Topography

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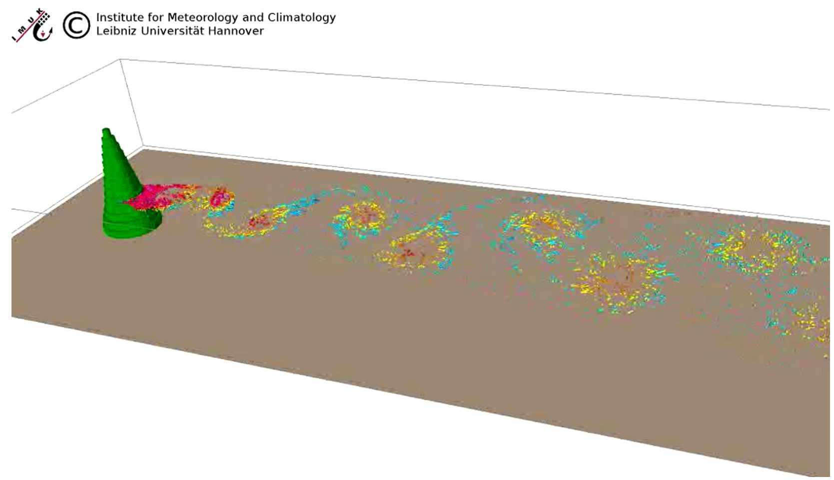
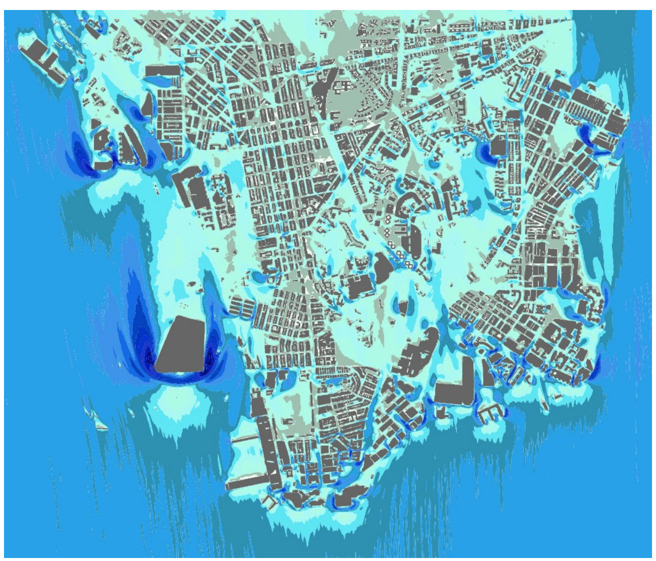
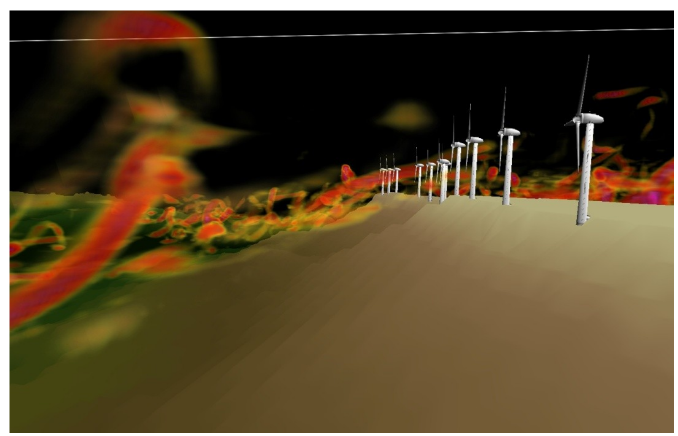
Purpose of Topography

- Optional feature to simulate flow around/above obstacles.
- Application fields
  - Urban meteorology
  - Wind engineering
  - Meso-scale meteorology
  - Oceanography
  - Indoor turbulence, ect.





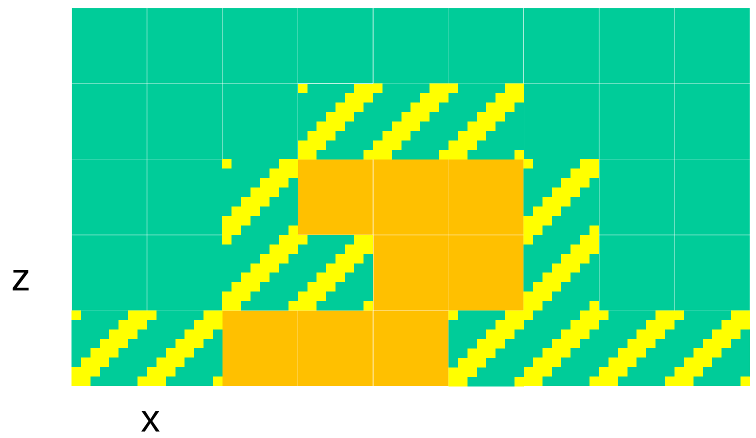


Topography in PALM covers solid, impermeable, fixed obstacles with a volume of at least one grid box.

- Following qualifies as topography: ✓
  - Hills, mountains
  - buildings
- The following does NOT qualify as topography: ✕
  - Permeable obstacles (e.g. vegetation)
  - Moving obstacles (e.g. vehicles, wind turbine rotors)
  - Small (subgrid-scale) obstacles (e.g. signposts)
- Topography *parameterization* options in PALM:
  - Canopy model (plant canopy model)
  - Wind turbine model (wind turbine model)
  - Local roughness length
  - Double-canyon approach for non-building resolving simulations
  - (urban-surface and radiation)

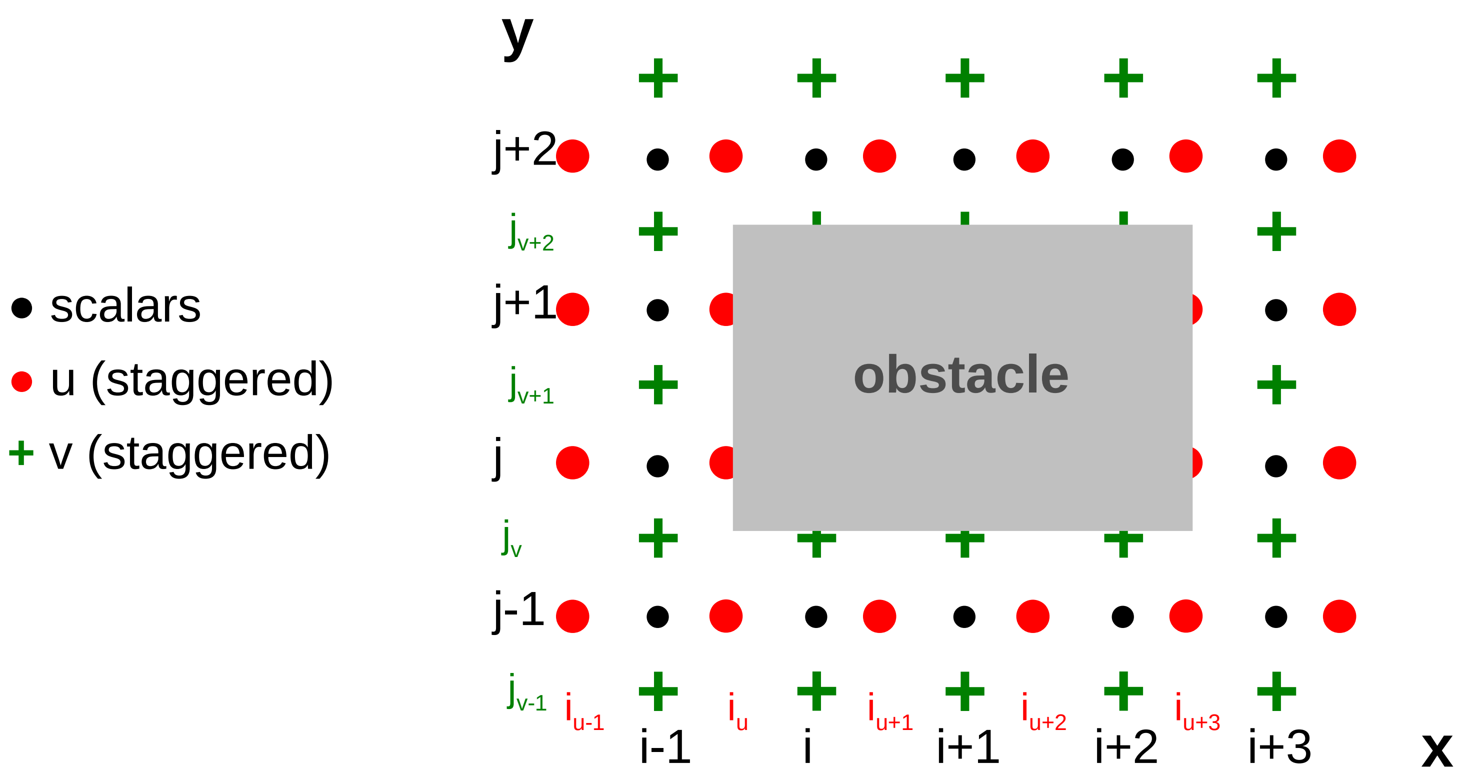
Realization

- Flow cannot enter topography and is forced around/above it.
- Grid boxes are either
  - 100 % free fluid or
  - 100 % obstacle
- Obstacle surfaces that do not match the grid are approximated by grid boxes like a step function
- Overhanging structures, holes, bridges, tunnels, etc. are allowed.
- Special treatment of grid boxes adjacent to obstacles ( ):
  - No-slip boundary condition, i.e. wall-normal velocity component is zero at obstacle surface.
  - A local surface layer is assumed.
  - Neutral case Monin-Obukhov similarity for vertical walls.
  - Order of 5th-order advection scheme is degraded near walls.



Realization (grid layout)

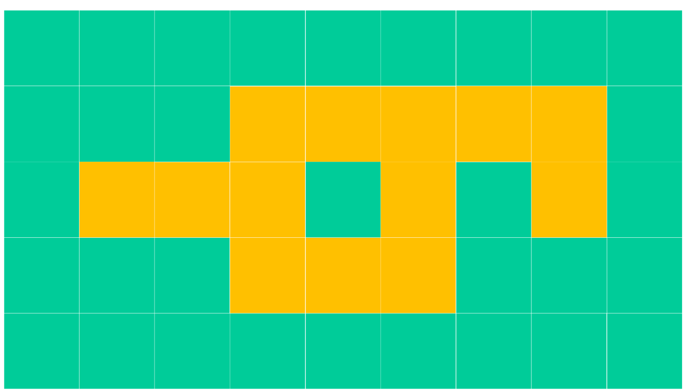
- Location of wall-normal velocity component defines location of impermeable obstacle surface.
- Due to staggered grid, the numbers of obstacle grid points along a dimension vary for different variables.



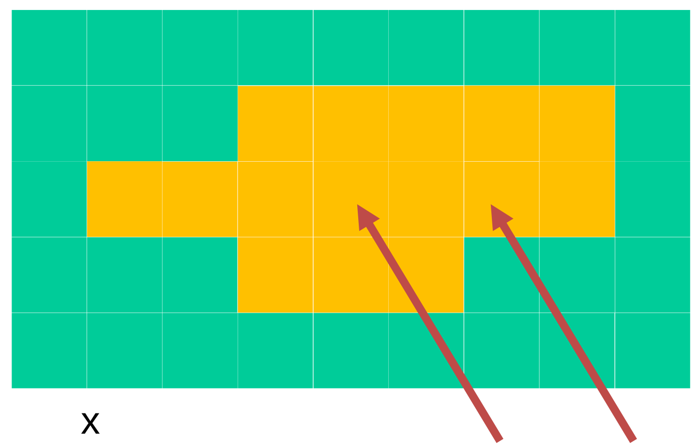
Realization (filtering)

To avoid numerical instabilities, grid points surrounded by 3 or more walls, are filled by the lowest height of neighbouring grid points. Also narrow, poorly-resolved cavitites (up to 9 grid points) are filtered.

Input (unfiltered)



filtered



Strengths (+) and limitations (-)

+ Horizontal and vertical surfaces can be exactly resolved (thanks to the finite difference Cartesian grid architecture).
+ Conforms with 2.5D format of Digital Elevation Models (DEM).
+ Overhanging elements are possible.

- Grid boxes can only be 100 % fluid or 100 % obstacle (a cut-cell approach is under way).
- Obstacle surfaces that do not match the grid are approximated by grid boxes like a step function, which can modify the real obstacle size or the size and orientation of the obstacle faces (might have implications for the energy balance, shading and reflections).
- Small-scale structures in the topography (less than the grid spacing) cannot be resolved.

Topography

Control parameters

Topography is controlled via the initialization parameter **topography**.

Possible settings:

topography =

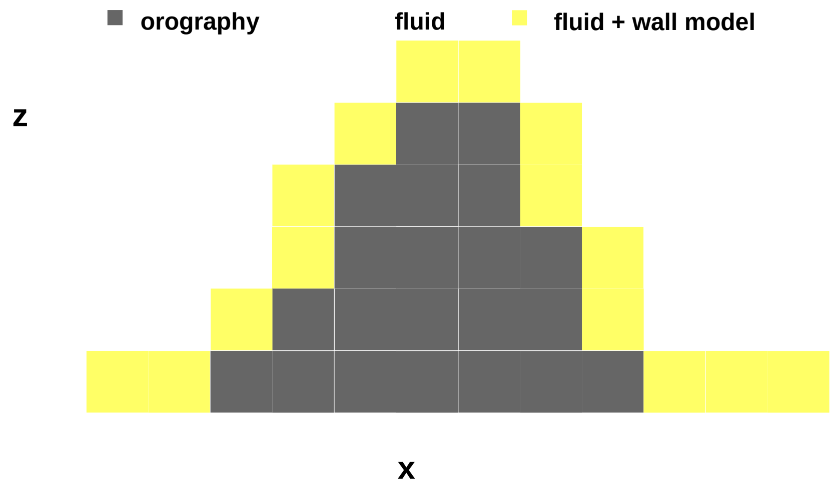
- **'flat'** — no topography (default)
- **'single_building'** — generic single building
- **'single_street_canyon'** — generic single street canyon
- **'tunnel'** — generic tunnel
- **'read_from_file'** — input via file (ASCII or static driver)
- *<any other string>* — processed by subroutine **user_init_grid**

Input via file

- In order to use the topography information in PALM, data must be converted to a rastered file (ASCII (deprecated) or netCDF).
- The layout of the topography must conform to the domain layout (grid cell sizes **dx**, **dy**, **dz** and numbers **nx**, **ny**, **nz**)
- **2D input** (ASCII or netCDF)**:**
  - Provide height information in meter above ground.
  - Only surface-mounted topography possible (no overhanging structures).
- **3D input** (netCDF)**:**
  - Provide 3D bit array which must be conform to the PALM grid, where
    - 0 = atmosphere grid point
    - 1 = obstacle grid point.
- Example topography files:
  - `packages/palm/model/tests/cases/topo_from_ASCII_file/INPUT/`
  - `packages/palm/model/tests/cases/urban_environment/INPUT/`

2D topography input

- Control parameter **topography** = **'read_from_file'**
- Requires an external file:
  - ASCII: **example_topo**
  - netCDF: **example_static**
- File must be available within the job folder **JOBS/example/INPUT**
- Layout must conform to domain and grid size **dx** and **dy**.
- Height data in meters above ground
- Height information are approximated to the nearest grid level by PALM



3D topography input

- Control parameter **topography** = **'read_from_file'**
- Requires a static driver file (netCDF) **example_static**
- The file must follow the PALM input data standard (PIDS)
- More details for the static driver can be found within
  - our online documentation https://palm.muk.uni-hannover.de/trac/wiki/doc/app/iofiles/pids/static
  - the lecture “Static and dynamic drivers”

Topography

Application example: City simulation

- Flow over an artificial island in Macau
- Set-up: neutral boundary layer
- shown quantity:
  magnitude of rotation of velocity vector
  (white = weak, red = strong turbulence)
- Turbulent structures are generated by buildings
- DOI: 10.5446/14368
- https://youtu.be/y1sSRXFBN7k

General control parameters – Suitable driving methods

- **“Meteorological” set-up:** geostrophic wind / Coriolis force
  - Set **omega** ≠ 0.0
  - Construct a non-zero profile of geostrophic wind u_g and/or v_g using **ug_surface**, **ug_vertical_gradient** and **ug_vertical_gradient_level** and/or respective parameters for v_g
- **“Engineering” set-up:** direct external pressure gradient / no Coriolis force
  - Set **omega** = 0.0
  - Set-up 1: direct external pressure gradient (bulk velocity adjusts respectively)
    - Parameters: **dp_external**, **dp_smooth**, **dp_level_b**, **dpdxy**
  - Set-up 2: constant bulk velocity (non physical forcing)
    - Parameters: **conserve_volume_flow**, **conserve_volume_flow_mode**, **u_bulk**, **v_bulk**
- **“Thermal” set-up:** directly prescribe building surface sensible heatflux
  - **surface_heatflux** at ground level only
  - **wall_heatflux(0:5)** at top/left/right/south/north/bottom obstacle face
  - Surface models in conjunction with radiation allow much more realistic heating

General control parameters – Initialization of set-ups

- **“Meteorological” set-up**
  - Initialize a non-zero profile of geostrophic wind u_g and/or v_g using
    - **initializing_actions** = **'set_constant_profiles'** (e.g. for convective BL)
    - Parameters: **ug_surface** ≠ **0.0** and/or **vg_surface** ≠ **0.0**
    - **initializing_actions** = **'set_1d-model_profiles'** (e.g. for neutral BL)
    - 1D model prerun parameters with suffix **_1d** (e.g. **end_time_1d**, **damp_level_1d**)
- **“Engineering” set-up**
  - Good initialization may require *a priori* knowledge, e.g. from previous test runs.
  - Here, **ug_**... and **vg_**... do not refer to geostrophic wind but to the initial wind profile.
    - **initializing_actions** = **'set_constant_profiles'**
    - Parameters: **ug_surface**, **ug_vertical_gradient[_level]** or v-component
    - Parameters: **u_profile**, **v_profile** wind profile e.g. from measurements
    - **initializing_actions** = **'set_1d-model_profiles'**
    - **initializing_actions** = **'by_user'** (processed by user_init_3d_model)
- **“Thermal” set-up**
  - Any of the above may apply

General control parameters – Boundary conditions

- **Lateral boundary conditions**
  - See lecture “Non-cyclic boundary conditions” for cyclic / non-cyclic conditions.
- **Bottom boundary conditions**
  - See lecture “Numerics and boundary conditions”.
  - See lectures “Land surface model” and “Building surface model” about advanced surface-layer treatment.
  - Extended constant flux layer at bottom surface (sometimes required for comparisons with wind-tunnel data):
    - set **`dp_level_b`** > 0 and **`dp_smooth`** `= .T.`
- **Top boundary conditions**
  - Channel: **`bc_uv_t`** `= 'dirichlet_0'` (no-slip)
  - Open channel: **`bc_uv_t`** `= 'neumann'` (slip)

General control parameters – Pressure solver

- The pressure solver ignores topography, i.e. no pressure boundary conditions are considered at the topography surfaces (except the bottom surface of the model).
- The solver *sees* the topography because of zero velocities at grid points within the topography.
- Possible choices:
  - FFT scheme: **psolver** ='poisfft'
    - Good performance for urban PALM version.
    - Can be used with all kind of lateral boundary conditions, except for idealized inflows with 'dirichlet/radiation'.
  - Multigrid scheme: **psolver** = 'multigrid'
    - Performance for very large number of grid points may be better than FFT.
    - Choose **nx**, **ny**, **nz** carefully to allow for enough multigrid-levels (minimum should be 2 levels). Check divergence reduction in the run-control file (**_rc**). Should be at least 1-2 orders of magnitude.
    - This is the only possible choice for non-cyclic boundary conditions with idealized inflows 'dirichlet/radiation'.

Calculation of turbulence quantities – Some considerations (I)

- Calculation of turbulence quantities depend on definition of turbulent fluctuations.
- **Spatial eddy correlation (EC) method:**
  - Turbulent fluctuations are defined as deviation from representative instantaneous spatial average.
  - Used by PALM to calculate statistics on-the-fly, e.g. 1D vertical profiles.
  - Not suitable for topography unless a direction of homogeneity exists.
- **Temporal EC method (typically used by experimentalists)**
  - Turbulent fluctuations are defined as deviation from representative temporal average of a local time series.

$\Psi' = \Psi - \Psi$

Ψ: resolved-scale quantity
Ψ: temporal mean
Ψ': deviation

  - Suitable for all applications including topography.
  - Requires much hard-disk space and post-processing CPU time.
  - Not supported by PALM per default, but following procedure works:
    1) Collect time-series data during the simulation (standard 2D/3D data output, virtual measurements or user-defined quantities).
    2) Check for (quasi-)steady turbulent state and sufficient averaging time.
    3) Calculate statistics by making use of the **Reynolds decomposition** for each grid point, e.g.:

$$\overline{w'\theta'} = \overline{w\theta} - \overline{w}\,\overline{\theta}$$

w, θ, and wθ must be collected

Calculation of turbulence quantities – Some considerations (II)

So how to get turbulence statistics for horizontally non-homogeneous cases?

- If a horizontal direction of homogeneity exists, e.g. along the x-axis, calculate the turbulent fluctuation as the deviation from the mean along x.
- If no direction of homogeneity exists, use the temporal EC method.
- Both methods currently must be realized via PALM's user-interface (implementation is planned for a future release).
- The temporal EC method assumes stationarity in time
  - The statistical turbulence quantities should not change within the averaging interval.
  - This might not be fulfilled for non-stationary setups (simulation of a daily cycle,…)
  - Alternative: Carry out an ensemble of runs with randomly varied initial conditions and use ensemble averages.

Rules of good practice (I)

- If you run PALM with topography, make sure that it is really LES!
  - “Large eddies” are “small” between obstacles. Use small grid size to resolve turbulence. *Rule of thumb:* minimum of 20 grid points per face direction.
  - Check ratio of resolved to SGS fluxes.
- Check for (quasi-)steady turbulent state and sufficient averaging time.
  - Check fluctuations of time series of E, E*, maximum velocity components etc.
- Make sure that your PALM result is independent of numerical parameters such as domain size and grid size.
  - Carry out sensitivity studies.
- If you intend to do a comparison with reference data, it is essential to configure the set-up of PALM in the same way as the reference experiment.
  - E.g. if you compare PALM with wind-tunnel results, you should follow the wind-tunnel set-up for setting up PALM.

Rules of good practice / current status

- PALM‘s topography features have been frequently applied within the last years, but ...

We ask you for your responsibility and contribution

- Please always check your set-up carefully.
- Design a simple test case and test your expectation.
- Please report potential bugs using our trouble-ticket system.

Examples of topography applications with PALM

Street canyon flows

Lo, K.W. and K. Ngan, 2015: Characterising the pollutant ventilation characteristics of street canyons using the tracer age and age spectrum. *Atmos. Environ.*, 122, 611-612, doi:10.1016/j.atmosenv.2015.10.023

Airflow within or over building arrays

Abd Razak A., A. Hagishima, N. Ikegaya and J. Tanimoto, 2013: Analysis of airflow over building arrays for assessment of urban wind environment. *Building and Environment*, 59, 56-65, doi:10.1016/j.buildenv.2012.08.007

Kanda, M., A. Inagaki, T. Miyamoto, M. Gryschka and S. Raasch 2013: A New Aerodynamic Parameterization for Real Urban Surfaces. *Boundary-Layer Meteorol.*, 148, 357-377, doi:10.1007/s10546-013-9818-x

Thermal effects of building walls

Park, S.B., J.J. Baik, S. Raasch and M.O. Letzel 2012: A large-eddy simulation study of thermal effects on turbulent flow and dispersion in and above a street canyon. *J. Appl. Meteor. Climatol.*, 51, 829-841, doi: 10.1175/JAMC-D-11-0180.1

PALM coupled to a building energy model

Yaghoobian, N., J. Kleissl and K. T. Paw U, 2014: An Improved Three-Dimensional Simulation of the Diurnally Varying Street-Canyon Flow. *Boundary-Layer Meteorol.*, doi: 10.1007/s10546-014-9940-4.

Effect of stratification on ventilation ratio

Kurppa, M., A. Hellsten, M. Auvinnen, S. Raasch, T. Vesala and L. Järvi (2018): Ventilation and air quality in city blocks using large-eddy simulation - Urban planning perspective , Atmosphere, 9, 65, doi: 10.3390/atmos9020065

Gronemeier, T., S. Raasch, and E. Ng (2017): Effects of unstable stratification on ventilation in Hong Kong, Atmosphere, 8 (9), 168, doi: 10.3390/atmos8090168

Effects of complex building structures

Gronemeier, T. and M. Sühring (2019): On the Effects of Lateral Openings on Courtyard Ventilation and Pollution – a Large-Eddy Simulation Study, Atmosphere, 10(2), 63, doi: 10.3390/atmos10020063

The end

PALM online:

https://palm.muk.uni-hannover.de

Our YouTube channel:

youtube.com/user/palmhannover

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