Building surface model

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Content

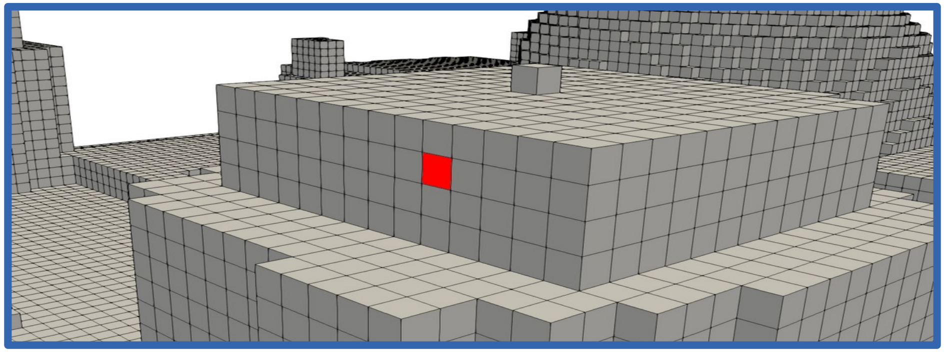
- General concept of the building surface model
- Differences to land surface model
- Usage
- Examples
- Indoor climate model: Outline

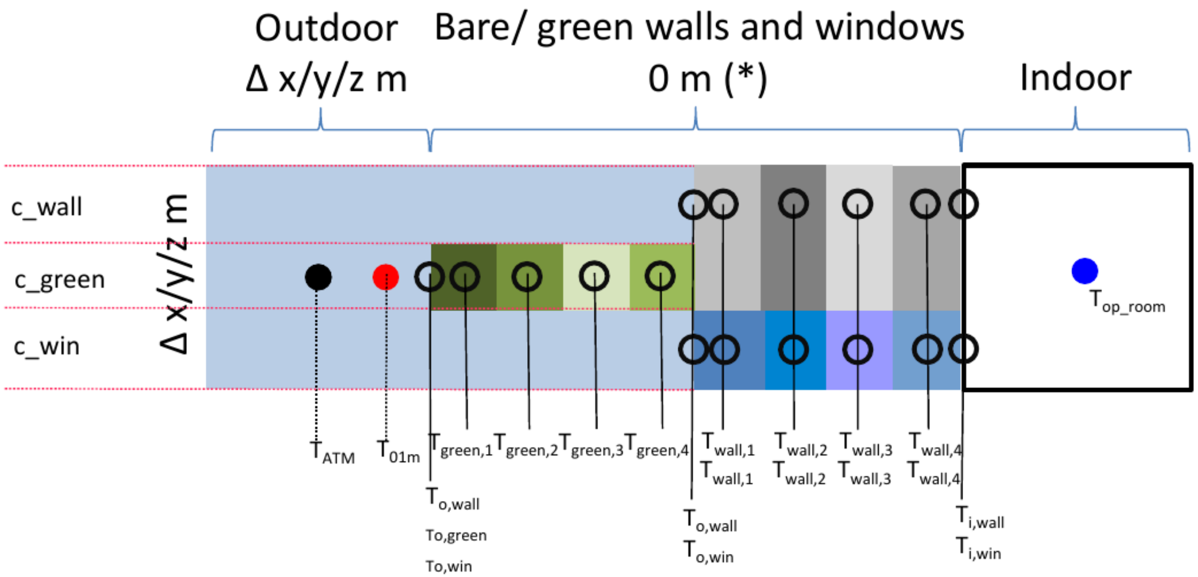
General concept

- Representation of buildings as obstacles
- Commonly done in CFD models, but
  - No thermodynamics, or
  - Prescribed surface temperature / fluxes at building surfaces.
  - Thermodynamic interactions are usually ignored!
- If interactions between atmosphere and buildings are important:
  - Building surface model (BSM)
- Treatment similar as in Land surface model (LSM)
  (1D, building surfaces on Cartesian grid)
- Coupled to indoor climate model (ICM)
- Terms BSM and USM (urban surface model, deprecated) used synonymously

General concept

- Energy balance solver for T_0
- Tile approach:
  - Wall fraction c_wall
  - Window fraction c_win
  - Green fraction c_green
- 3-layer wall model
- Boundary condition:
  - ICM: T_{op_room}
  - no ICM: $T_{wall,4}$

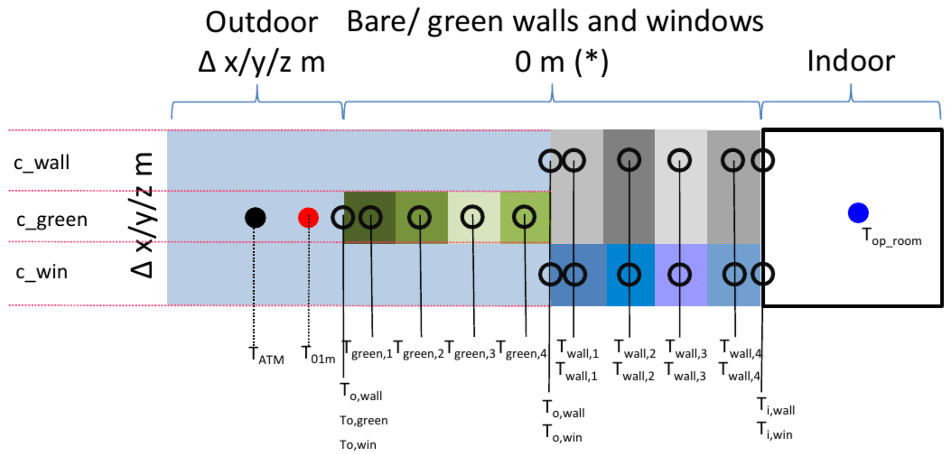




(*) wall thickness on 3D grid in PALM

General concept

- Physical properties of surfaces, walls, windows, green elements are stored in a database
- Insulation of windows is characterized by the U-value (in a single layer)
- Absorption of shortwave radiation inside window layers follows logarithmic function
- Absorbed heat by windows is taken into account
- Green elements similar to LSM, but extraction of water from deeper soil layers by plants is neglected (substrate is saturated for now)



(*) wall thickness on 3D grid in PALM

- For details, see Resler et al. (2017, Geosci. Model Dev. , Vol 10)

Building database

- Physical properties of surfaces, walls, windows, green elements are stored in a database
- Classification:

building_type	Description (Usage, Year of construction)
0	User-defined
1	Residential, < 1950
2	Residential, 1950 - 2000
3	Residential, > 2000
4	Office, < 1950
5	Office, 1950 - 2000
6	Office, > 2000

Building database

- Each building_type in the database sets 136 parameters automatically

```
building_pars(:,2) = (/    &
      0.73_wp,          & !< parameter 0   - wall fraction above ground floor level
      0.27_wp,          & !< parameter 1   - window fraction above ground floor level
      0.0_wp,           & !< parameter 2   - green fraction above ground floor level
      0.0_wp,           & !< parameter 3   - green fraction roof above ground floor level
      1.5_wp,           & !< parameter 4   - LAI roof
      1.5_wp,           & !< parameter 5   - LAI on wall above ground floor level
      2000000.0_wp,     & !< parameter 6   - heat capacity 1st/2nd wall layer above ground floor level
      103000.0_wp,      & !< parameter 7   - heat capacity 3rd wall layer above ground floor level
      900000.0_wp,      & !< parameter 8   - heat capacity 4th wall layer above ground floor level
      0.35_wp,          & !< parameter 9   - thermal conductivity 1st/2nd wall layer above ground floor level
      0.38_wp,          & !< parameter 10  - thermal conductivity 3rd wall layer above ground floor level
      0.04_wp,          & !< parameter 11  - thermal conductivity 4th wall layer above ground floor level
      299.15_wp,        & !< parameter 12  - indoor target summer temperature
      293.15_wp,        & !< parameter 13  - indoor target winter temperature
      0.92_wp,          & !< parameter 14  - wall emissivity above ground floor level
      0.86_wp,          & !< parameter 15  - green emissivity above ground floor level
      0.87_wp,          & !< parameter 16  - window emissivity above ground floor level
      0.7_wp,           & !< parameter 17  - window transmissivity above ground floor level
      0.001_wp,         & !< parameter 18  - z0 roughness above ground floor level
      0.0001_wp,        & !< parameter 19  - z0h/z0g roughness heat/humidity above ground floor level
      4.0_wp,           & !< parameter 20  - ground floor level height
      0.78_wp,          & !< parameter 21  - wall fraction ground floor level
      0.22_wp,          & !< parameter 22  - window fraction ground floor level
      0.0_wp,           & !< parameter 23  - green fraction ground floor level
      0.0_wp,           & !< parameter 24  - green fraction roof ground floor level
      1.5_wp,           & !< parameter 25  - LAI on wall ground floor level
      2000000.0_wp,     & !< parameter 26  - heat capacity 1st/2nd wall layer ground floor level
      103000.0_wp,      & !< parameter 27  - heat capacity 3rd wall layer ground floor level
      900000.0_wp,      & !< parameter 28  - heat capacity 4th wall layer ground floor level
      0.35_wp,          & !< parameter 29  - thermal conductivity 1st/2nd wall layer ground floor level
      0.38_wp,          & !< parameter 30  - thermal conductivity 3rd wall layer ground floor level
      0.04_wp,          & !< parameter 31  - thermal conductivity 4th wall layer ground floor level
      0.92_wp,          & !< parameter 32  - wall emissivity ground floor level
      0.11_wp,          & !< parameter 33  - window emissivity ground floor level
```

Building database

- Each building_type in the database sets 136 parameters automatically
- A selected number of parameters can be overwritten in the static driver

Technical details

- Calculation of surface resistances for vertical surfaces (LSM and BSM)

Horizontal:
Monin-Obukhov Similarity Theory

$$H = -\rho\ c_\mathrm{p}\ \frac{1}{r_\mathrm{a}}(\theta_1 - \theta_0)$$
$$= \rho\ c_\mathrm{p}\ \overline{w'\theta'}_0$$
$$= -\rho\ c_\mathrm{p}\ u_*\ \theta_*$$

$$u_*\ \theta_* = \frac{1}{r_\mathrm{a}}(\theta_1 - \theta_0)$$

$$\rightarrow r_\mathrm{a} = \frac{\theta_1 - \theta_0}{u_*\ \theta_*}$$

Vertical:
Krayenhoff & Voogt (2007)

$$H = \left(\frac{z_0}{z_{0,\mathrm{concrete}}}(11.8 - 4.2U) - 4.0\right)(\theta_1 - \theta_0)$$

$$\rightarrow r_\mathrm{a} = \frac{\rho c_p}{\left(\frac{z_0}{z_{0,\mathrm{concrete}}}(11.8 - 4.2U) - 4.0\right)}$$

Namelist input parameters

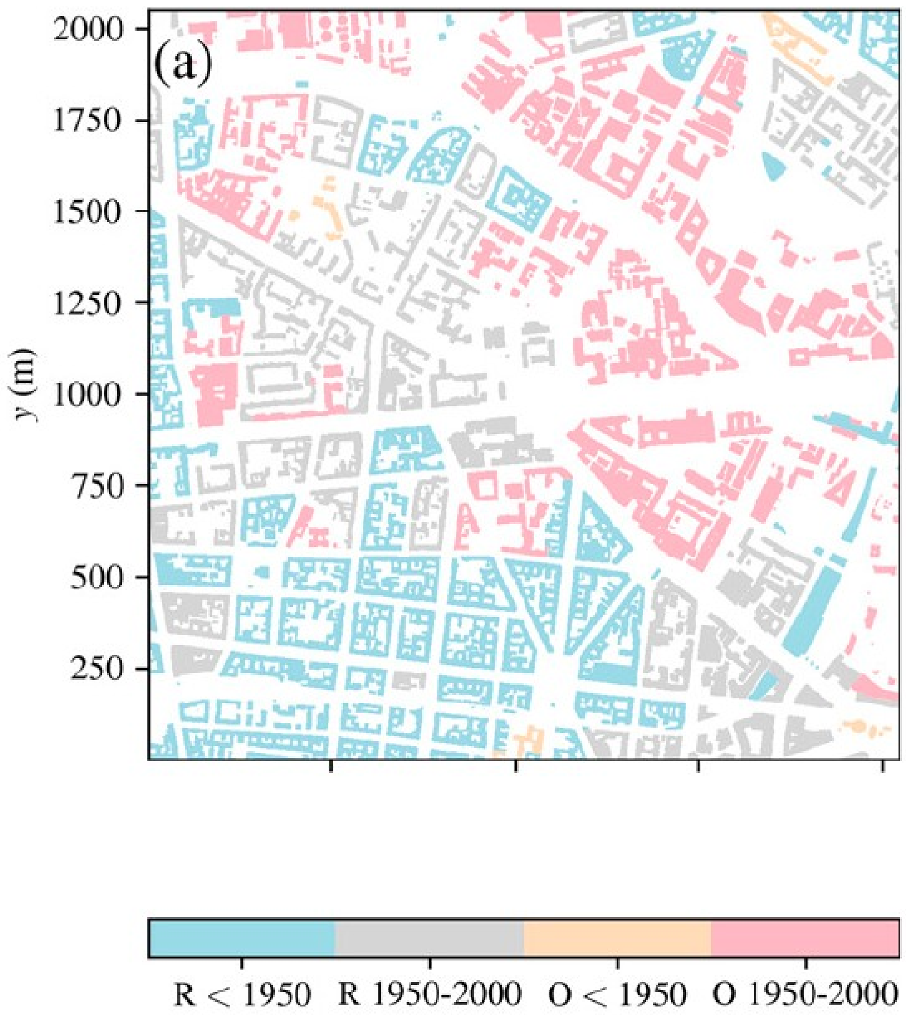
- If NAMELIST is set BSM, is activated
- If no ICM is used:
  set inner temperatures as boundary conditions
- Attention: there are some deprecated parameters that should not be used (especially when a static driver provides all information)
- See also https://docs.palm-model.org/23.04/Reference/LES_Model/Namelists/#urban-surface-parameters

```
&urban_surface_parameters

   wall_inner_temperature = 295.0,
   window_inner_temperature = 295.0,
   roof_inner_temperature = 295.0,

 /
```

Input from static driver

- Building type is stored in variable
  `building_type(y,x)`

- 2D map, values 1-6
- More detailed information via
  `building_pars(:,y,x)`
  and
  `building_surface_pars(:,ns)`



Other requirements

- In order to use BSM or the LSM in complex terrain, a special scheme for urban radiative transfer is needed (RTM)
- In most cases, BSM and LSM must be used at the same time
- ICM is an optional component

Output variables

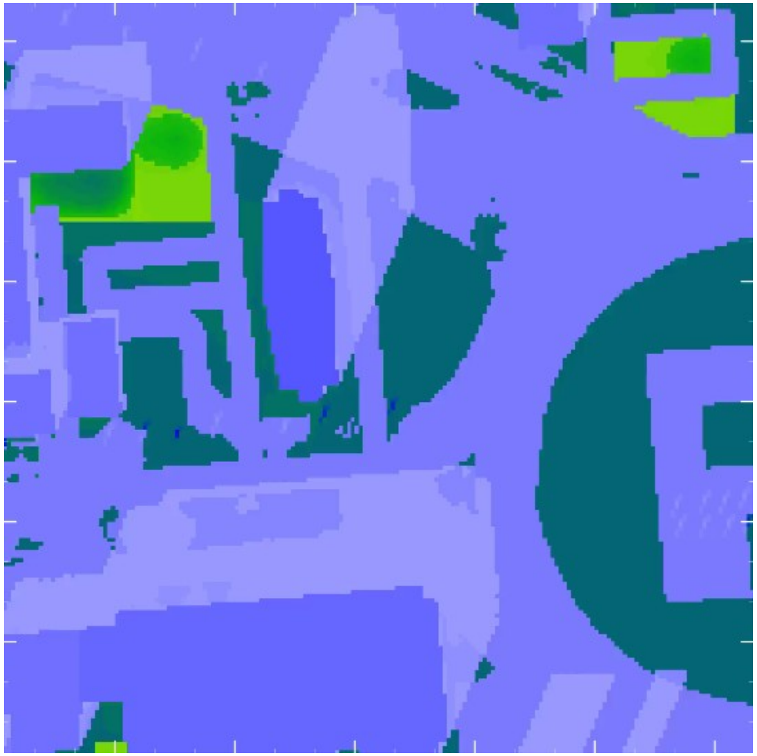
```
&runtime_parameters

   data_output = ...,
           'usm_t_wall_north',
           'usm_t_window_south,
           'usm_t_green_west',
           'usm_swc_east',

           'usm_surfz',
           'usm_surfcat',
           'usm_surfwintrans',
           'usm_wshf',
           'usm_qsws', 'usm_qsws_veg', 'usm_qsws_liq',
           'usm_wghf', 'usm_wghf_window', 'usm_wghf_green',
           'usm_ighf', 'usm_ighf_window', 'usm_ighf_green',
           'usm_t_surf_wall', 'usm_t_surf_window', 'usm_t_surf_green',
           'usm_theta_10cm',
           'usm_t_wall', 'usm_t_window','usm_t_green',
           'usm_swc',
 /
```

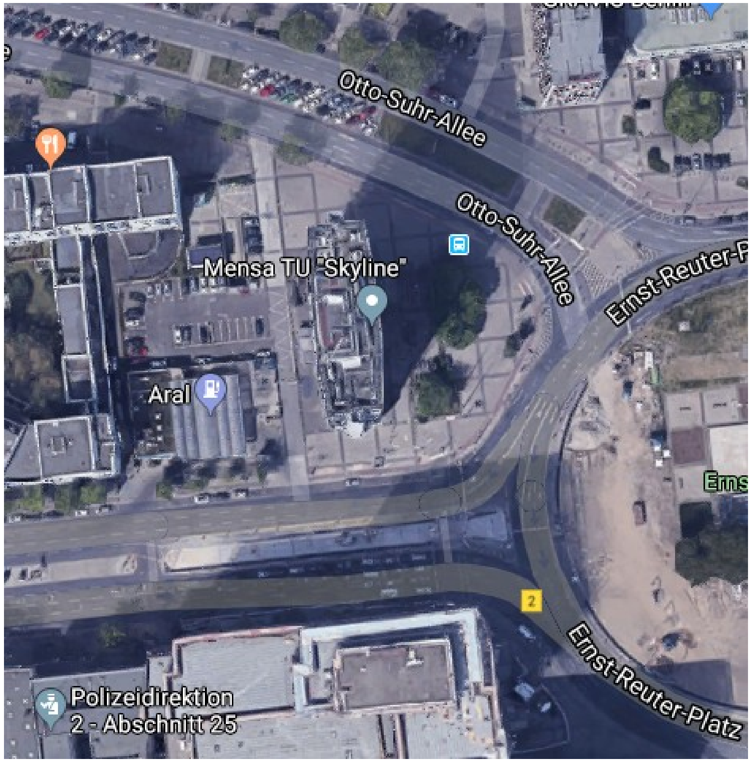
Limitations and upcoming improvements

- The BSM code still does not fully comply with PALM's coding standard and naming convention
- Some parts are deprecated and will be removed and or revised in near future (USM vs BSM naming convention)
- Our goal: a Unified Surface Model (USM)

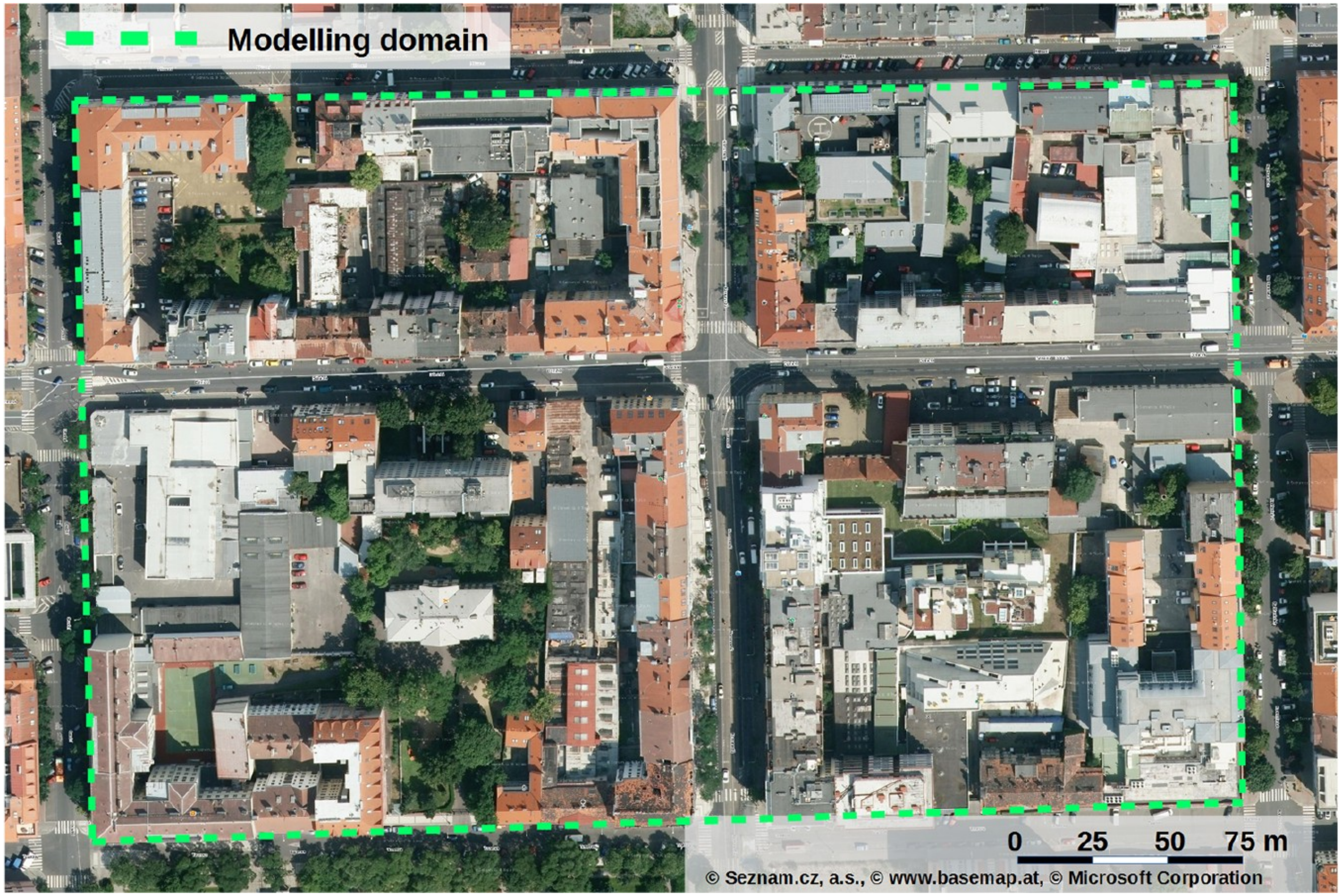
- Green facade/roof substrate is always saturated
- Issues with partial greening of surfaces (to be fixed soon)
- Slanted roofs will be available (immersed boundary condition)
- More building types will be implemented
- Snowpack on buildings is under development

Surface temperature at Ernst-Reuter-Platz, Berlin





Surface temperatures in a city quarter of Prague



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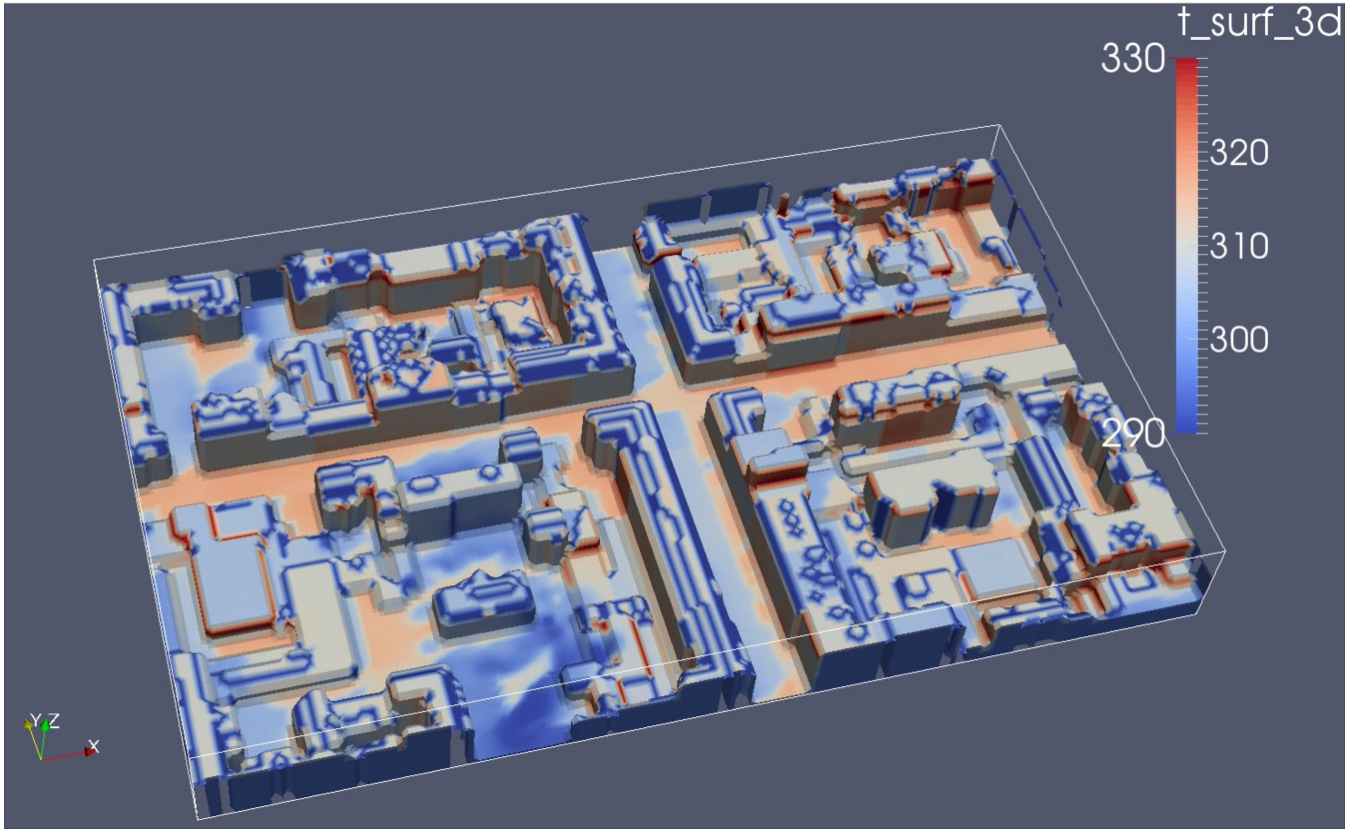

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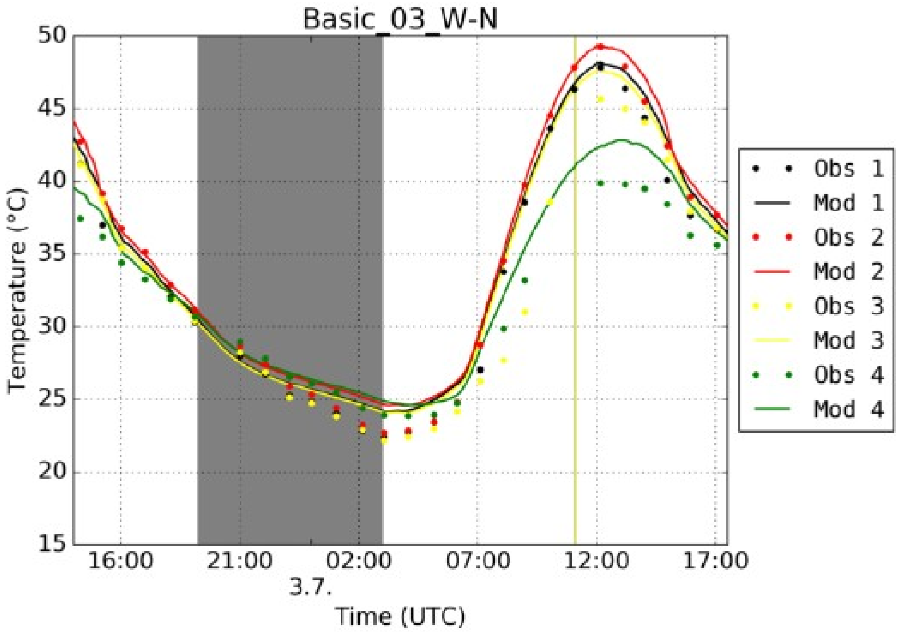

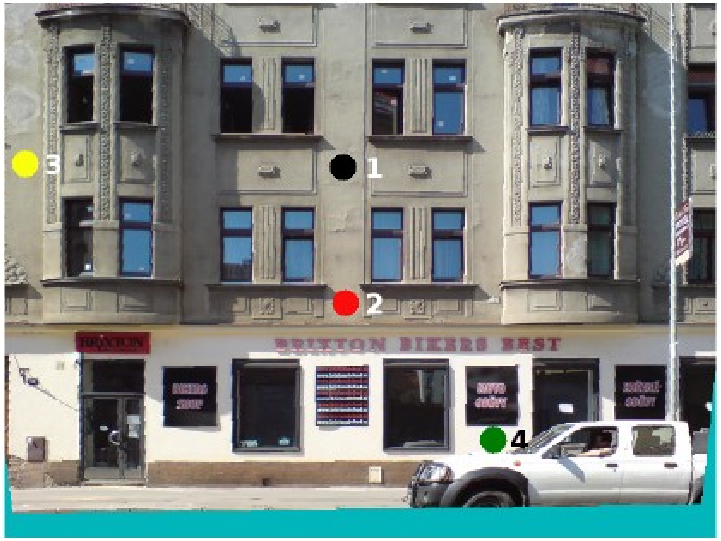

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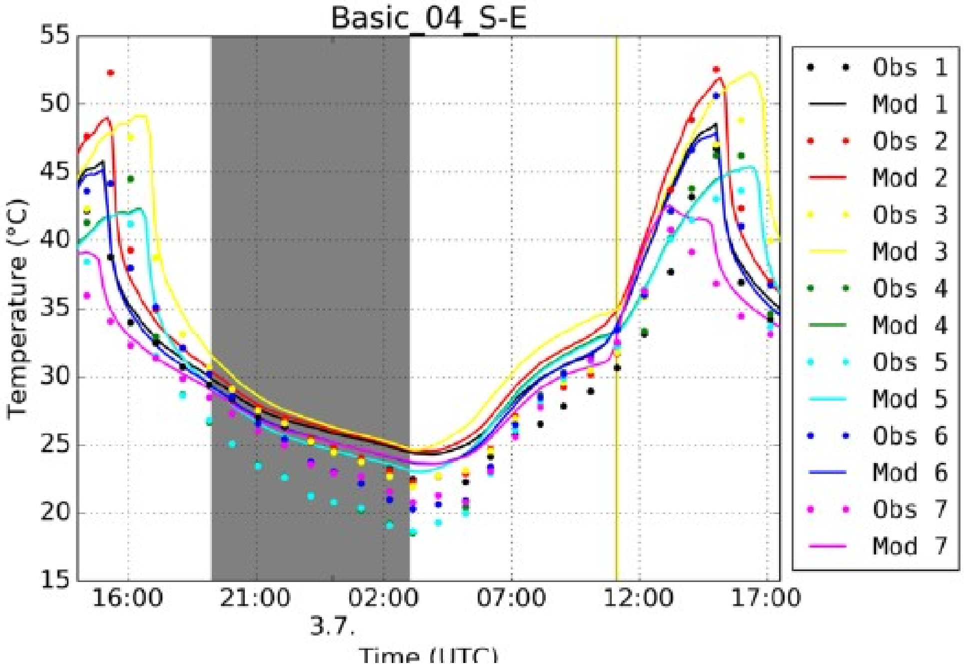

Indoor climate model (ICM)

- Based on an analytic solution of Fourier's equation
- Resistance model
- Time-stepping: Crank-Nicolson, dt = 1 h
- Output quantities: operative room temperature, energy demand for heating/cooling/lighting/ventilation, waste heat
- Uses the same information from the building database
- Coupling to BSM:
    - Inner wall/window/roof temperatures → indoor model
    - Near-facade temperature → indoor model
    - Inner wall heat flux → BSM

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Validation and first application:

- Pfafferott et al. (2021, 10.5194/gmd-14-3511-2021)
- Maronga et al. (2022, 10.1175/JAMC-D-21-0216.1)

Usage I: Input parameters

- The ICM is activated via NAMELIST:

```
&indoor_parameters
   initial_indoor_temperature = 293.0,
 /
```

- Building types have to be given in static driver file

Usage II: Output quantities

- Output quantities

```
&runtime_parameters

   data_output = im_t_indoor_mean,
                 im_hf_roof,
                 im_hf_roof_waste,
                 im_hf_wall_win,
                 im_hf_wall_win_waste,
 /
```