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Analysis of heat-related hazard reducing actions during heatwaves in Berlin

with an urbanized regional climate model COSMO-CLM/DCEP-BEM

Luxi Jin, Sebastian Schubert, Christoph Schneider

Geography Department, Humboldt Universität zu Berlin

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Contact: luxi.jin@geo.hu-berlin.de

Outline

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  - Original COSMO-CLM/DCEP
  - Building Energy Model (BEM)
- Model evaluation (Berlin, winter and summer 2018)
- Case Study (Berlin, 25-31 July, 2018)
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  - Result 3: energy consumption
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Background and Motivation

Figure 1: Alexanderplatz (photo: Bernd Settnik)

Urban expansion
– population 55% (2018) → 68% (2050) [1]

Change in urban landscape → more buildings and more anthropogenic heat flux (AH) from buildings

→ RQs:
– estimation of AH
– impact of AH on temperatures
– energy consumption for indoor heating / cooling

[1] United Nations, Department of Economic and Social Affairs, Population Division (2018): World Urbanization Prospects: The 2018 Revision, Highlights.

Estimation of AH

– Inventory approach[1]

– Energy budget closure[1]

– Building energy models[1] (TEB, WRF-BEM)

– Other approaches: EnergyPlus[2], TERRA-URB[3]

- energy consumption within buildings
- feedback of AH to atmosphere

Dynamically and explicitly!

[1] Sailor, D. J. (2011). A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment. International Journal of Climatology, 31(2), 189–199. https://doi.org/10.1002/joc.2106

[2] Crawley, D. B., Lawrie, L. K., Winkelmann, F. C., Buhl, W. F., Huang, Y. J., Pedersen, C. O., … Glazer, J. (2001). EnergyPlus: Creating a new-generation building energy simulation program. Energy and Buildings. https://doi.org/10.1016/S0378-7788(00)00114-6

[3] Wouters, H., Demuzere, M., Blahak, U., Fortuniak, K., Maiheu, B., Camps, J., … Van Lipzig, N. P. M. (2016). The efficient urban canopy dependency parametrization (SURY) v1.0 for atmospheric modelling: Description and application with the COSMO-CLM model for a Belgian summer. Geoscientific Model Development, 9(9), 3027–3054. https://doi.org/10.5194/gmd-9-3027-2016

Model Description COSMO-CLM/DCEP-BEM

COSMO – CLM[2]

- mesoscale
- non-hydrostatic
- climate mode

+

DCEP

- urban scheme

+

BEM

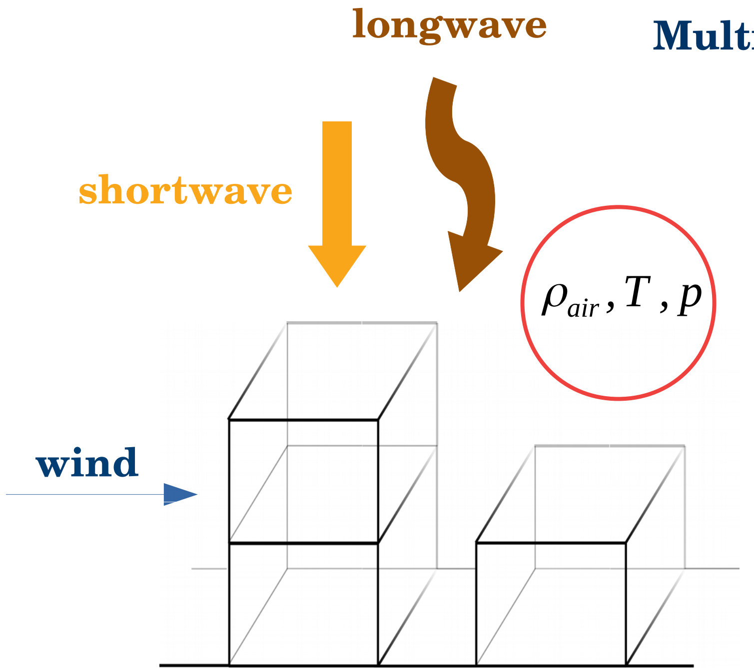
- building energy model

= **CCLM/DCEP-BEM**

[2] U.Schättler, G.Doms and C.Schraff, A description of the nonhydrostatic regional COSMO-Model

Model Description COSMO–CLM/DCEP

Multi-layer urban Double Canyon Effect Parametrization scheme [1]



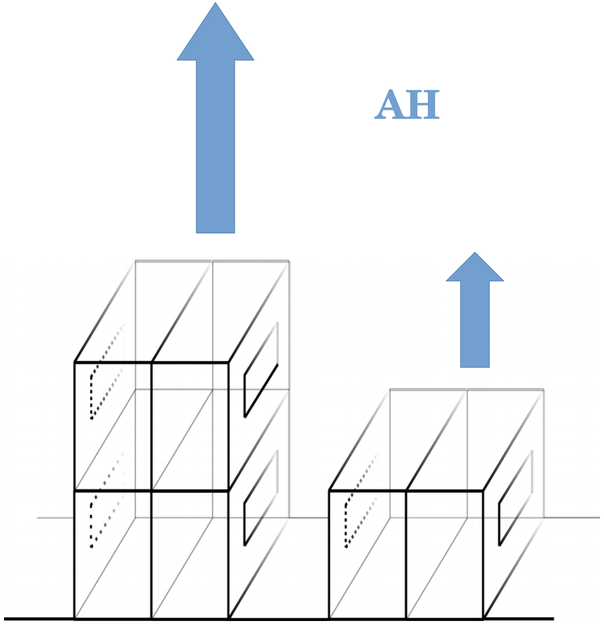
Street Canyon

Incoming / outgoing radiation
on
roof, wall, road

Integrated back to
mesoscale height level

[1] S. Schubert, S. Grossman-Clarke, A. Martilli (2012); A Double-Canyon Radiation Scheme for Multi-Layer Urban Canopy Models; Boundary Layer Meteorology, doi:10.1007/s10546-012-9728-3

Model Description DCEP–BEM



Street Canyon

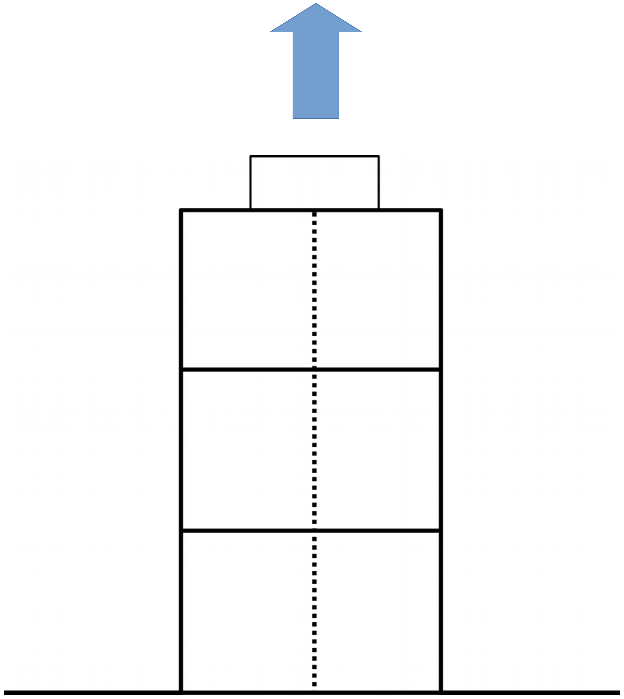
Building Energy Model [4]

- Add details, e.g. windows on canyon side
- Indoor sensible and latent load
  - equipment and person
  - heating / cooling system → regulate temperature
- Feedback to the atmosphere (anthropogenic heat AH)
  - wall / window conduction
  - ventilation
  - waste heat emission by AC outdoor unit

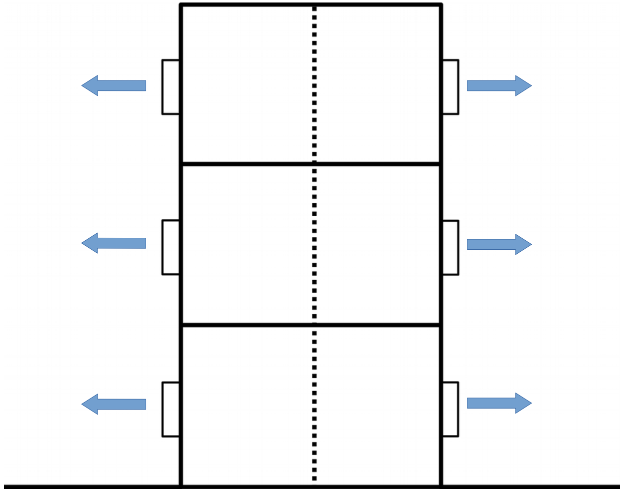
[4] Salamanca, F., Krpo, A., Martilli, A. et al. A new building energy model coupled with an urban canopy parameterization for urban climate simulations. Theor Appl Climatol (2010) 99: 331. https://doi.org/10.1007/s00704-009-0142-9

Model Description

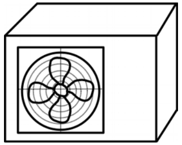
AC waste heat by DCEP–BEM



AC_HOR

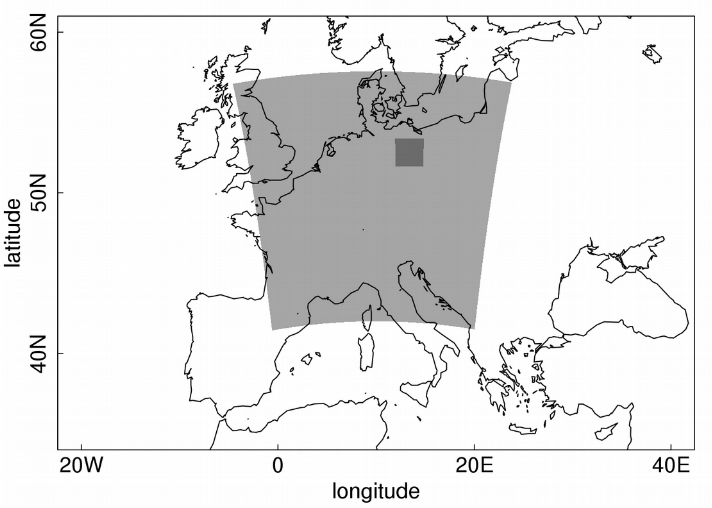


AC_VER



Outdoor unit

Model Evaluation Simulation setup



CCLM setup:

2 periods: 15.02.2018 – 10.03.2018
25.07.2018 – 17.07.2018

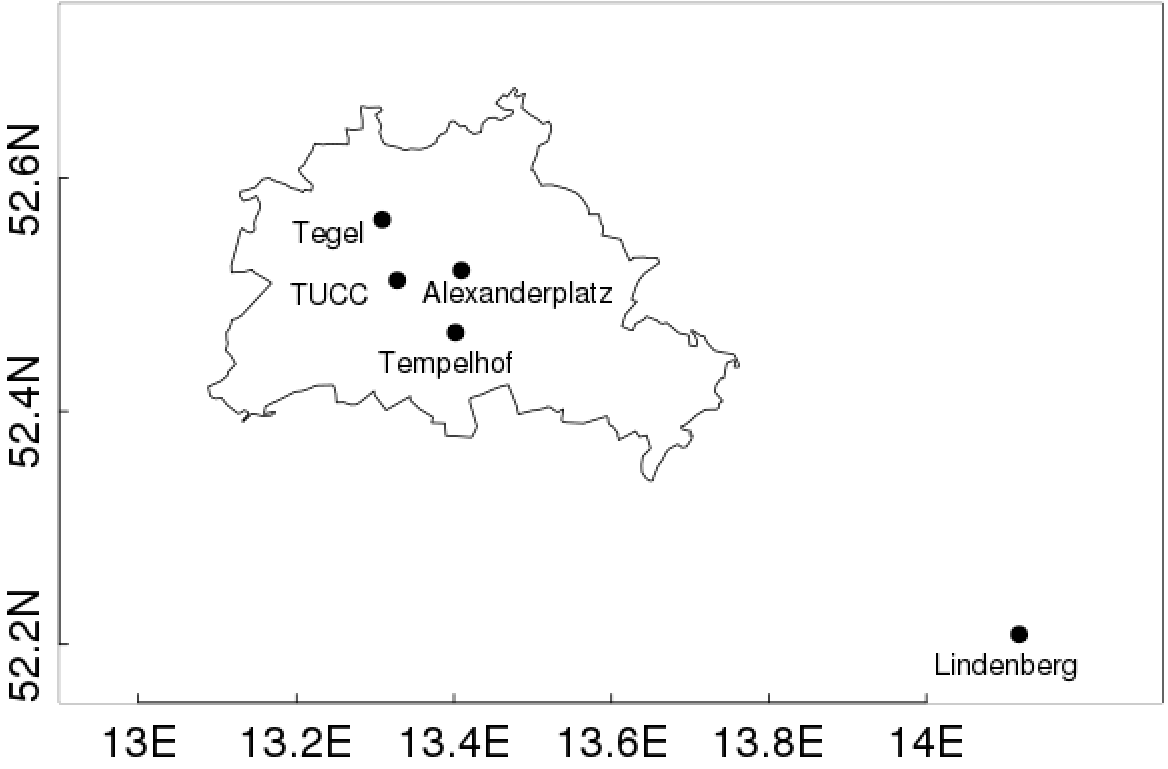
Two-step one-way nesting (COSMO 5.0/CLM9)

ERA5 → CCLM 7km → CCLM/DCEP 1km (reference)
→ CCLM/DCEP-BEM 1km

BEM setup

– indoor target temperature: based on measurement (ca. 21°C) in winter; not regulated in summer.
– ventilation: 0.1 (daytime) / 0 (nighttime) in winter; 0.25 in summer

Model Evaluation Measurements



Urban site: Berlin-Alexanderplatz

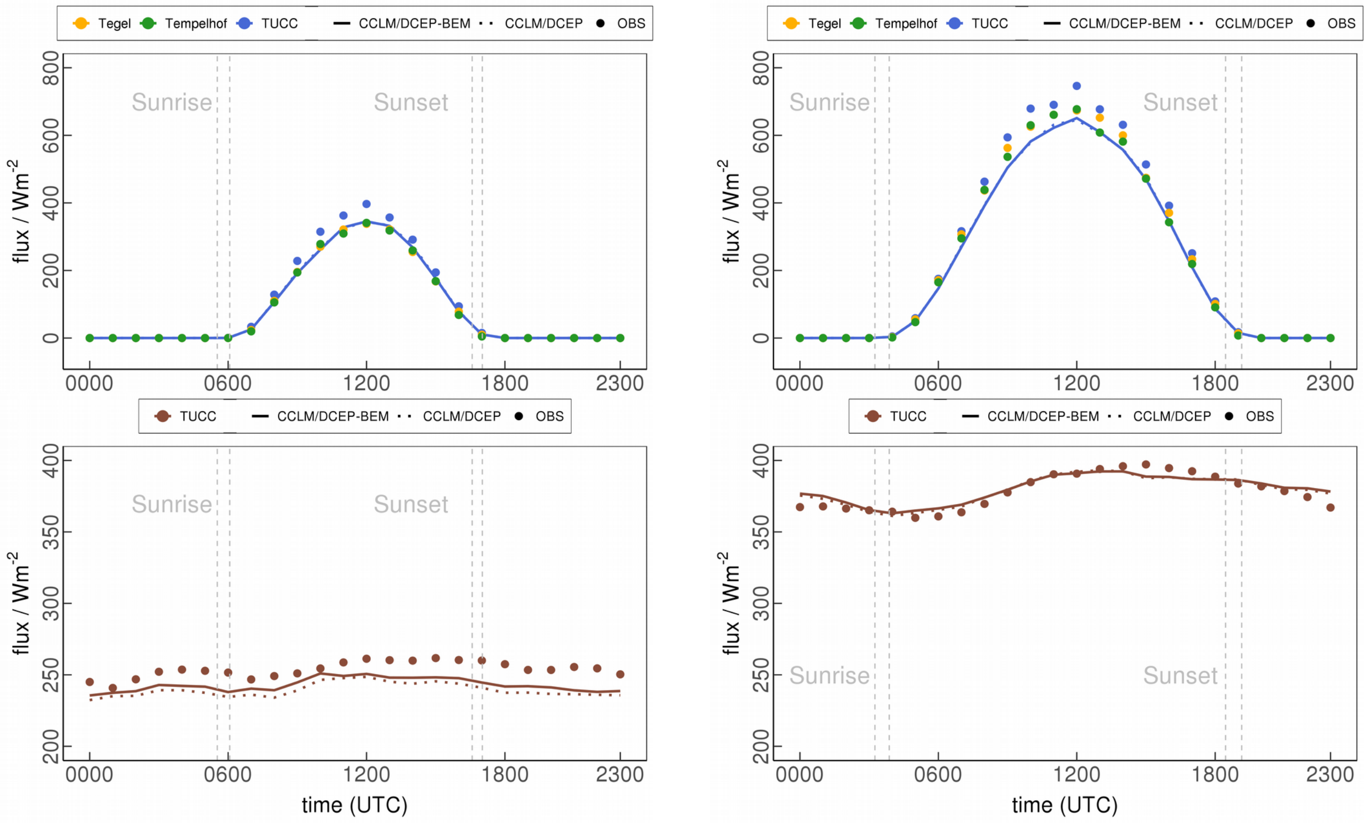
Rural site: Lindenberg

Energy balance site: TUB Campus Charlottenburg (TUCC)

Reference site for radiative fluxes:

Berlin-Tegel and Berlin-Tempelhof

Model Evaluation Radiative fluxes



WINTER   SUMMER

Downward shortwave radiation (SW)

– measurement uncertainty (max. 57 Wm^{-2} in winter; 73 Wm^{-2} in summer)

– good fit at reference sites in winter; underestimation in summer

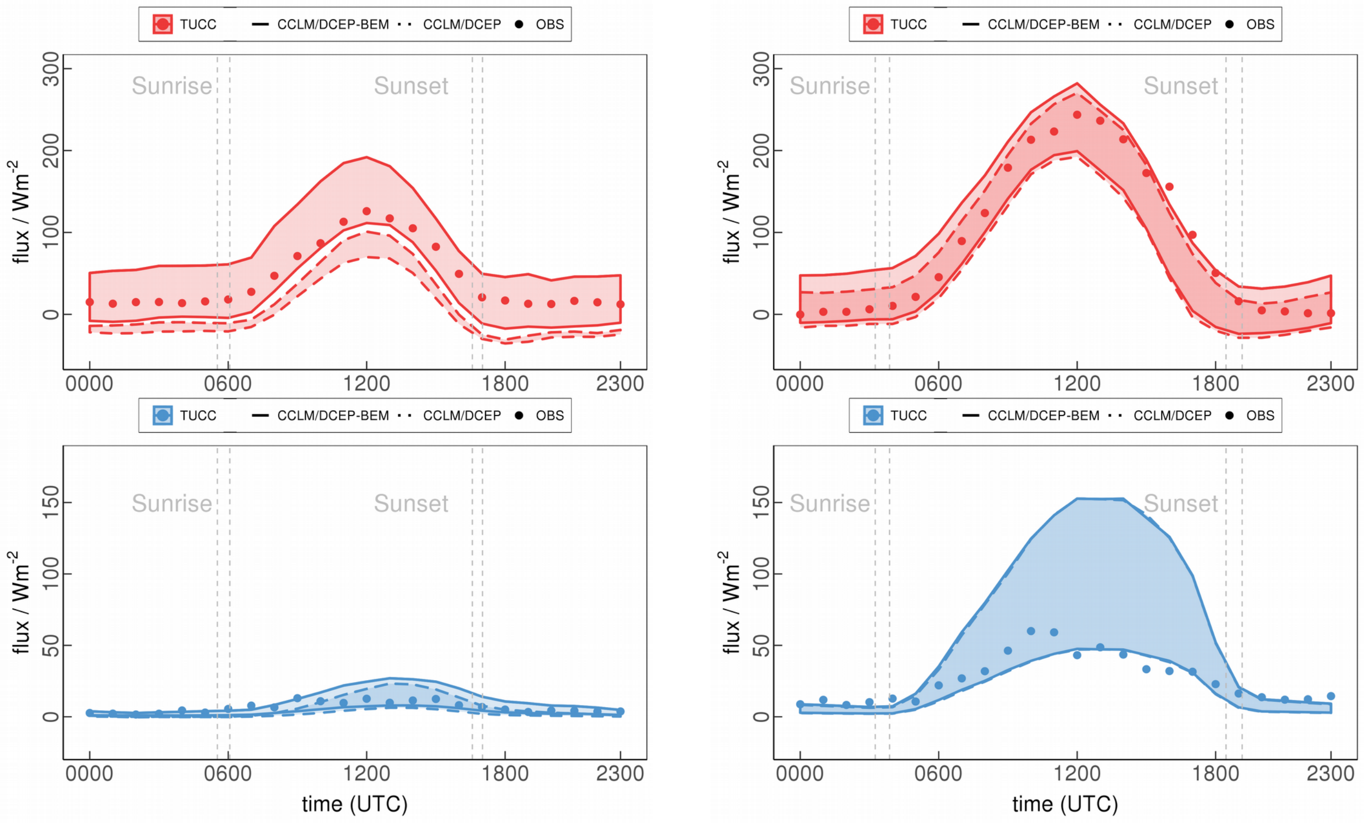
– No obvious difference between DCEP and DCEP/BEM

Downward longwave radiation (LW)

– underestimation in winter; good fit summer

– No obvious difference between DCEP and DCEP/BEM

Model Evaluation Surface fluxes (fetch = 1 grid box)



WINTER

SUMMER

Sensible heat flux (QH)

– winter: underestimation by DCEP

→ increase after adding anthropogenic heat release from buildings (DCEP-BEM)

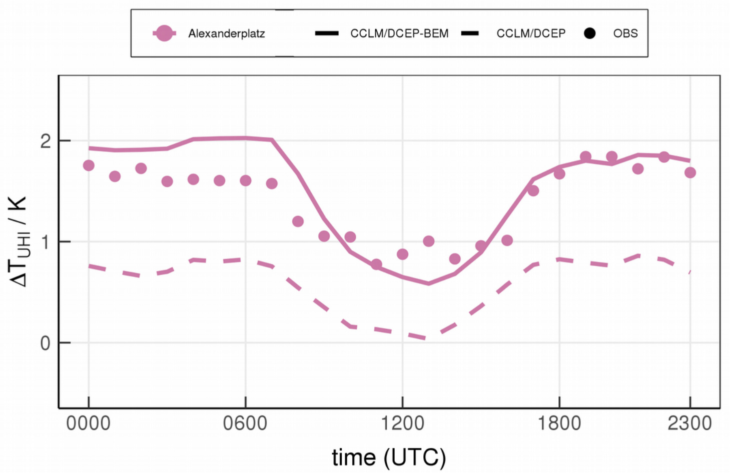
– summer: small increase by DCEP-BEM ← QH by indoor equipment, occupant and natural ventilation

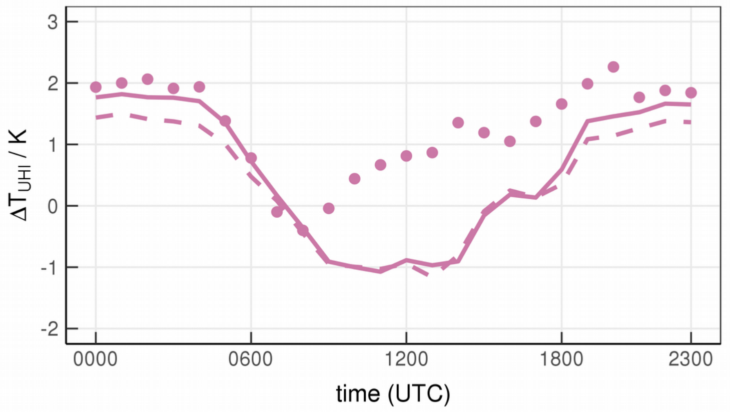
Latent heat flux (QE)

– winter: small increase by DCEP-BEM ← QE by indoor occupant and natural ventilation

– summer: No obvious difference between DCEP and DCEP-BEM

Model Evaluation Urban heat island intensity (ΔT_{UHI})





$$\Delta T_{UHI} = T_{2m}^{urb} - T_{2m}^{rur}$$

Winter ΔT_{UHI}

– underestimation by DCEP

– increased by DCEP-BEM due to indoor heating

Summer ΔT_{UHI}

– underestimation by DCEP

– small increase by DCEP-BEM especially during the night

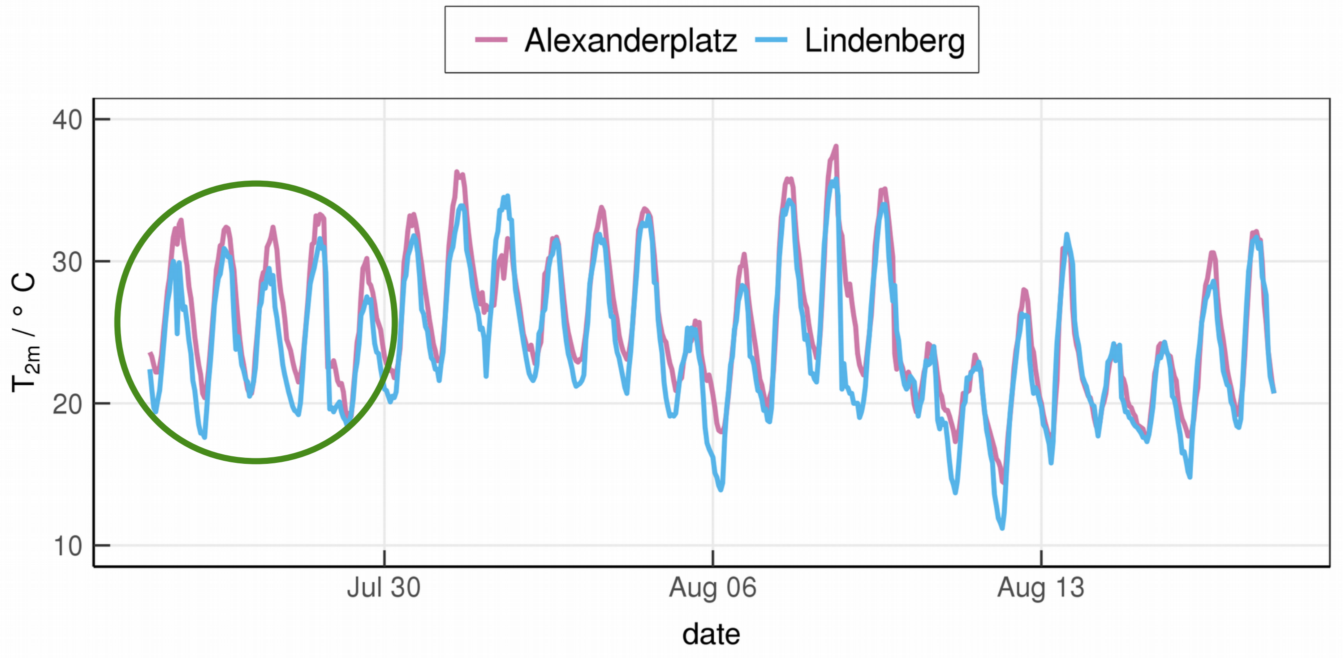
Case Study A Heatwave Event (25–31 July, 2018)

Meteorological conditions at urban site:

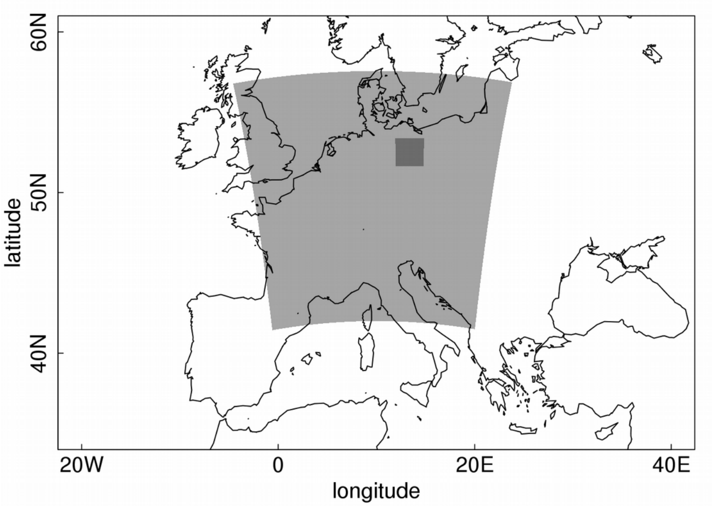
– Stable synoptic situation

– Tmax > 30°C; Tmin > 20°C

– No precipitation



Case study Simulation setup



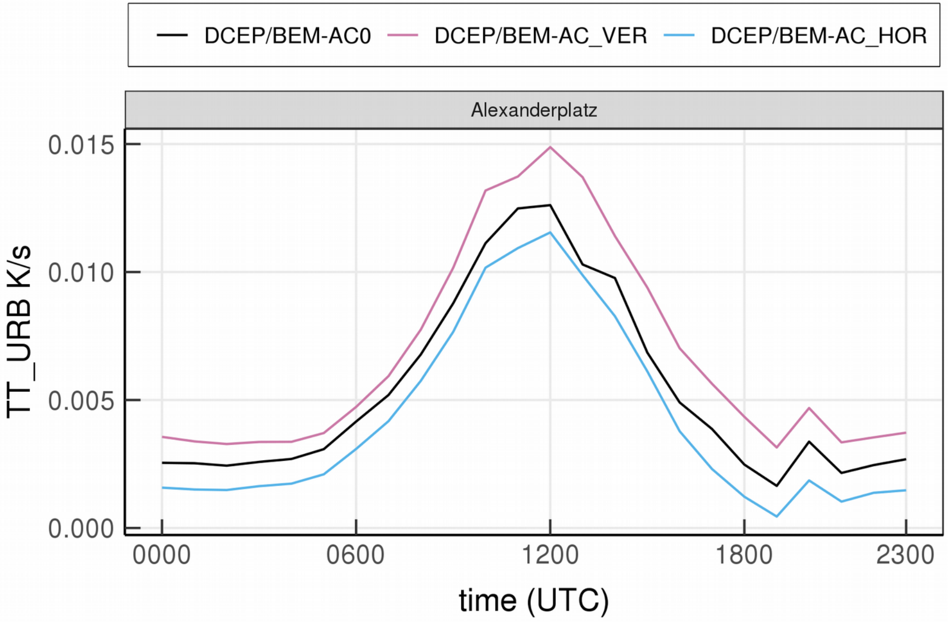
Two-step one-way nesting (COSMO 5.0/CLM9)

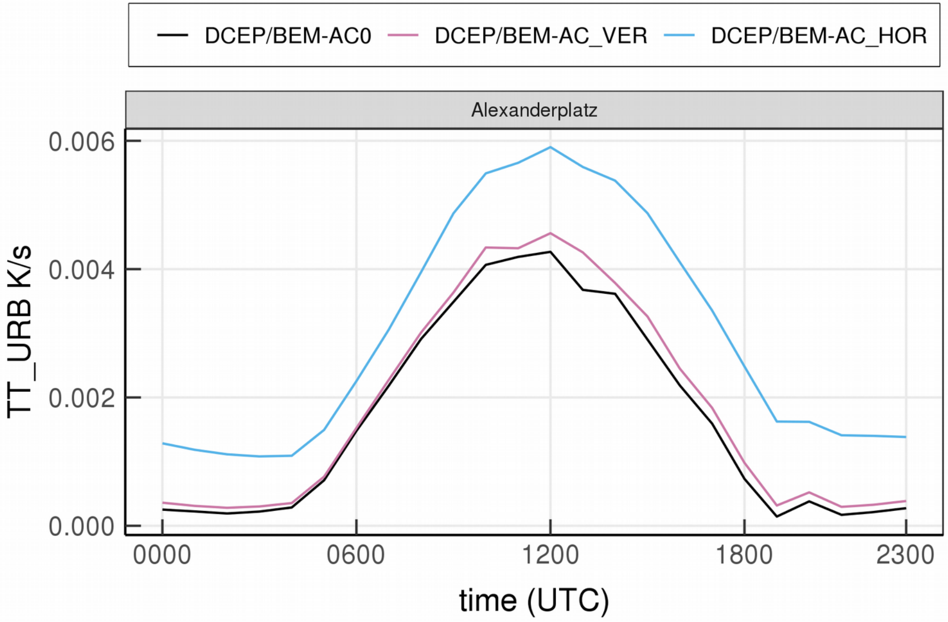
ERA5 → CCLM 7km → CCLM/DCEP-BEM-AC0 (reference)
→ CCLM/DCEP-BEM-AC_VER
→ CCLM/DCEP-BEM-AC_HOR

BEM setup

– indoor target temperature for AC: 24°C (297.15 K) ± 0.5 K
– ventilation: none

Case Study Result 1: Temperature tendencies at lowest model levels





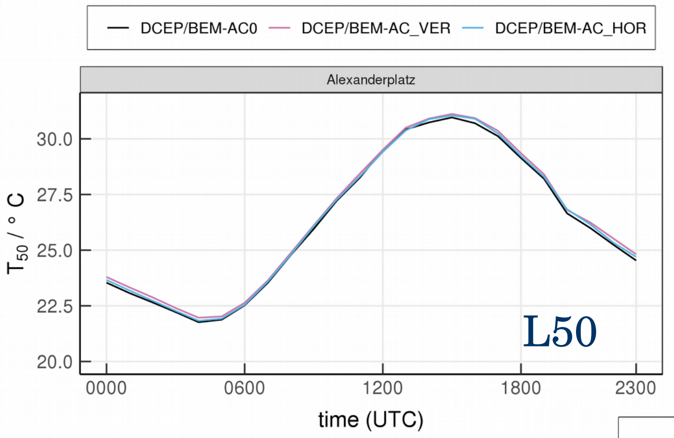
Lowest model level (L50): 0 – 20m

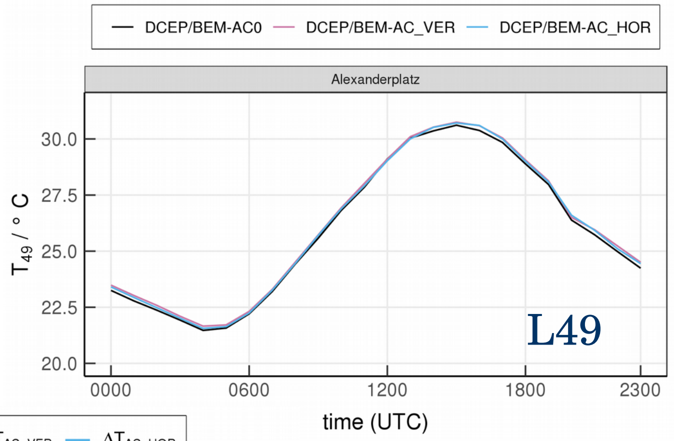
– $TT\_URB_{AC\_VER} > TT\_URB_{AC0} > TT\_URB_{AC\_HOR}$
– largest increase at noon

Second lowest model level (L49): 20 – 51.43m

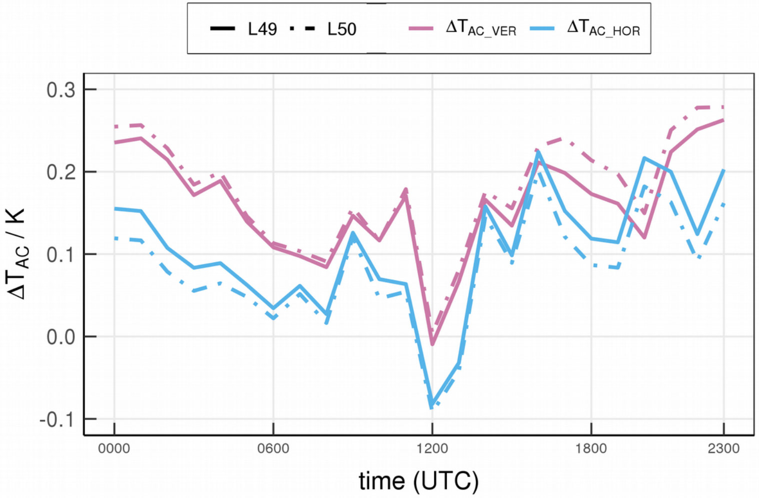
– $TT\_URB_{AC\_HOR} > TT\_URB_{VER} > TT\_URB_{AC0}$
– largest increase at noon

Case Study Result 2: Temperature at lowest model levels



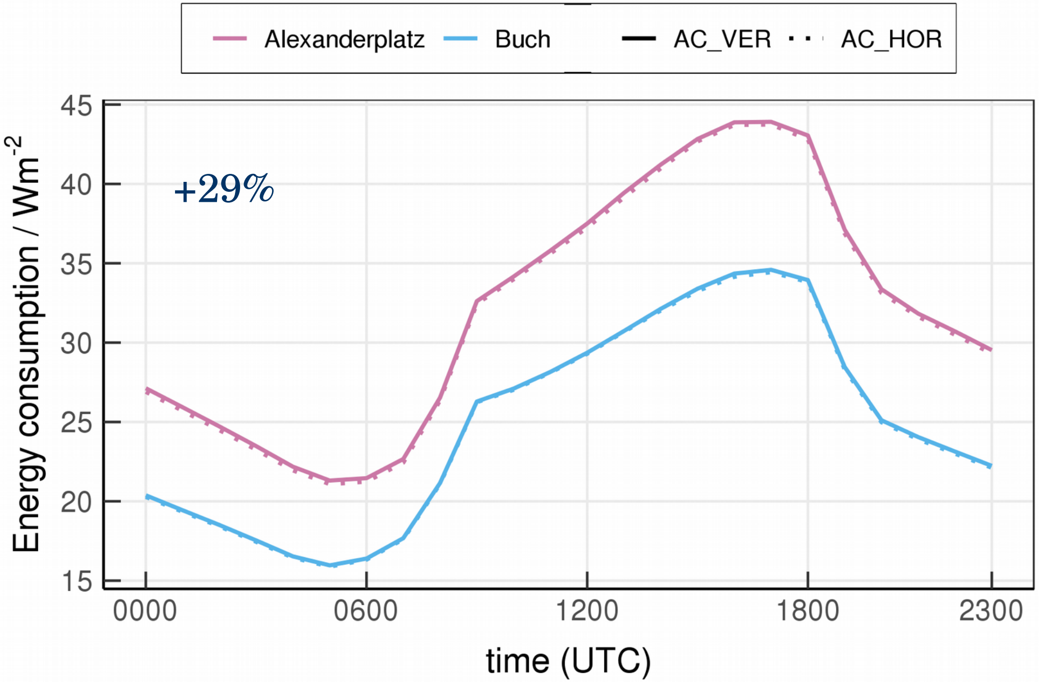


$\Delta T_{AC} = T_{AC} - T_{AC0}$



– more increase by AC_VER than AC_HOR
→ similar to TT_URB
– largest temperature increment during night
→ increase nighttime urban heat island
– no clear difference between L50 and L49
→ buildings < 20m dominant
– L50 to L49: ΔT_{AC_HOR} increases; ΔT_{AC_VER} decreases
→ impact of AC_HOR at L49 > L50

Case Study Result 3: Energy consumption due to AC cooling



Comparison with recent studies:

– Beijing: 52.91 Wm^{-2} (urb), 43.77 Wm^{-2} (suburb) [1]

Comparison of cooling load between urban and suburb sites:

– +17% [1] in Beijing
– +25% [2] in London
– +39% [3] for isolated buildings in Milan

[1] Xiaoyu, Xu & Gonzalez, Jorge & Shen, Shuanghe & Miao, Shiguang & Dou, Junxia. (2018). Impacts of urbanization and air pollution on building energy demands — Beijing case study. Applied Energy. 225. 10.1016/j.apenergy.2018.04.120.
[2] Kolokotroni, M., Zhang, Y., & Watkins, R. (2007). The London Heat Island and building cooling design, 81, 102–110. https://doi.org/10.1016/j.solener.2006.06.005
[3] Paolini, R., Zani, A., Meshkinkiya, M., Castaldo, V. L., Pisello, A. L., Antretter, F., … Cotana, F. (2017). The hygrothermal performance of residential buildings at urban and rural sites: Sensible and latent energy loads and indoor environmental conditions. Energy & Buildings, 152, 792–803. https://doi.org/10.1016/j.enbuild.2016.11.018

Summary and Outlook

- DCEP-BEM
  - Improvement of UHI intensity in winter with added AH
  - AC_VER influences L50 more; AC_HOR influences L49 more
  - Up to 0.3K temperature increase due to AC
  - Comparable energy consumption
- Add heat emission from traffic into lowest model levels
- Compare with other method

https://interfacelift.com/wallpaper/details/4057/after_work.html

Modification of vegetated area in urban grid cell (winter/summer):
- LAI 1.1/3.5; RD: 1.5; PLC: 0.48/0.88; RL:0.02/0.13

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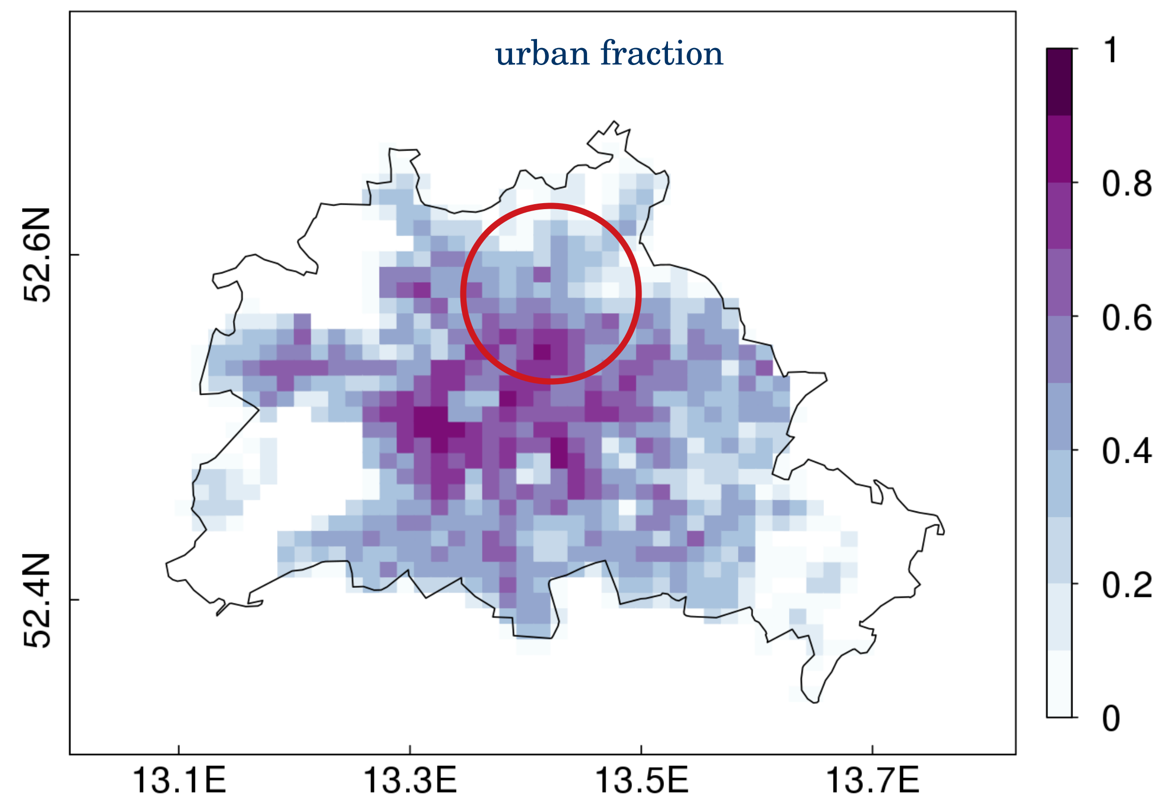
latent	Latent heat of vaporization [J/kg]	2.45×10^{6}
cop	Coefficient of performance of the A/C systems [-]	3.5
beta	Thermal efficiency of heat exchanger [-]	0.75
gaptemp	Comfort Range of the indoor Temperature, [K]	0.5
gaphum	Comfort Range of the specific humidity, [Kg/Kg]	0.005
targhum	Target humidity of the A/C systems, [Kg/Kg]	0.005
perflo	Peak number of occupants per unit floor area, [person/m^2]	0.01
hsesf	Peak heat generated by equipments, [W/m^2]	16
hsequip (24)	Diurnal heating profile of heat generated by equipments	0.25 for 0-6UTC, 0.5, 1 for 8-17 UTC, 0.5, 0.25 for 19-23 UTC
fr_window	Coverage area fraction of windows in the walls of the building [-]	0.2
p_num	Number of panes in the windows (1,2 or 3)	2
q_num	Category number for the windows (q_num= 4, standard glasses)	4
emwin	Emissivity of windows	0.9

Street direction	-45°, 0°, 45°, 90° from north
Window fraction	0.16
Sensible / latent heat gain by person	160 W m^{-2}
Sensible heat gain by equipment	7.4 W m^{-2}
Coefficient of Performance (COP)	3.5
Volumetric heat capacity of exterior ground / wall / roof	1.94×10^{6} 2.25×10^{6} 1.769×10^{6}
Thickness of wall / roof	0.3145 m
Initial temperature	296 K (summer) 273 K (winter)
Target indoor temperature	20-22°C (based on measurements)
ventilation	Winter: 0700-1800 UTC (0.1), nighttime 0 Summer: 0.1


urban fraction
52.6N
52.4N
13.1E
13.3E
13.5E
13.7E
1
0.8
0.6
0.4
0.2
0