Energy use
- Vegetation

Heat capacity & conductivity

- ground is less dense
- has a lower heat capacity
- and has an insulating layer above

- high density materials
- with high heat capacity
- and high thermal conductivity

Solar absorptivity

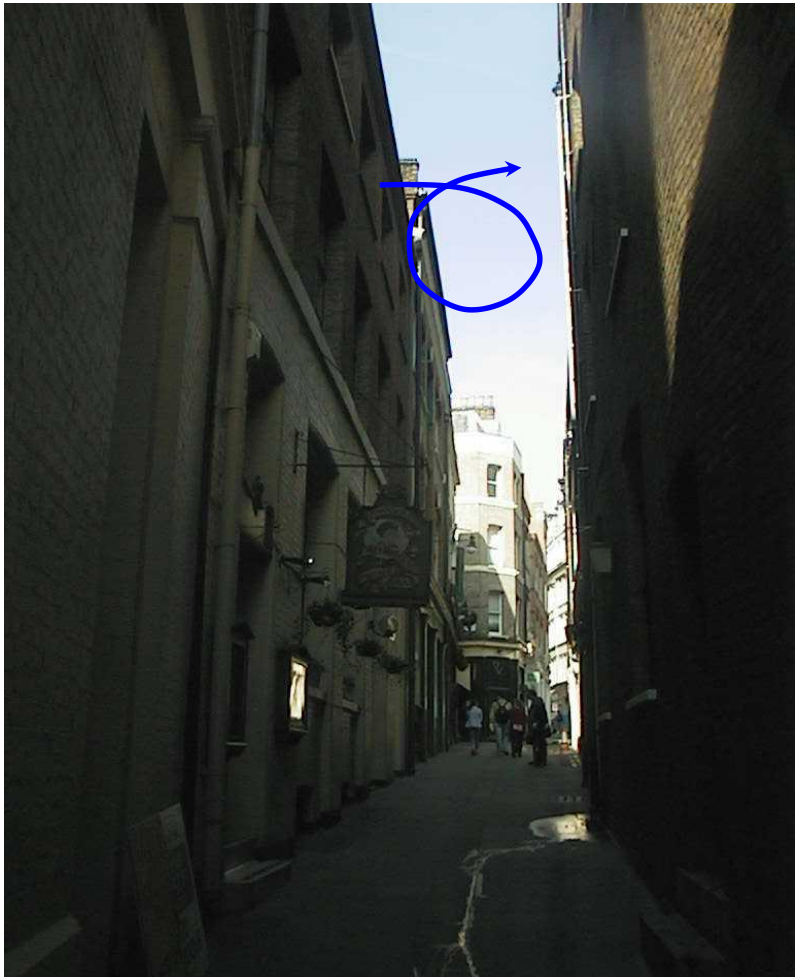
Albedo (solar reflectivity) varies in both rural and urban areas

Sky factor

reduced effectiveness of long-wave radiation for cooling

Wind speed

- Average rural wind speeds are higher than urban ones because the ground surface is smoother
- The “rougher” urban surfaces reduce wind speeds, but there are local variations
- Wind flowing across a deep narrow street canyon will create little disturbance at ground level



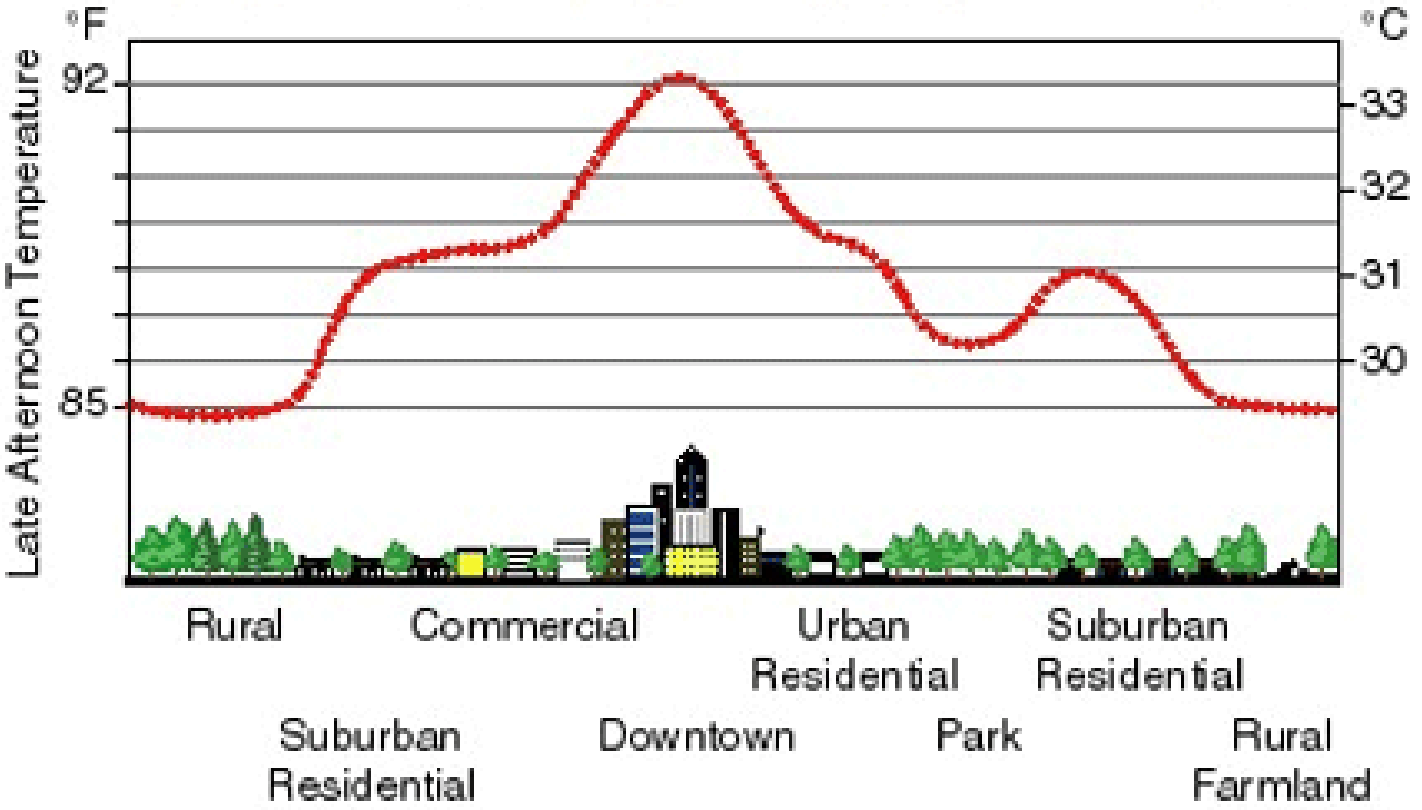
Energy use releases heat

- Rural energy use is small compared to the energy received from the sun
- Energy use density in urban areas is much higher

Vegetation

- To evaporate water requires energy - this helps keep plants and the air around them cool
- Urban areas are “harder”. They have less vegetation, less evaporative cooling and less shading of the ground
- parks provide “rural” oases

What is the effect of these factors?

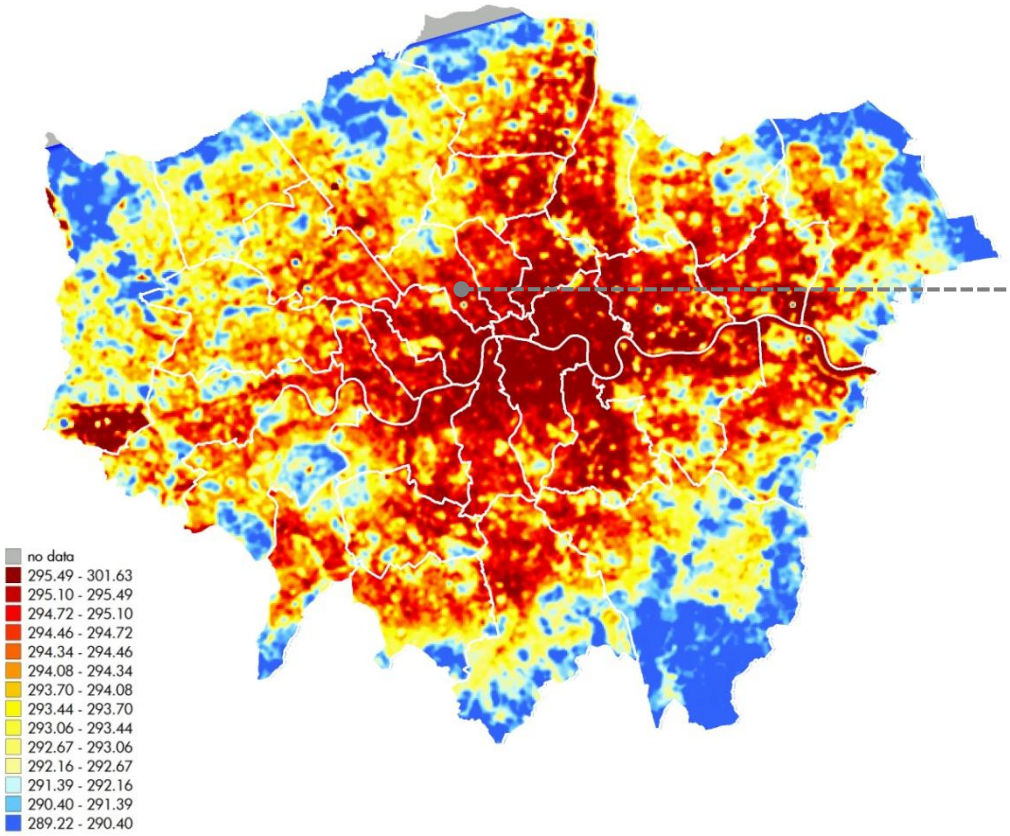


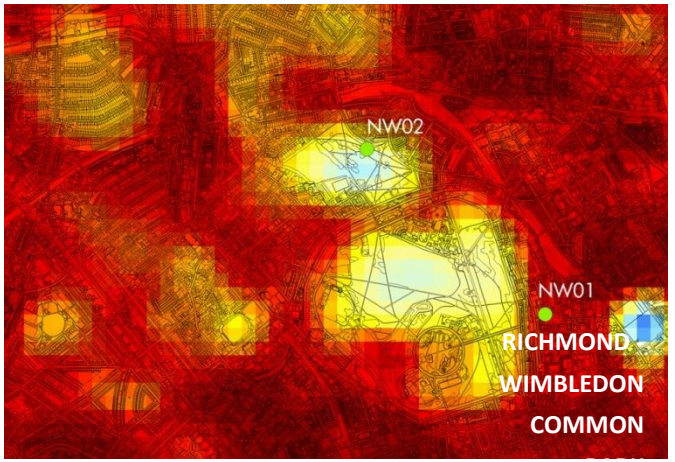
It is known as Urban Heat Island effect

Source: The LUCID project

http://www.lucid-project.org.uk

Land Surface Temperature, 12 July 2006, 21.00 UT
ASTER satellite image



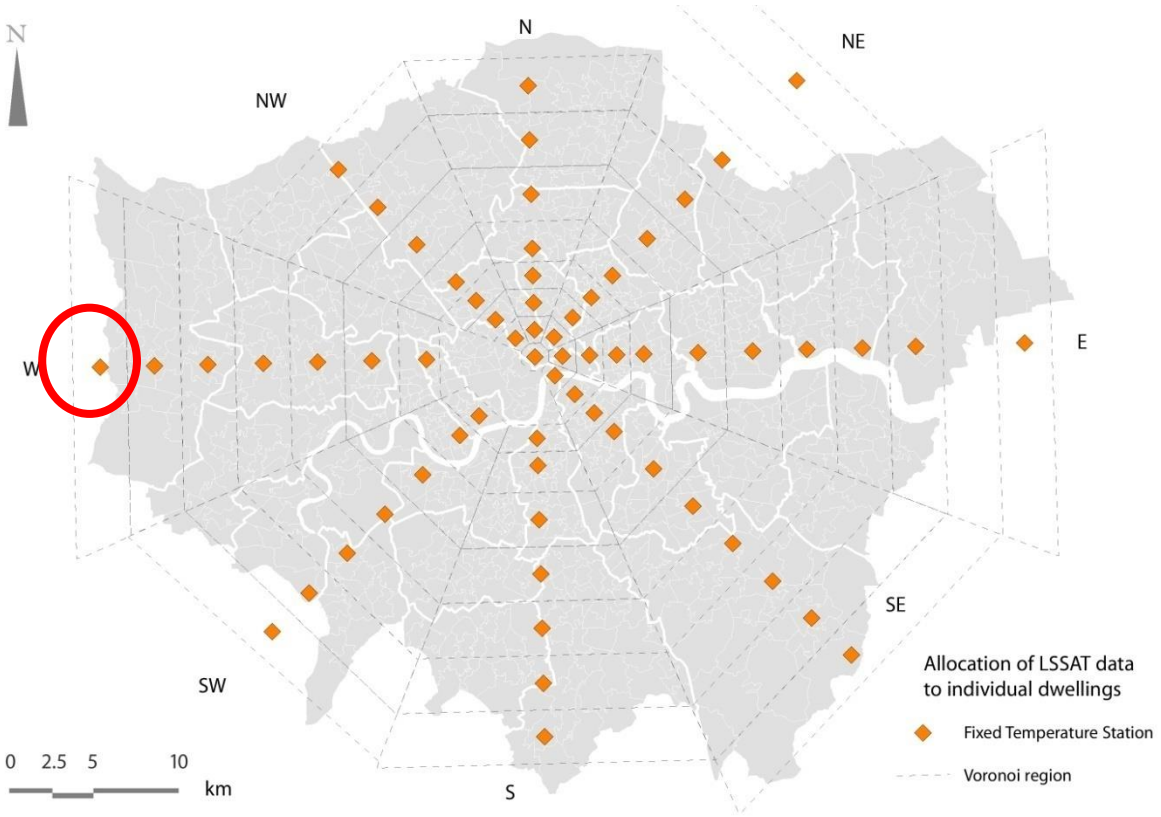


ENERGY Bits

Brunel UNIVERSITY LONDON

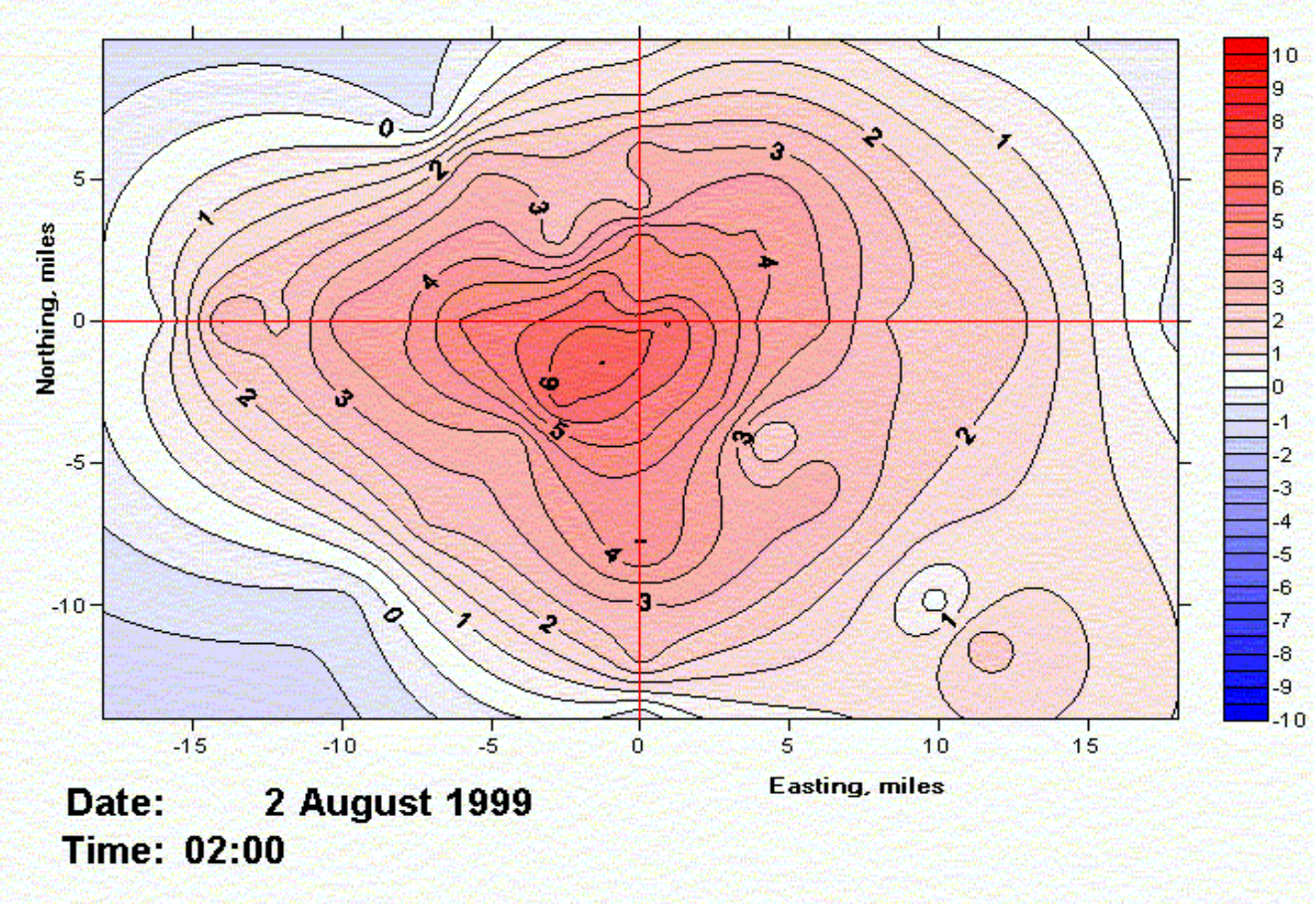
Urban Heat Island

- Body of work in hot climates, US, Europe and Asia
- What happens in moderate climates such as London?
- We measured it!



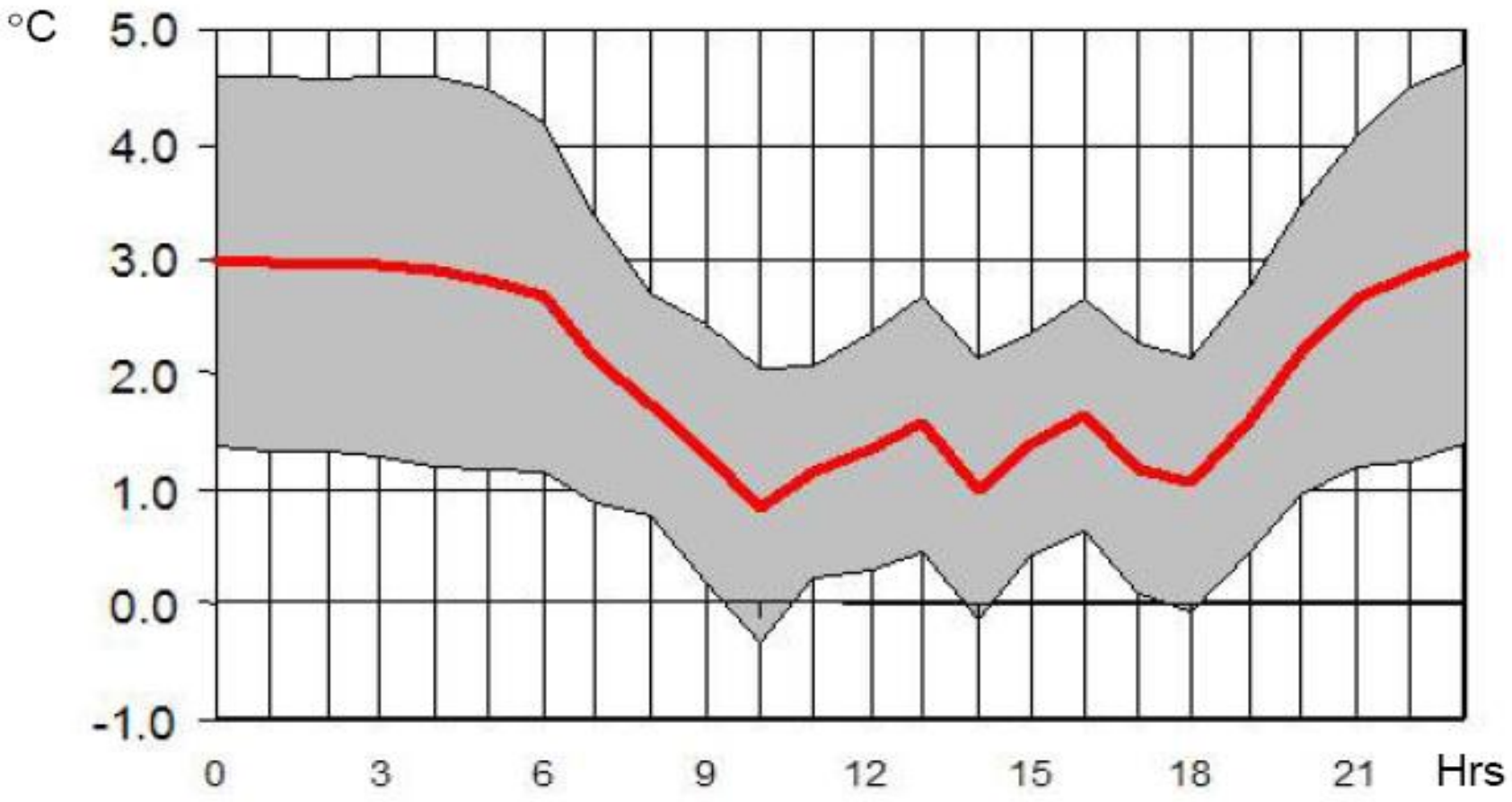
Measurement station

Example of the variation in heat island intensity across London

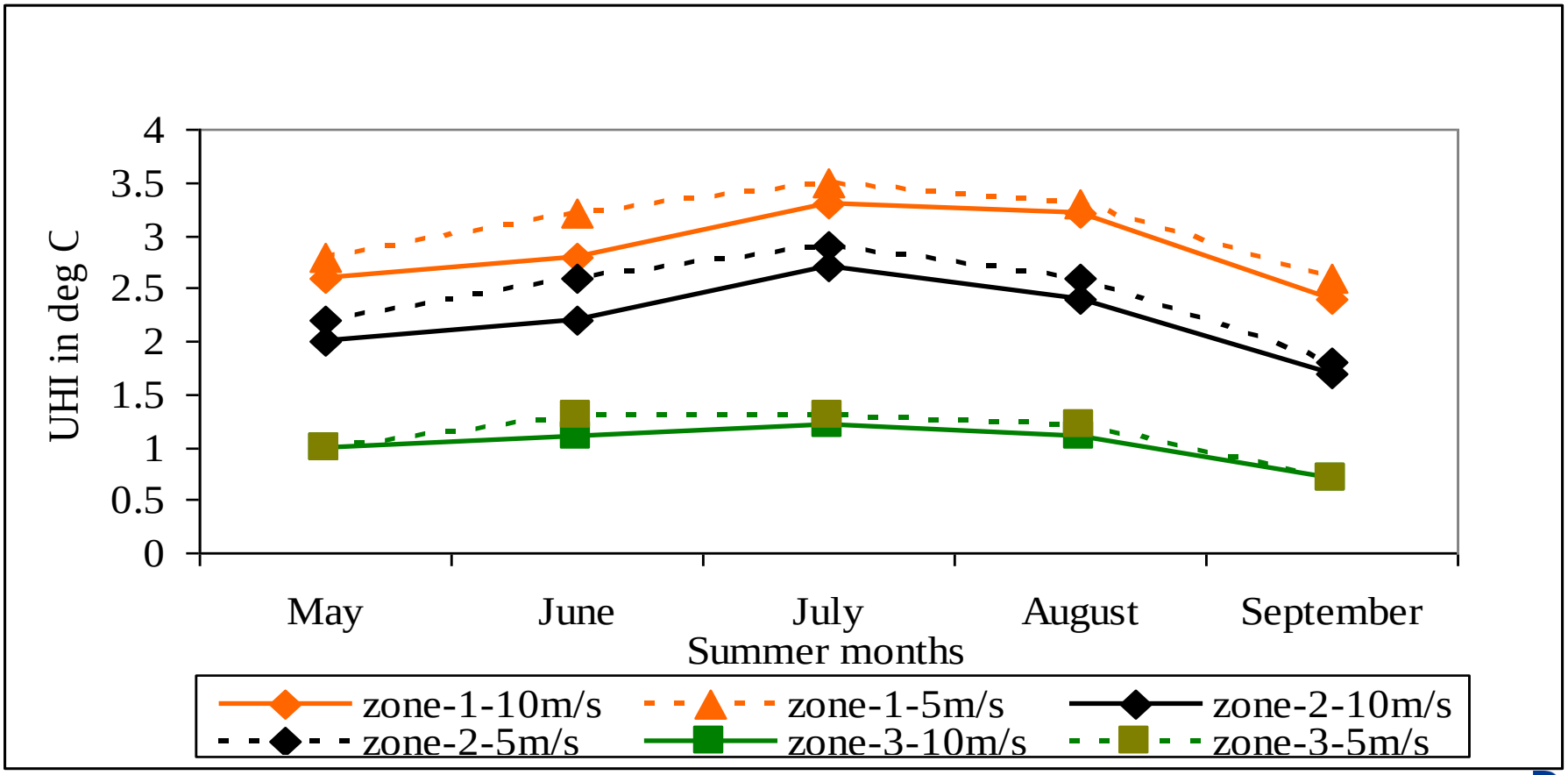


GLA report: London's Urban Heat Island

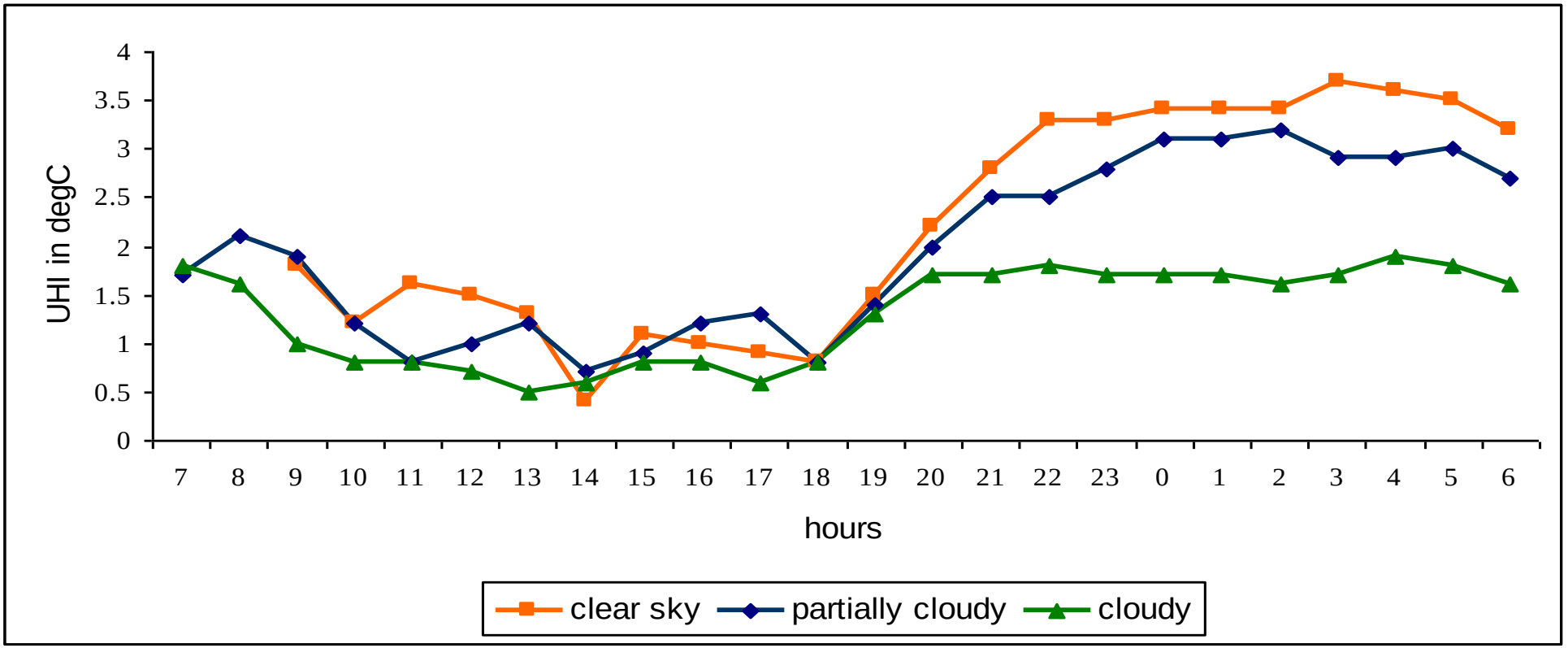
Figure 2: The variation in the UHI intensity for London over 24 hours for summer 2000. The solid red line indicates the average UHI intensity by hour while the shaded area shows the range of UHI intensity values for 68 percent of the observations.



Mean nocturnal UHI pattern in 3 geographical zones during clear sky periods under 3 categories of wind speed



Hourly mean UHI value with wind speed less than 5 m/s for Core Area (zone-1)



London to be divided into three zones – consistent with CIBSE Guide A, 2006

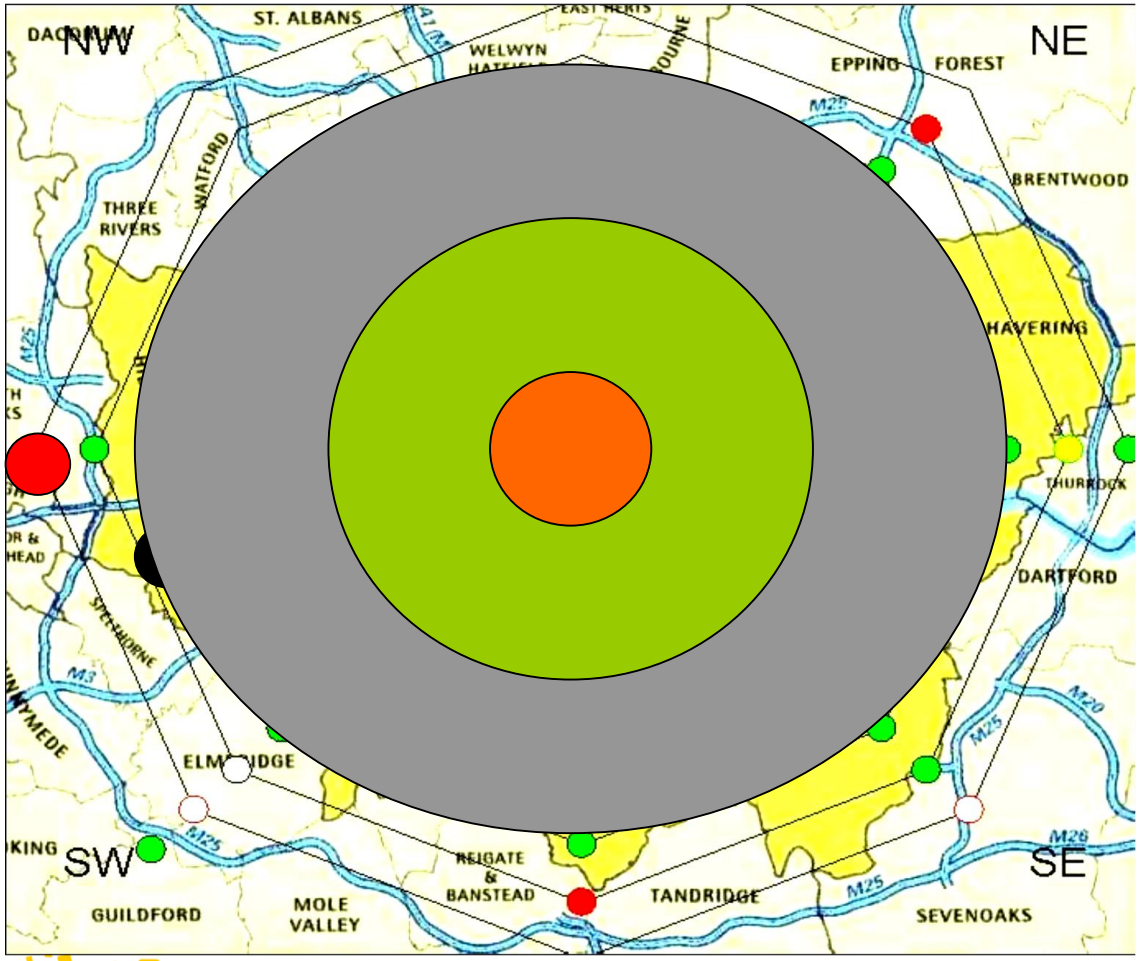


Table 2
Proposed air temperature corrections based on radial distance from city centre

Hour	Distance from city centre			Rural reference
	0–3 km	3–10 km	10–23 km	
0	1.9	1.0	−0.9	−2.3
1	1.9	1.1	−0.9	−2.5
2	1.9	1.1	−0.7	−2.0
3	1.7	0.9	−0.7	−2.3
4	1.5	0.8	−0.7	−2.3
5	1.4	0.7	−0.6	−2.3
6	1.7	1.3	−0.4	−2.5
7	1.5	1.9	0.8	−1.3
8	1.7	2.0	1.3	−0.7
9	1.8	2.2	1.5	−0.4
10	1.6	2.0	1.4	0.7
11	1.4	1.8	1.3	0.0
12	1.7	2.1	1.3	−0.2
13	1.6	2.2	1.4	−0.2
14	0.6	1.1	0.4	0.9
15	0.9	1.4	0.5	0.0
16	0.9	1.4	0.4	−0.1
17	0.7	1.0	0.2	−0.2
18	0.4	0.8	0.0	0.8
19	0.4	0.4	−0.4	−0.5
20	0.6	0.3	−0.9	−1.9
21	1.0	0.3	−1.4	−2.7
22	1.5	0.6	−1.3	−2.7
23	1.5	0.6	−1.3	−2.8
Average	1.3	1.2	0.0	−1.1

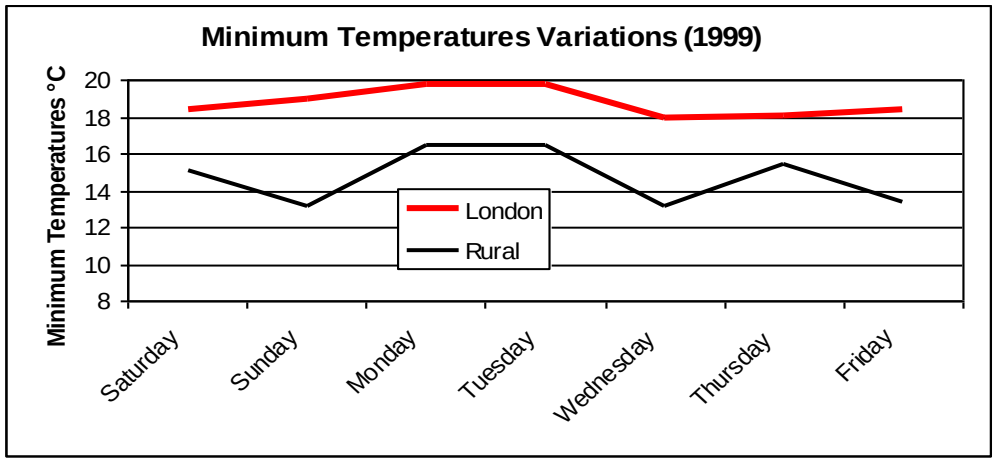
- Core
- Urban
- Semi-urban

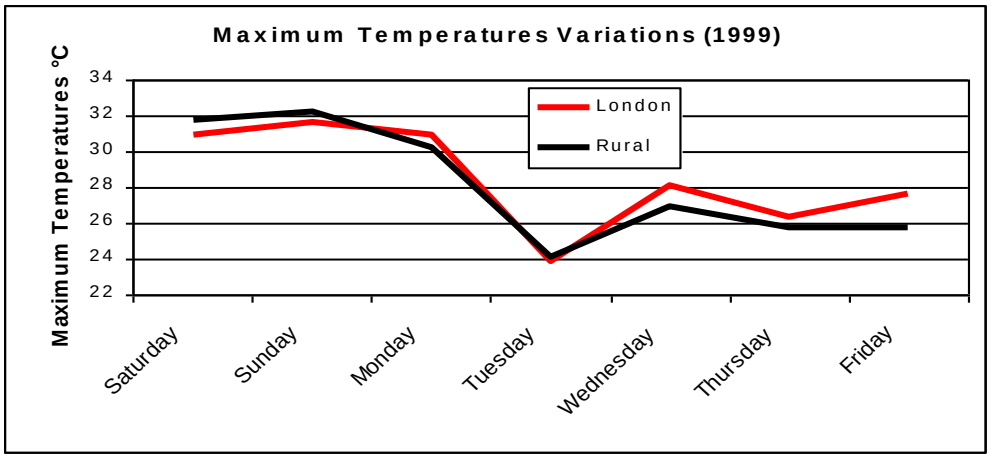
ENERGY Bits

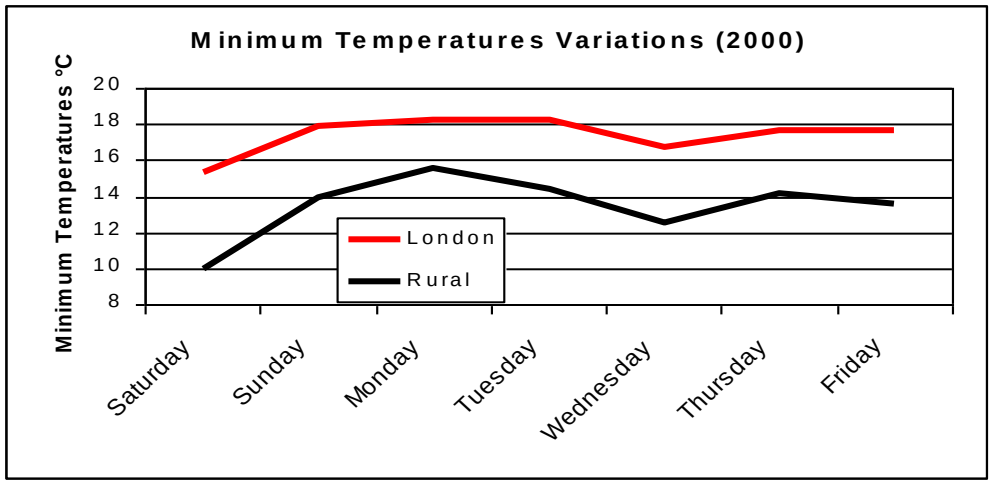
Brunel UNIVERSITY LONDON

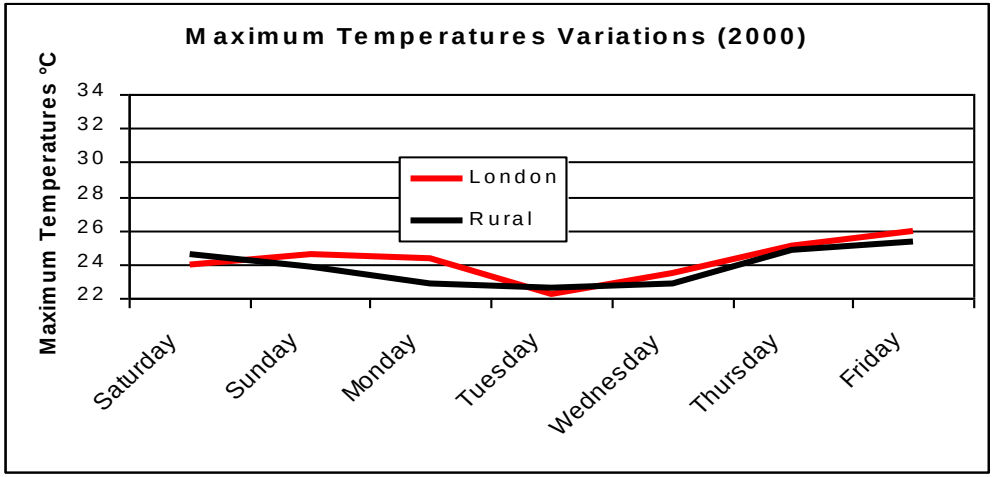
What is the effect on night ventilation?

Effect on air temperature





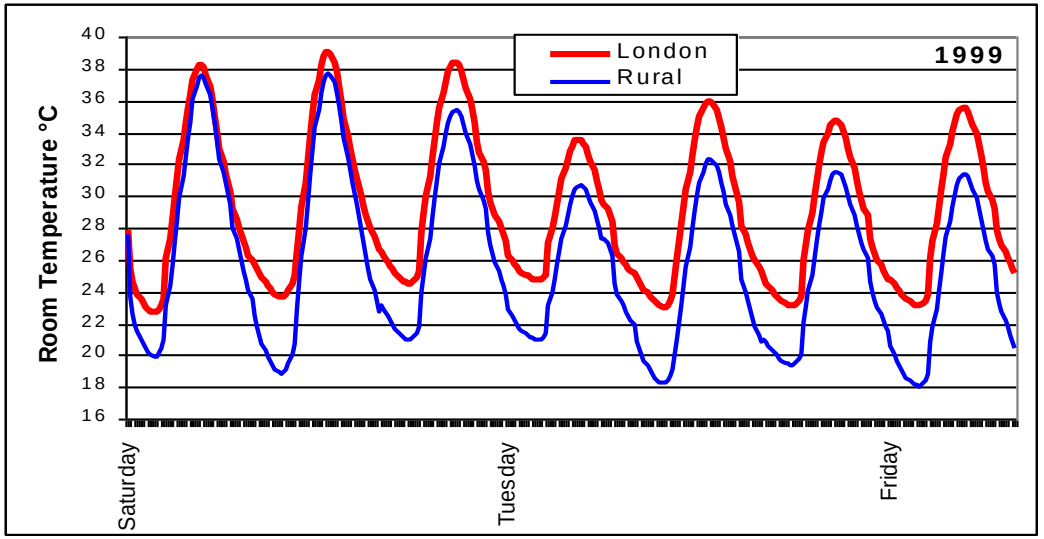


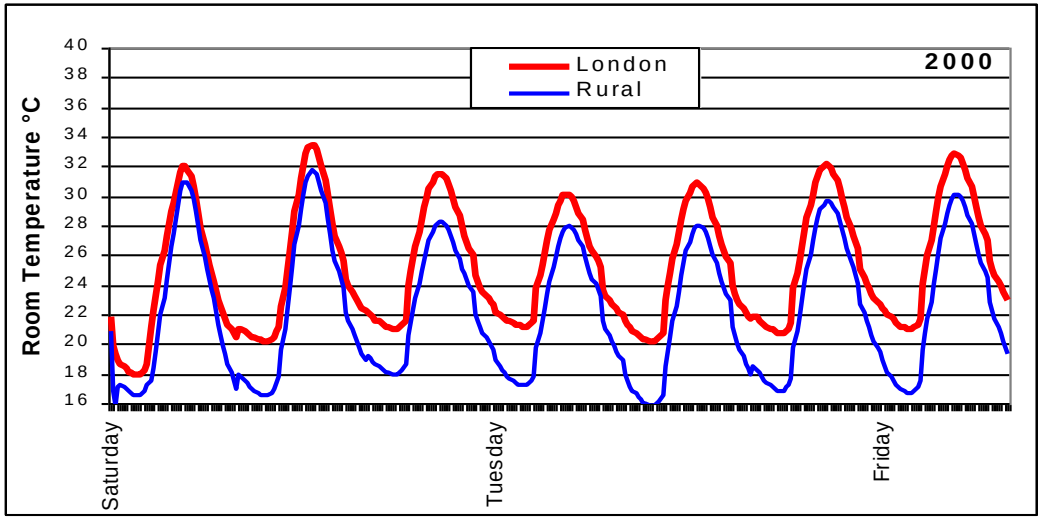


ENERGY Bits

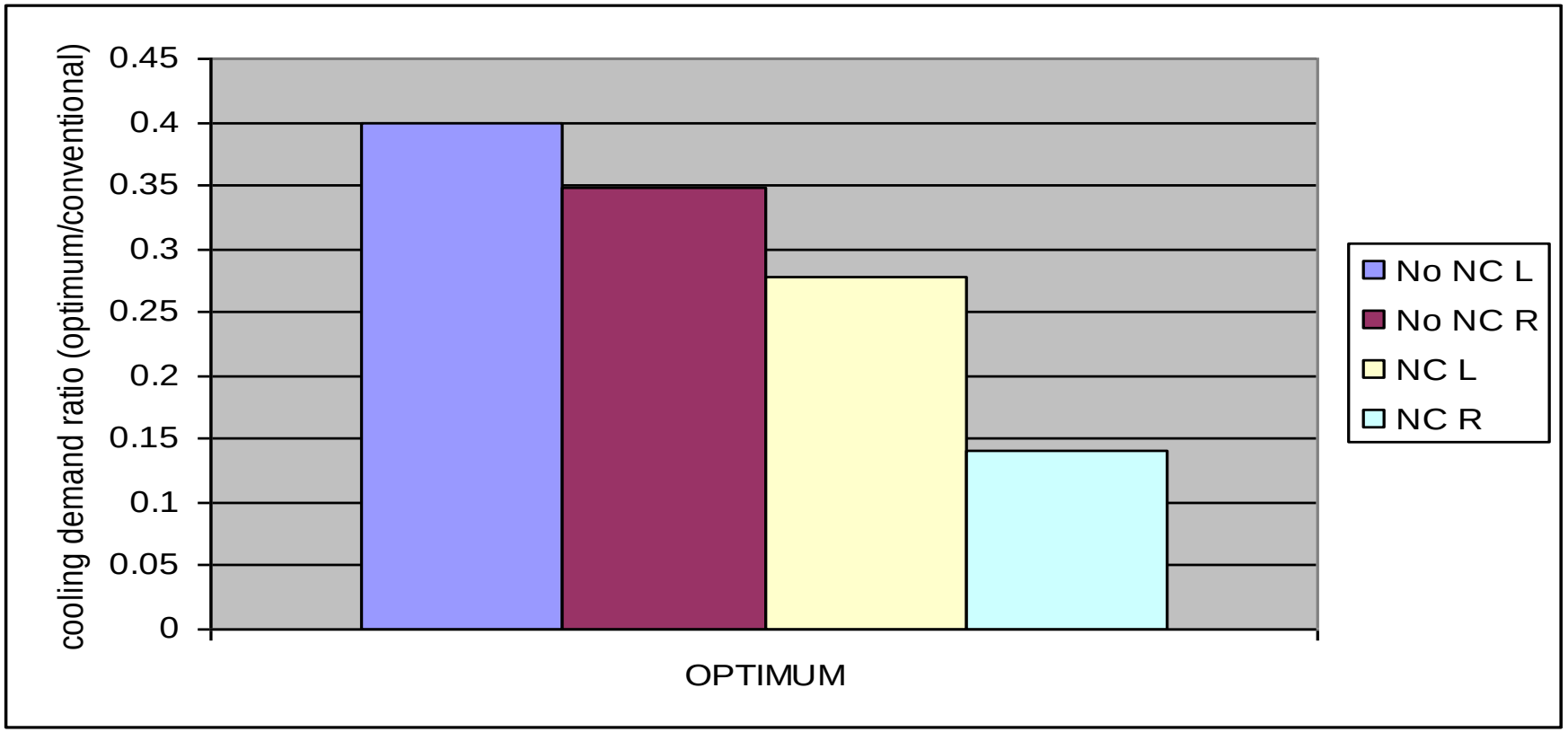
Brunel UNIVERSITY LONDON

Effect on night cooling strategy



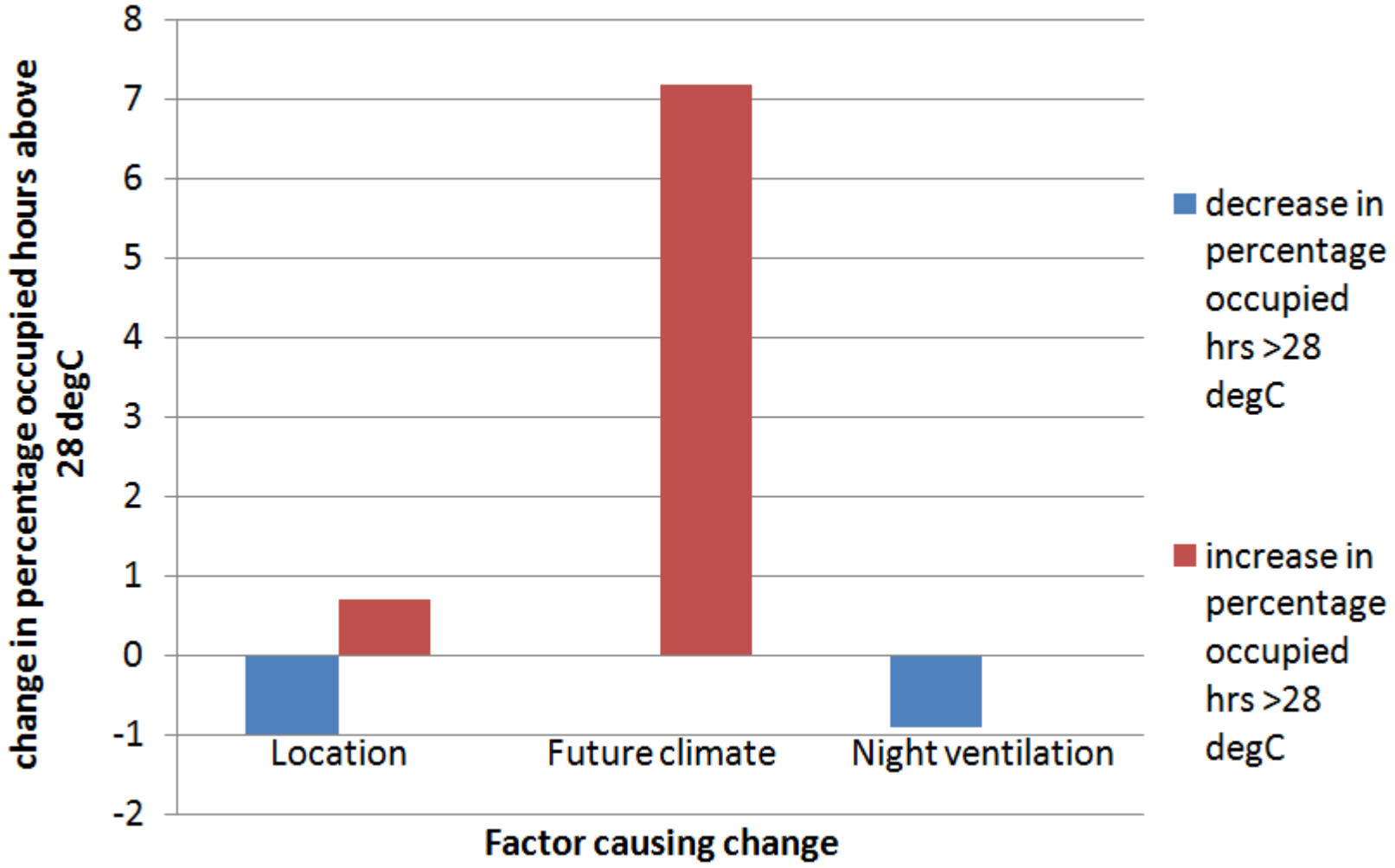


Cooling demand reduction potential through night ventilation



UHI, energy use and climate change

The challenge: to model the effect of future climate on buildings within UHI



EPSRC: LUCID: The Development of a Local Urban Climate Model and its Application to the Intelligent Development of Cities, UCL/Reading/Brunel, www.lucid-project.org.uk

LSSAT

ANN model for 77 fixed temperature stations.

Features:

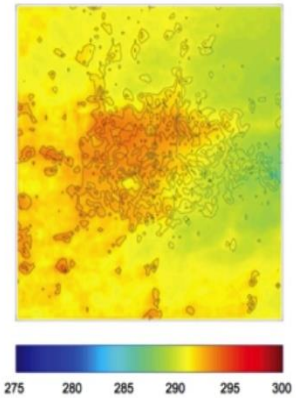
- Site specific hourly air temperature

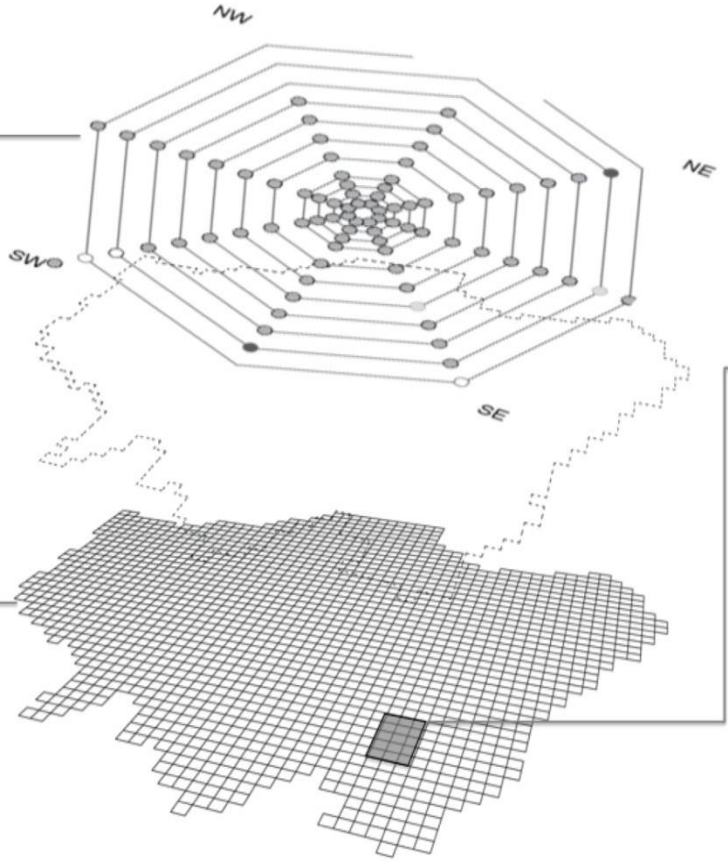
LondUM

Atmospheric model at 1km grid.

Features:

- 1.5m height surface temperatures



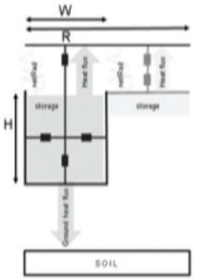


Arup Outdoor Room

Urban canyon radiative exchange model. Linked to LondUM

Features:

- Air & surface temperature

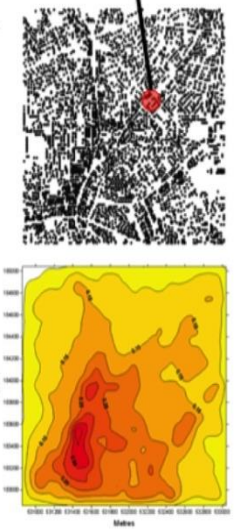


ADMS

Atmospheric dispersion model. Linked to LondUM

Features:

- Perturbations on temperature & humidity



LUCID models

LondUM

- The citywide model, the 'London Unified Model' (LondUM), represents the influence of the city on the urban boundary layer using a newly-developed parameterisation called MORUSES (the Met Office-Reading Urban Surface Exchange Scheme). The model outputs temperatures at multiple on a 1 km x 1 km grid and is capable of describing the impact the city has on the local climate.

ADMS – Excess Temperature & Relative Humidity

- This neighbourhood scale model (based on the ADMS model) predicts temperature and humidity changes across an urban area as a response to the underlying land use, e.g. buildings and surfaces. Values from LondUM are used to describe the upwind boundary layer profile for this model.

LSSAT

- The London Site Specific Air Temperature (LSSAT) prediction model is composed of a series of Artificial Neural Network (ANN) models that predict site specific hourly air temperature within the Greater London Area.

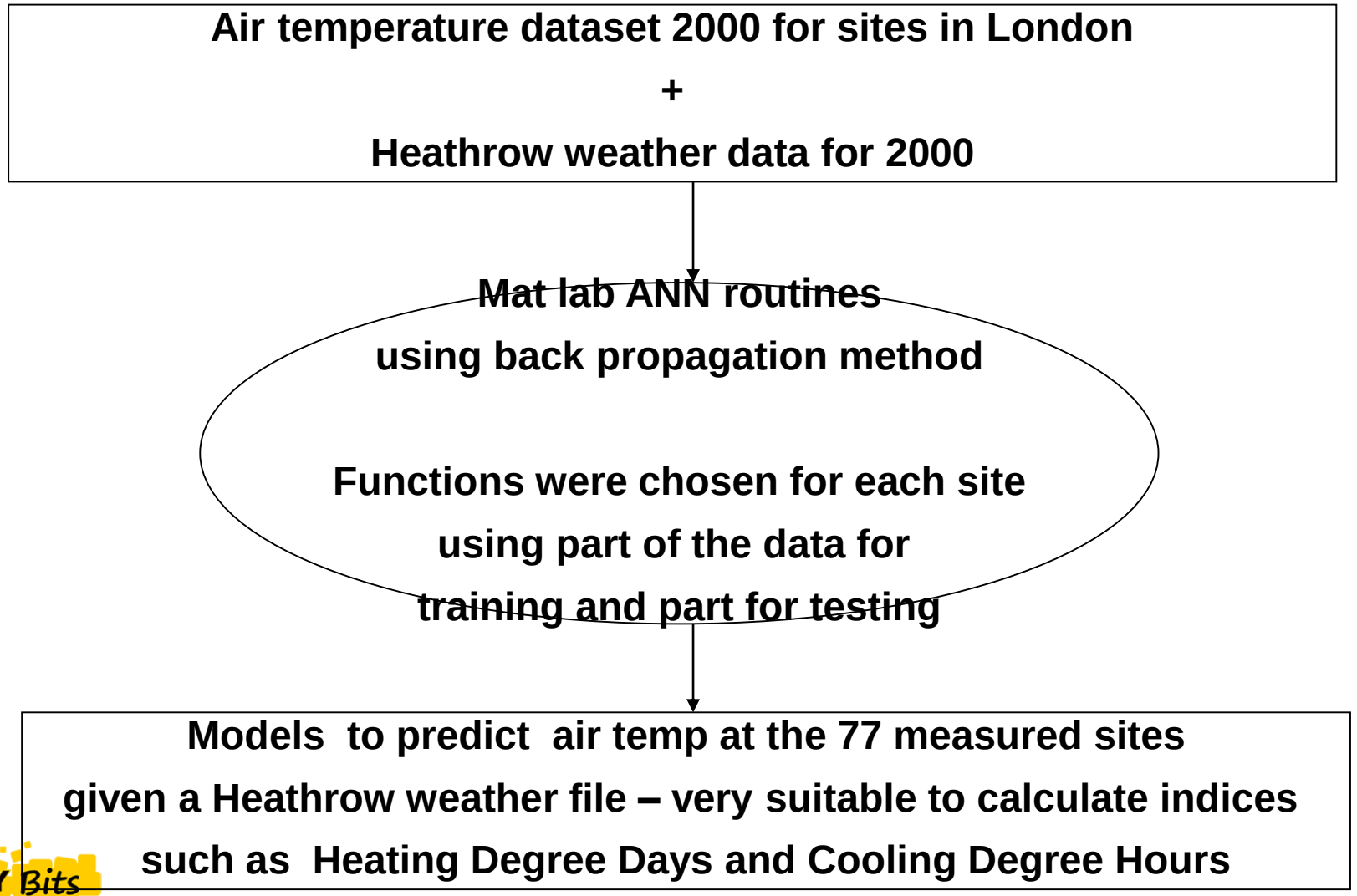
OutdoorROOM

- OutdoorROOM is a dynamic thermal model that deals with radiative exchanges and comfort conditions throughout outdoor spaces and in particular within urban canyons

ENERGY Bits

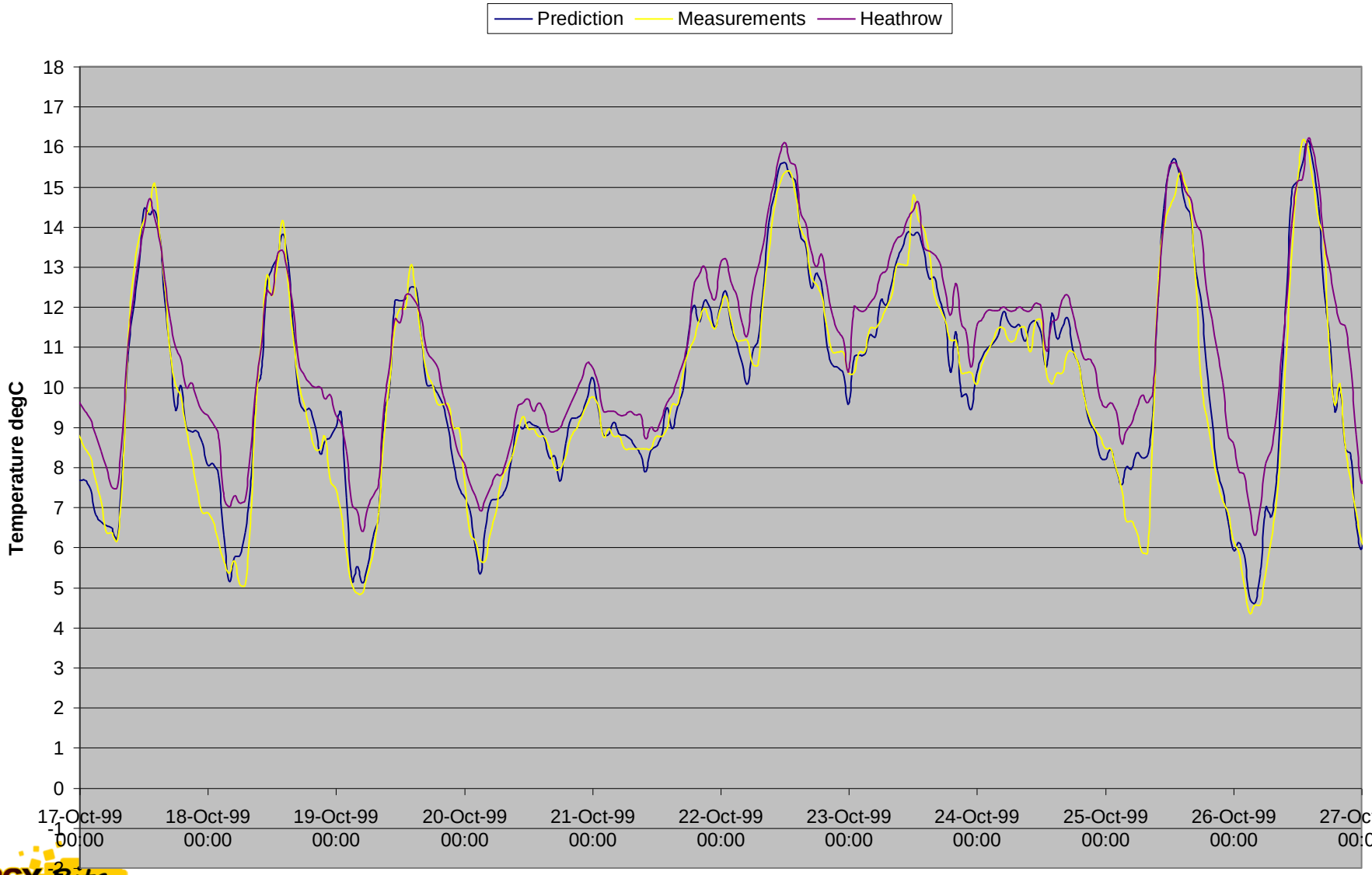
Brunel UNIVERSITY LONDON

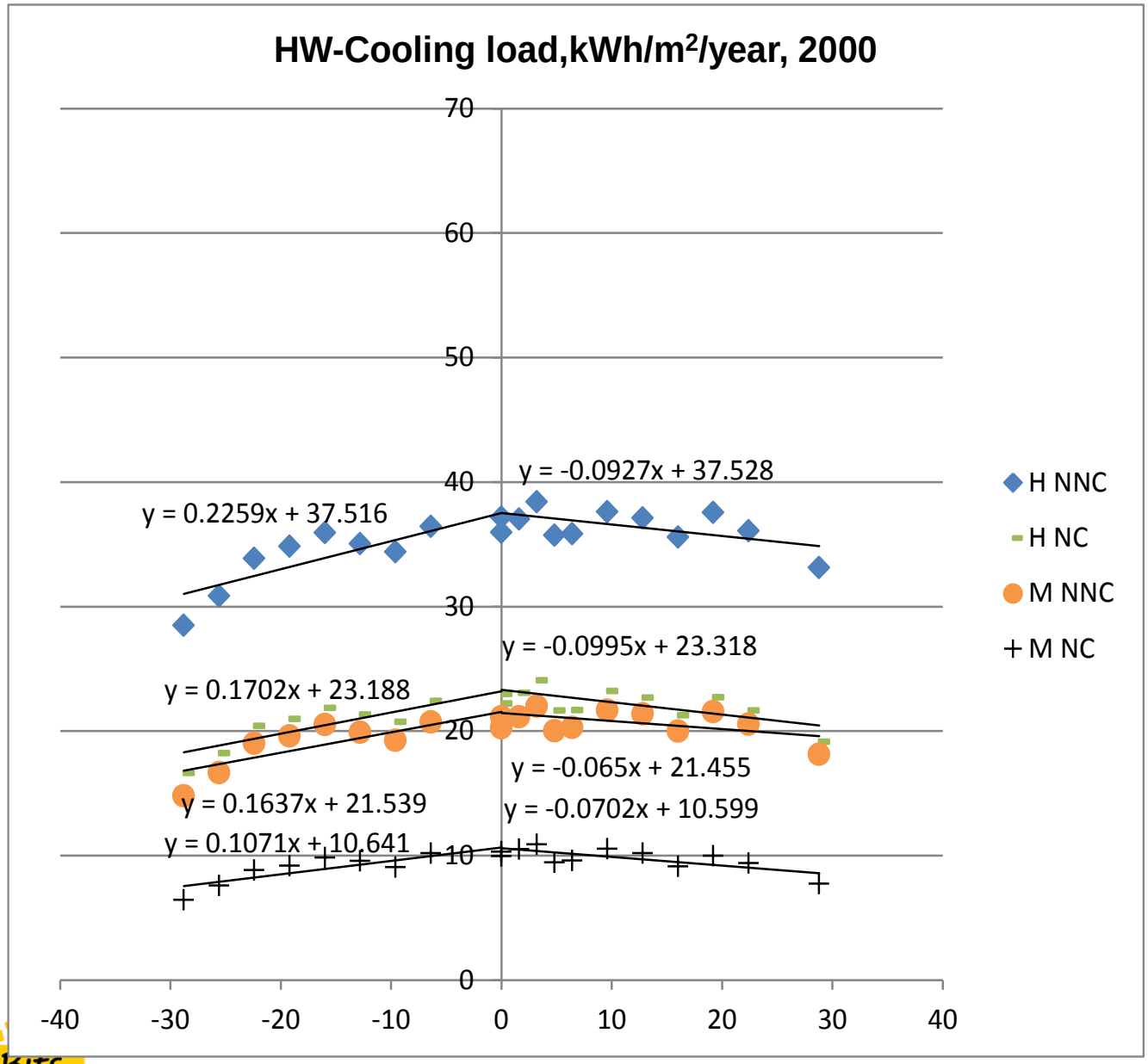
Step 1- Brief description of ANN model

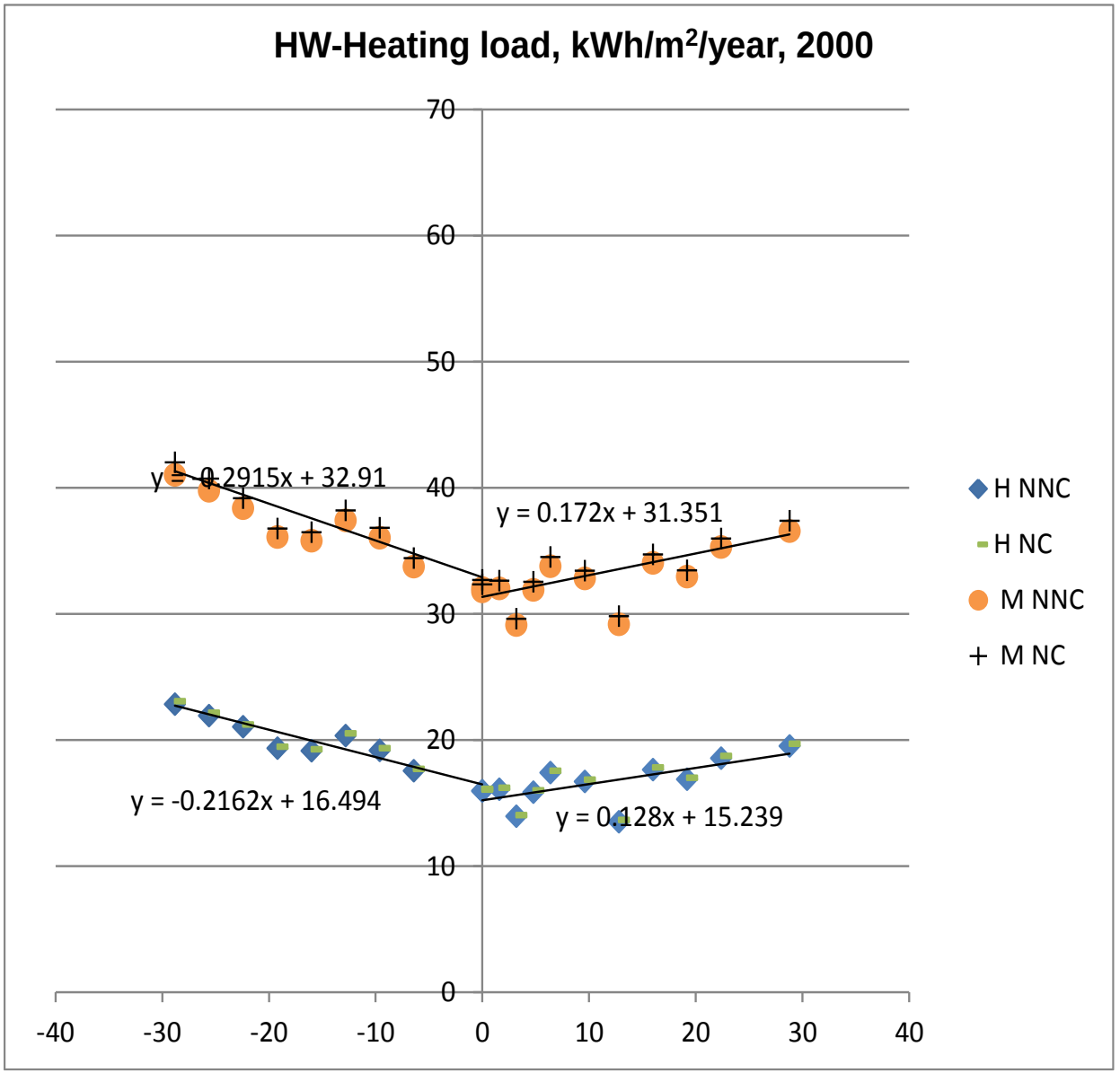


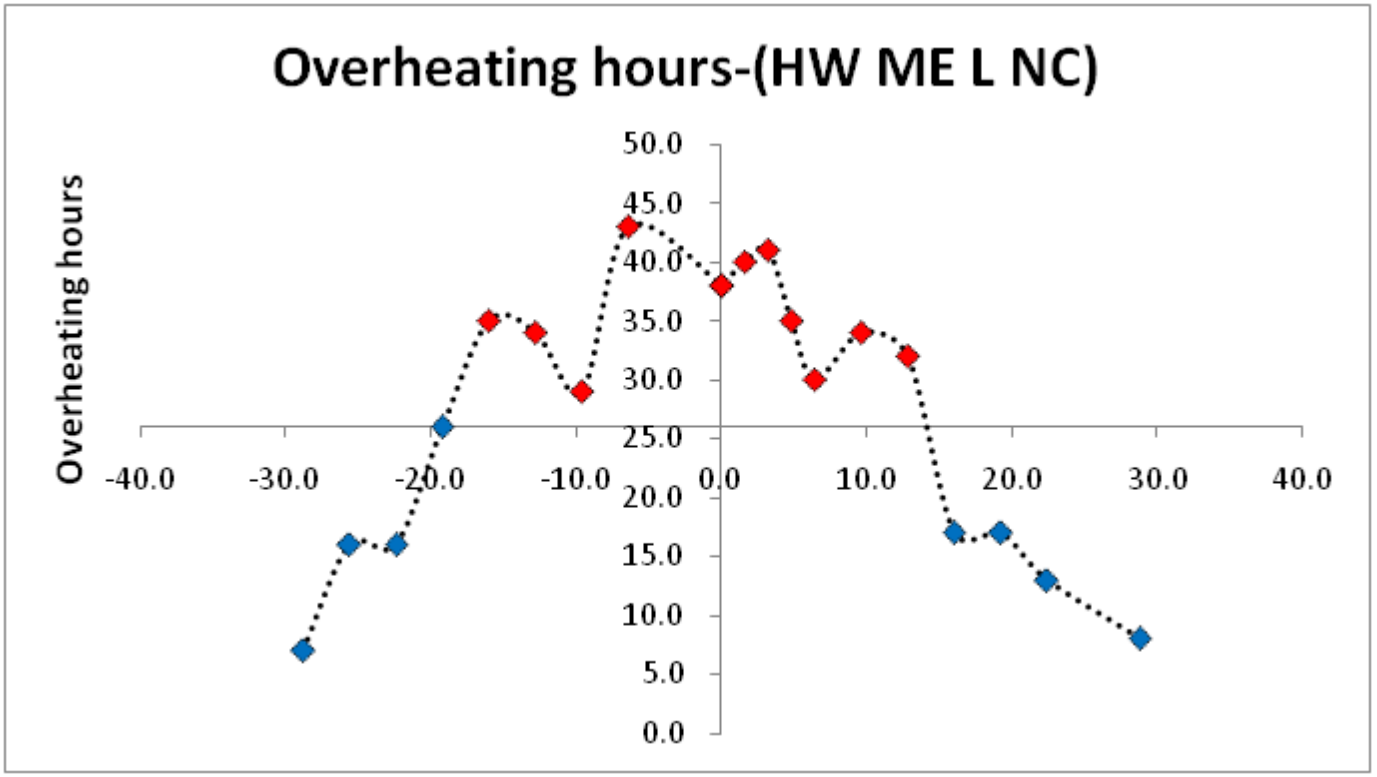
Comparison of measurement and prediction

WW11-Oct1999




HW-Cooling load,kWh/m²/year, 2000
70
60
50
40
30
20
10
0
-40
-30
-20
-10
0
10
20
30
40
y = 0.2259x + 37.516
y = -0.0927x + 37.528
y = 0.1702x + 23.188
y = -0.0995x + 23.318
y = 0.1637x + 21.539
y = -0.065x + 21.455
y = 0.1071x + 10.641
y = -0.0702x + 10.599
H NNC
H NC
M NNC
M NC


HW-Heating load, kWh/m²/year, 2000
70
60
50
40
30
20
10
0
-40
-30
-20
-10
0
10
20
30
40
y = -0.2915x + 32.91
y = 0.172x + 31.351
y = -0.2162x + 16.494
y = 0.128x + 15.239
H NNC
H NC
M NNC
M NC


Overheating hours-(HW ME L NC)
Overheating hours
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0

Using future weather files

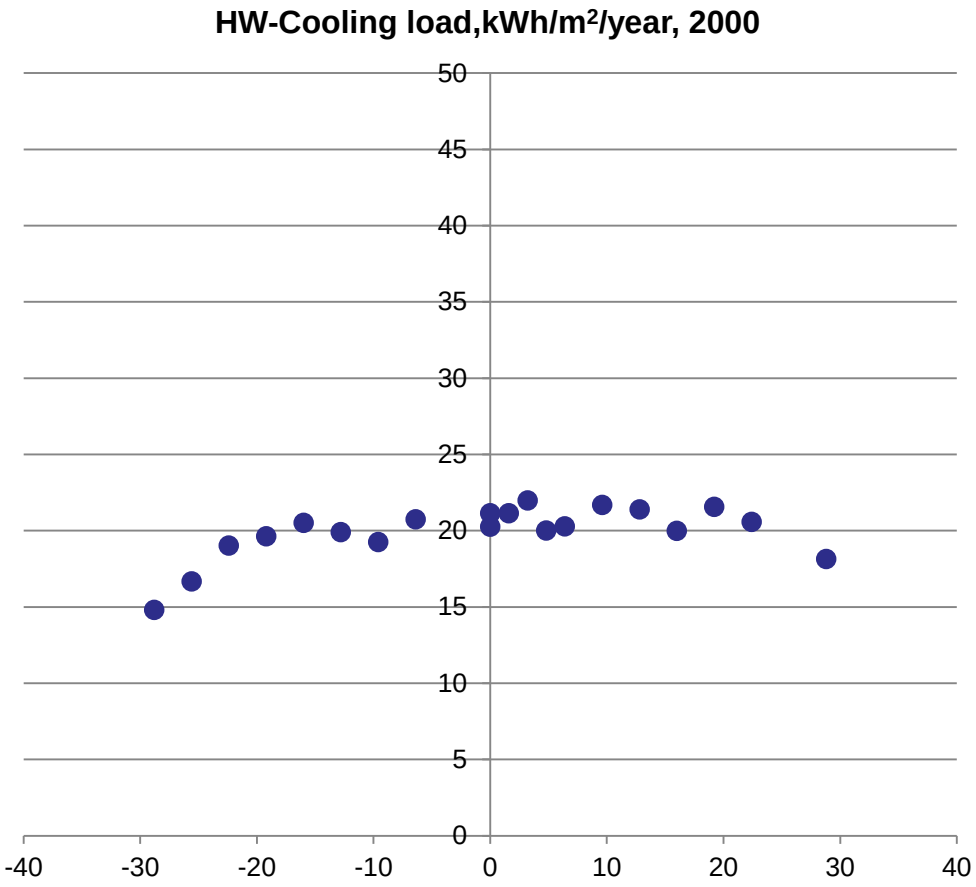
- we used CIBSE weather files for London 2050 (medium-high scenario, according to UKCP02)
- these were constructed using the method developed by Hacker and Blecher to predict parameters on an hourly basis
- we adapted air temperature based on the results of LSSAT. Everything else was kept the same over London.

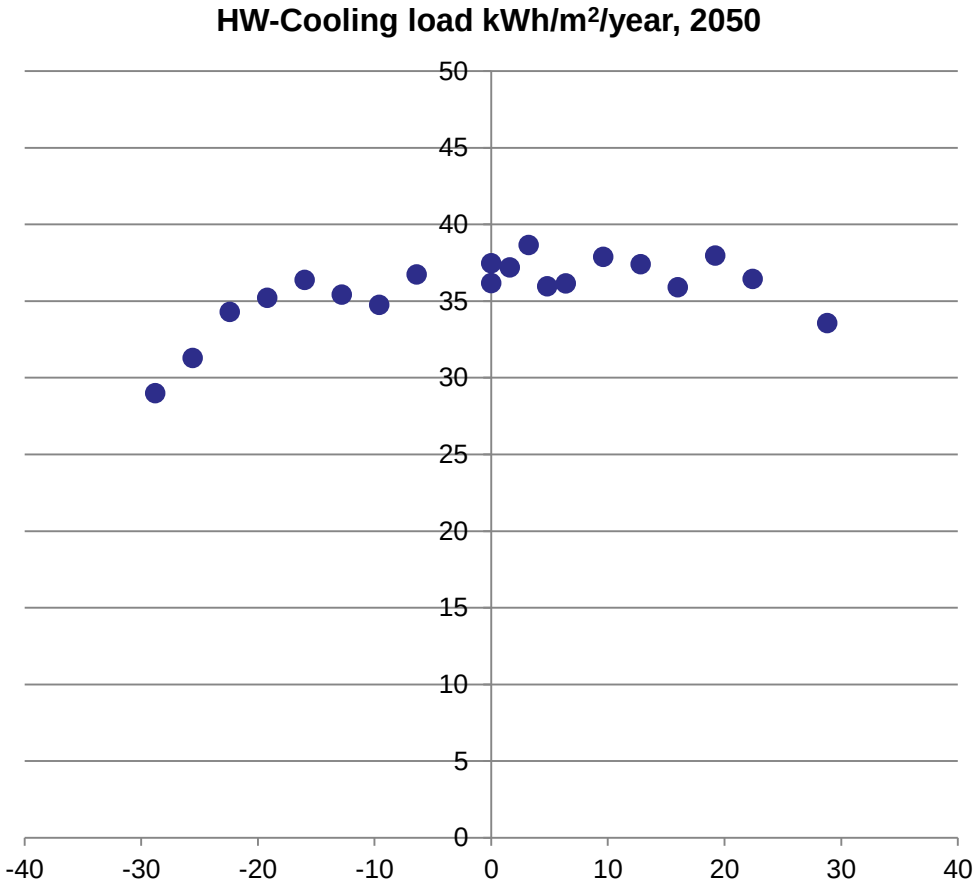
- More information:
- Demanuele C, Mavrogianni A, Davies M, Kolokotroni M, Rajapaksha I, (2012). *London's urban heat island: impact on overheating in naturally ventilated offices*. Serv. Eng. Res. Technol. 33, 4 (2012) pp. 351–369.
- Kolokotroni M., Ren X., Davies M., Mavrogianni A (2012). *London's urban heat island: impact on current and future energy consumption for heating and cooling*. Energy and Buildings, Vol 47, pp 302-311

ENERGY Bits

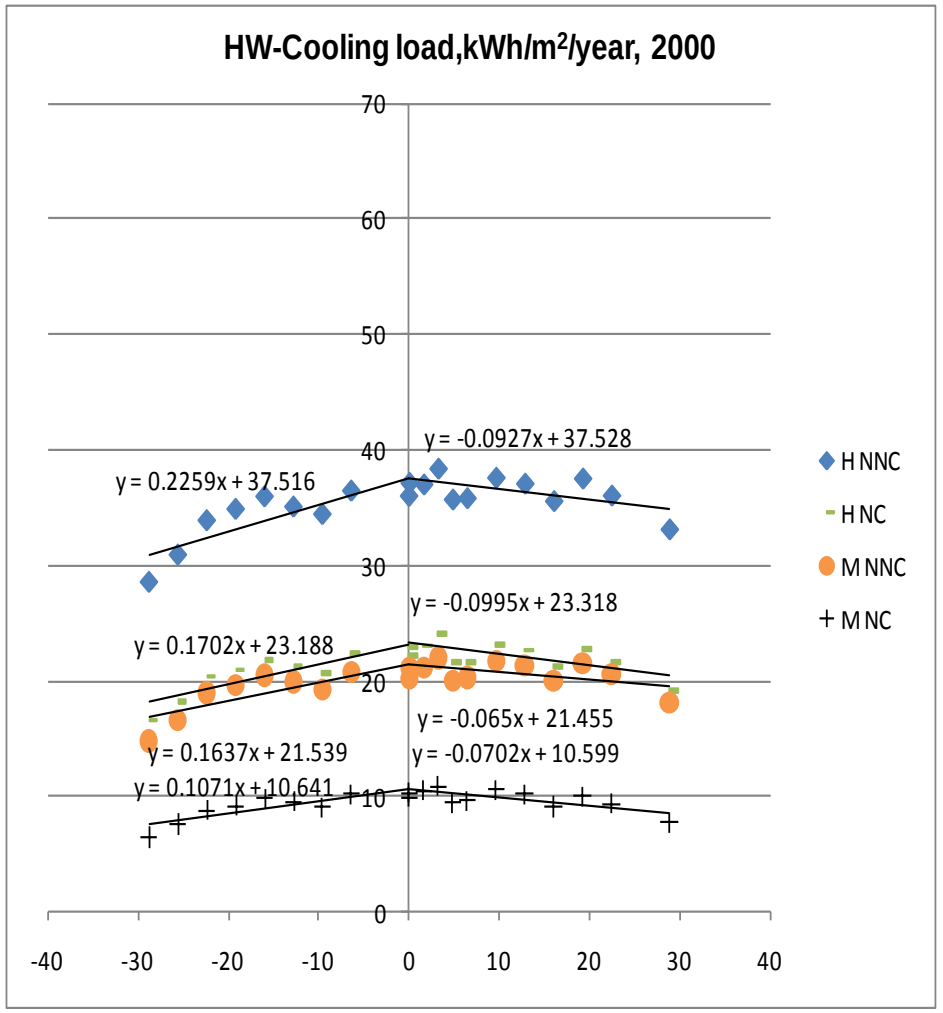
Brunel UNIVERSITY LONDON

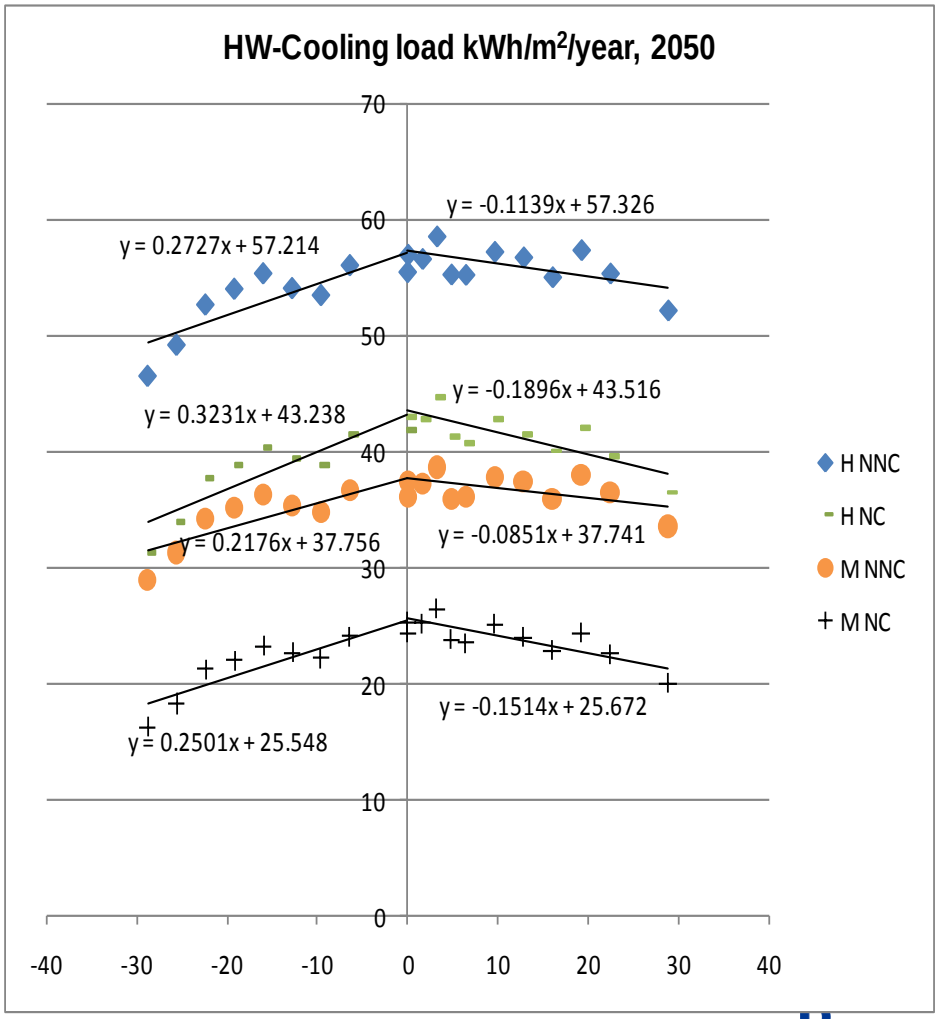
UHI, energy use and climate change



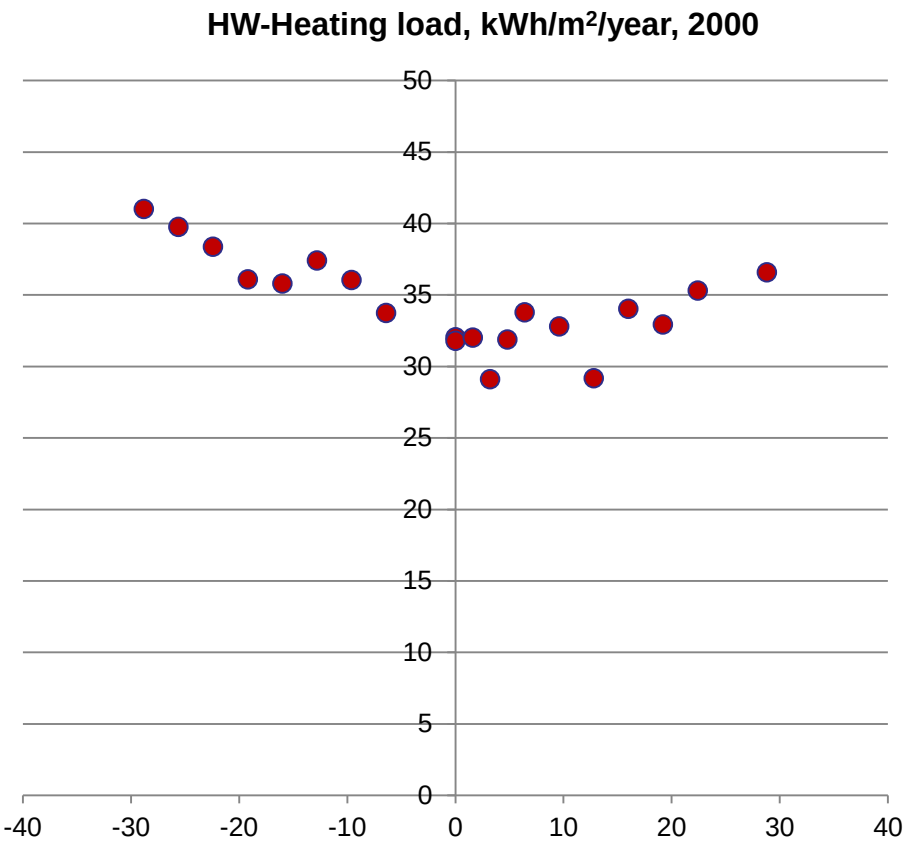


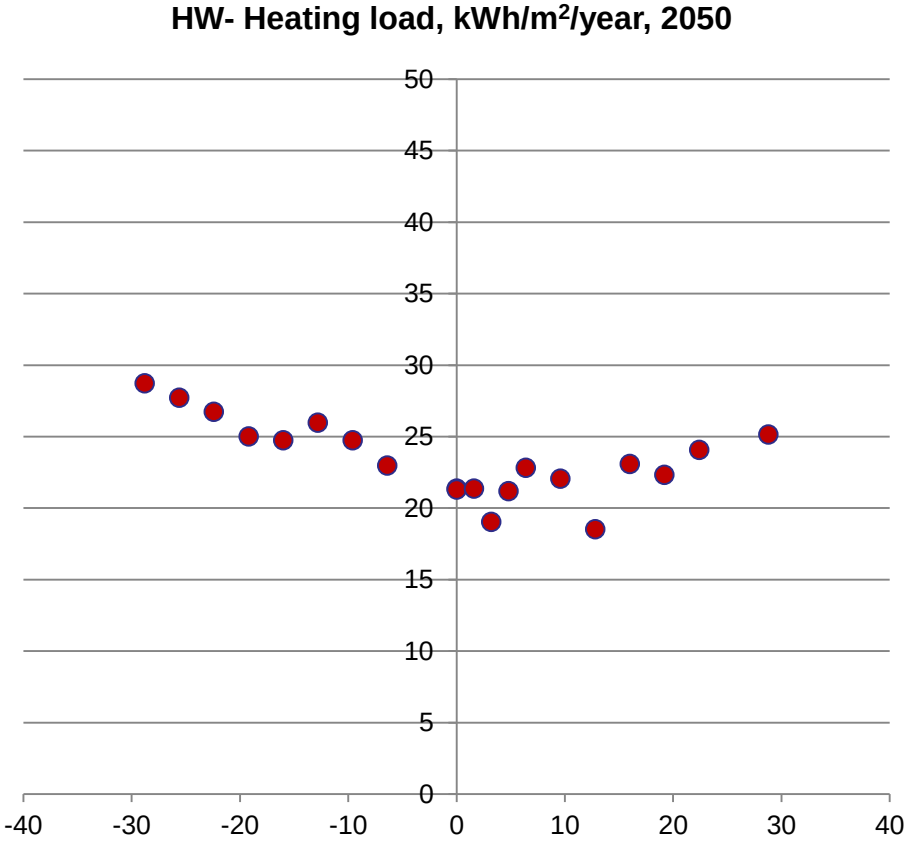
UHI, ventilation and climate change



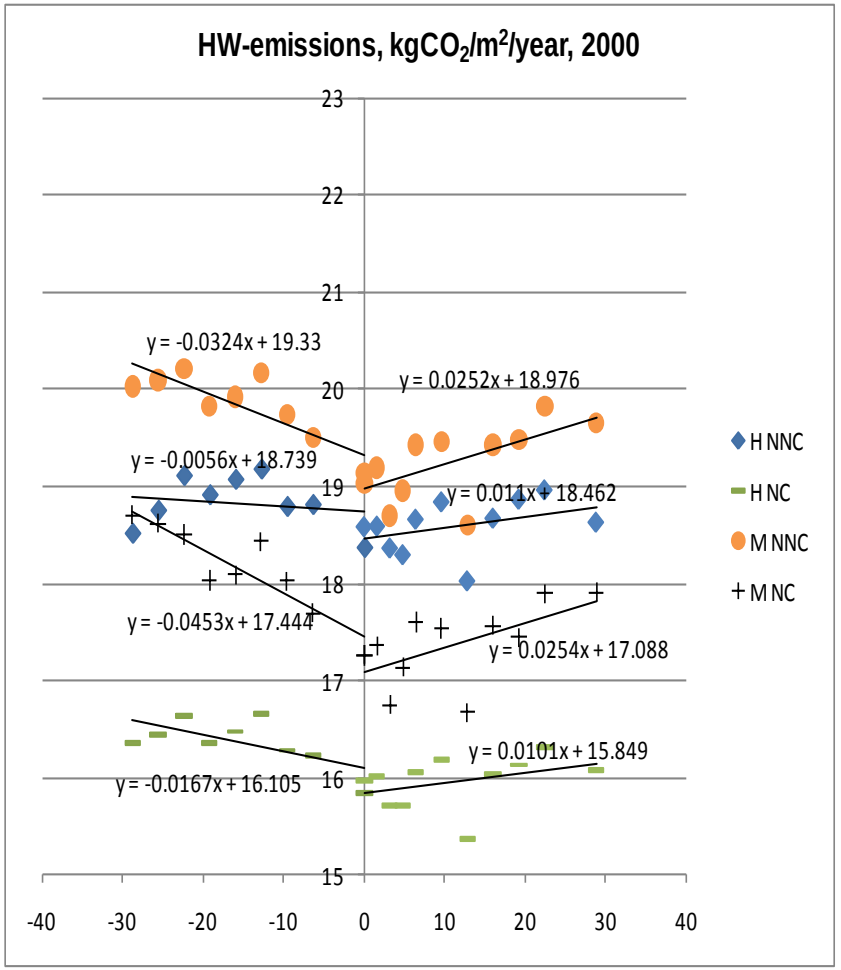


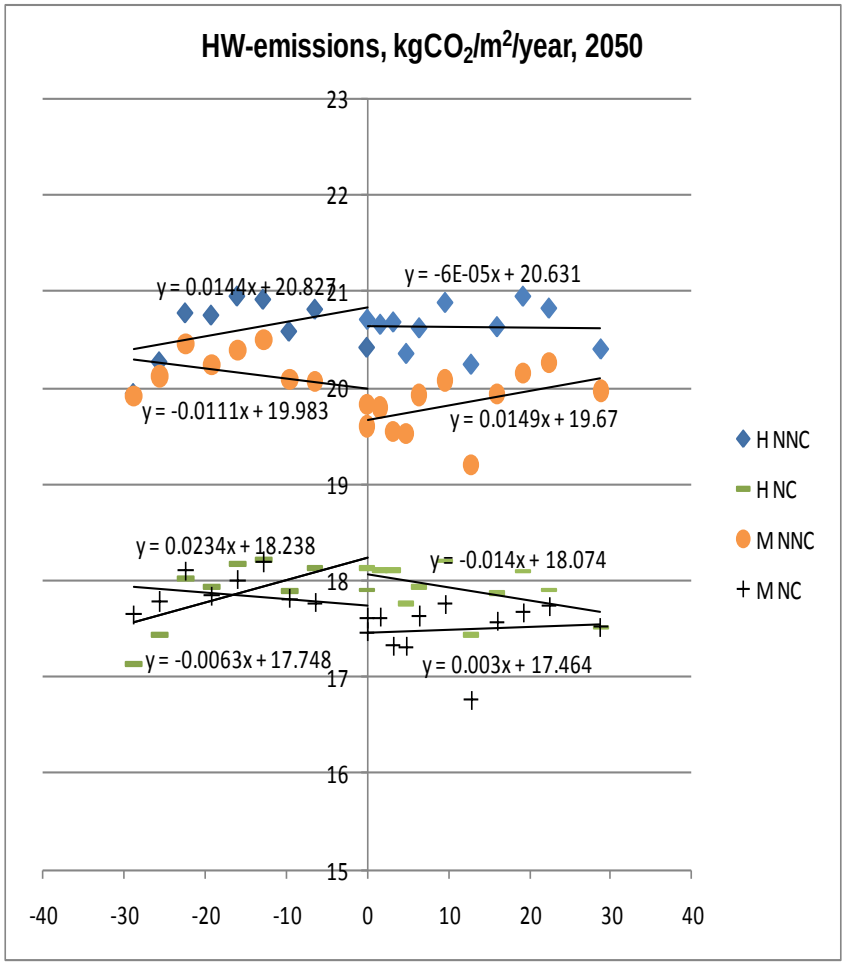
UHI, ventilation and climate change





UHI, ventilation and climate change





Some observations

- Offices with night ventilative cooling produce less CO2 in 2000 and 2050
- Difference between city and rural offices is less in 2050 with urban offices producing more CO2.
  - a 5–9% increase in CO2 emission is predicted in 2050 in the reference location and 13–15% in the city centre location.
  - In 2000, the environmental impact is up to 4% less in the city location compared to the reference location while in 2050 is 4.5% more.
- Overheating hours will increase up-to 140% in 2050 in the reference location and 110% in the city centre location. Heavy weight construction with night cooling has the highest increase but in terms of number of hours it still has the lowest number of overheating hours.
- Natural today versus AC in 2050: CO2 emissions increase between 230% and 340% in the reference location and between 480% and 670% in the city centre location.

Summary

- Urban buildings use more energy than rural buildings because of the Urban Heat Island Effect
- Less knowledge on how to improve thermal environment in cities, now and in the future, in particular moderate climates where requirements for heating fight requirements for cooling
- Challenge: How to design for ventilative cooling strategies and products taking into account future climate change predictions for the urban environment.

Thank you!