



# New features and optimizations in the hygrothermal transport model DELPHIN 6

Dr. Andreas Nicolai

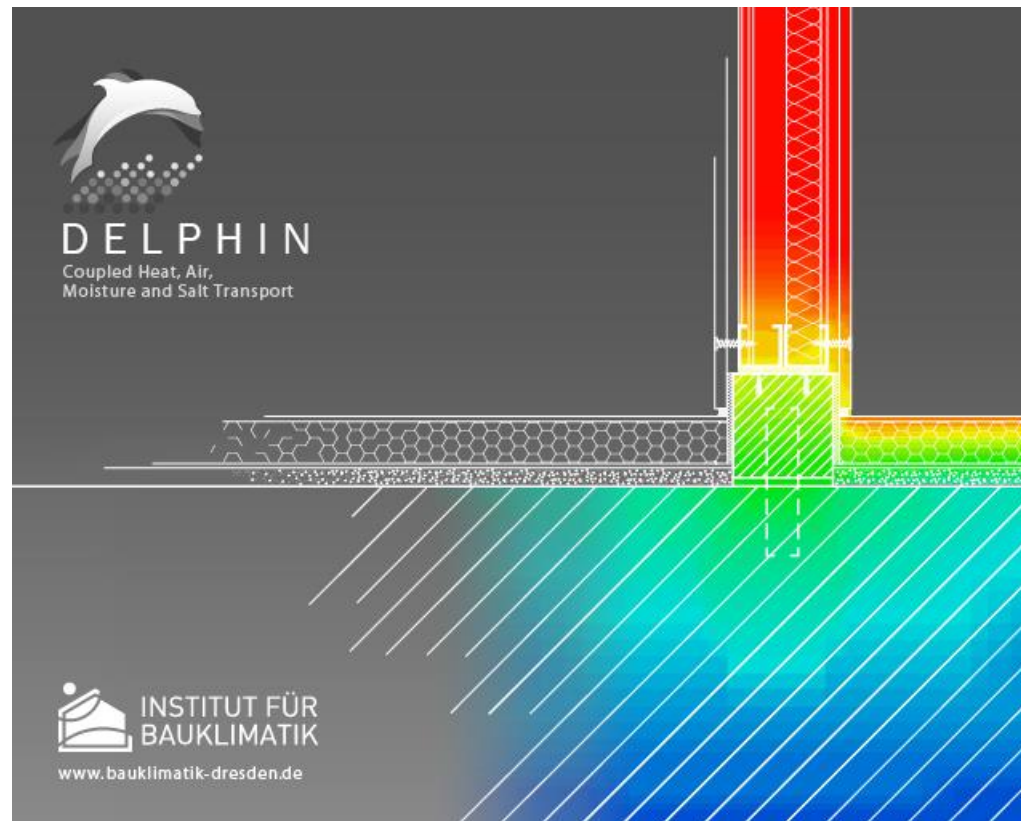
Dresden, 09/21 2017



- Physical model in DELPHIN 6
  - Coupled heat and moisture transport model with detailed moisture transport and storage model
  - Optional ice formation model
  - Optional air flow model (forced flow/bouancy driven), fully coupled to heat and moisture transport model
  - Optional salt transport model including transient phase transitions
  - Many boundary condition models, contact resistances, source/sink models, special models (e.g. interior longwave radiation exchange)
  
  - Mostly the same as in DELPHIN 5, but thoroughly reviewed and more efficient/stable (*routinely tested with automated benchmarks*)
  - Support for 3D geometries (in *solver*, not in user interface)
  
- Optimization of the solver engine
  - Iterative preconditioned Newton-Krylov-Methods significantly accelerate simulation of 2D details, enable 3D simulations
  - Parallel solver
  - Optimized memory layout for faster physics evaluation algorithms

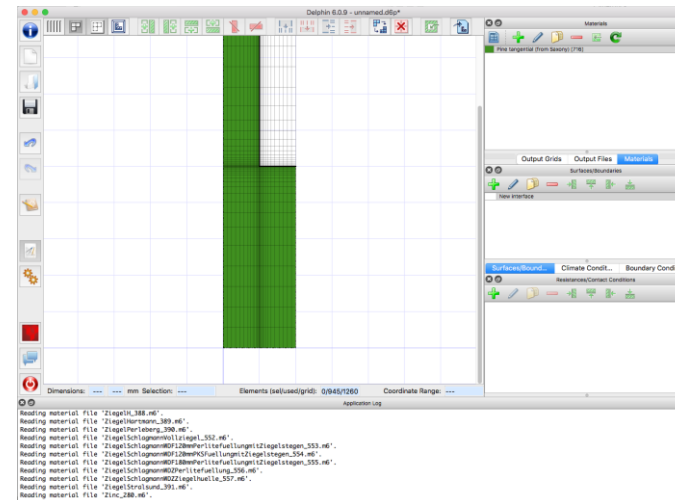
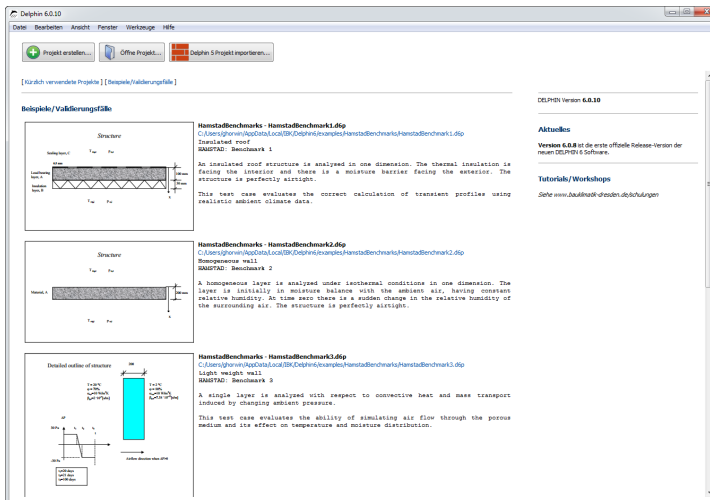
- Executables (Windows executables, on MacOSX and Linux similar naming)
  - DELPHIN 6 User Interface (modelling environment)  
**Delphin6.exe**
  - Console solver (command line argument controlled)  
**DelphinSolver.exe**
  - Graphical (modern) solver, just as fast as the command line solver (except for parallel solver variants), yet with live preview of simulation results  
**DelphinSolverUI.exe**
  - Command line discretizer (can be used to automatically perform grid sensitivity studies)  
**CmdDiscretise.exe**
  - DSixOutputConverter utility (extracts data from output files, converts data into other formats, creates TECPLOT files)  
**DSixOutputConverter.exe**
- Databases (Climatic Data and Materials)
- Post-Processing
  - Either *DELPHIN 5 Post-Processing* (can be installed alongside with DELPHIN 6)
  - Or new *POSTPROC 2* software (recommended for simulation analysis)

- New Icon and Splashscreen



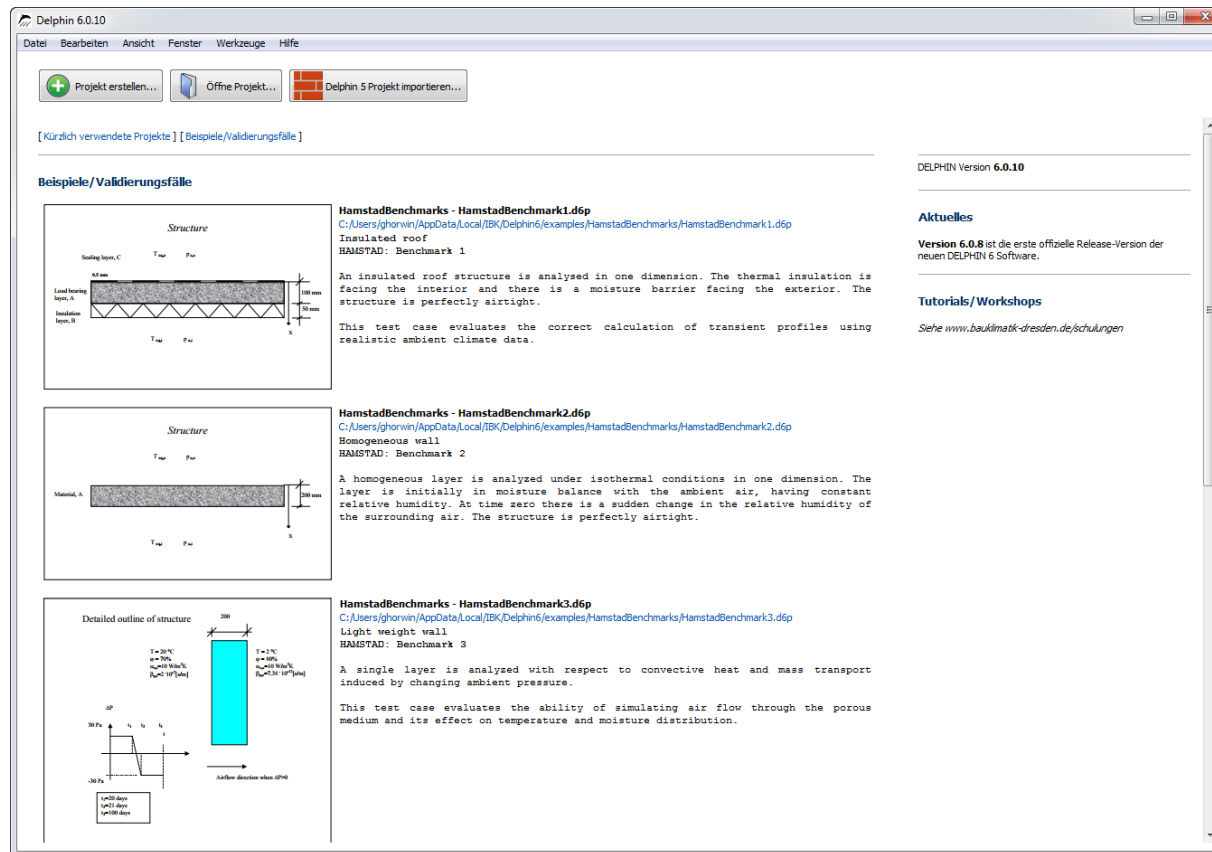
*Picture taken from IBK-GWT project about improving construction detail for intersection of interior separation wall with inside-insulated historic brick wall*

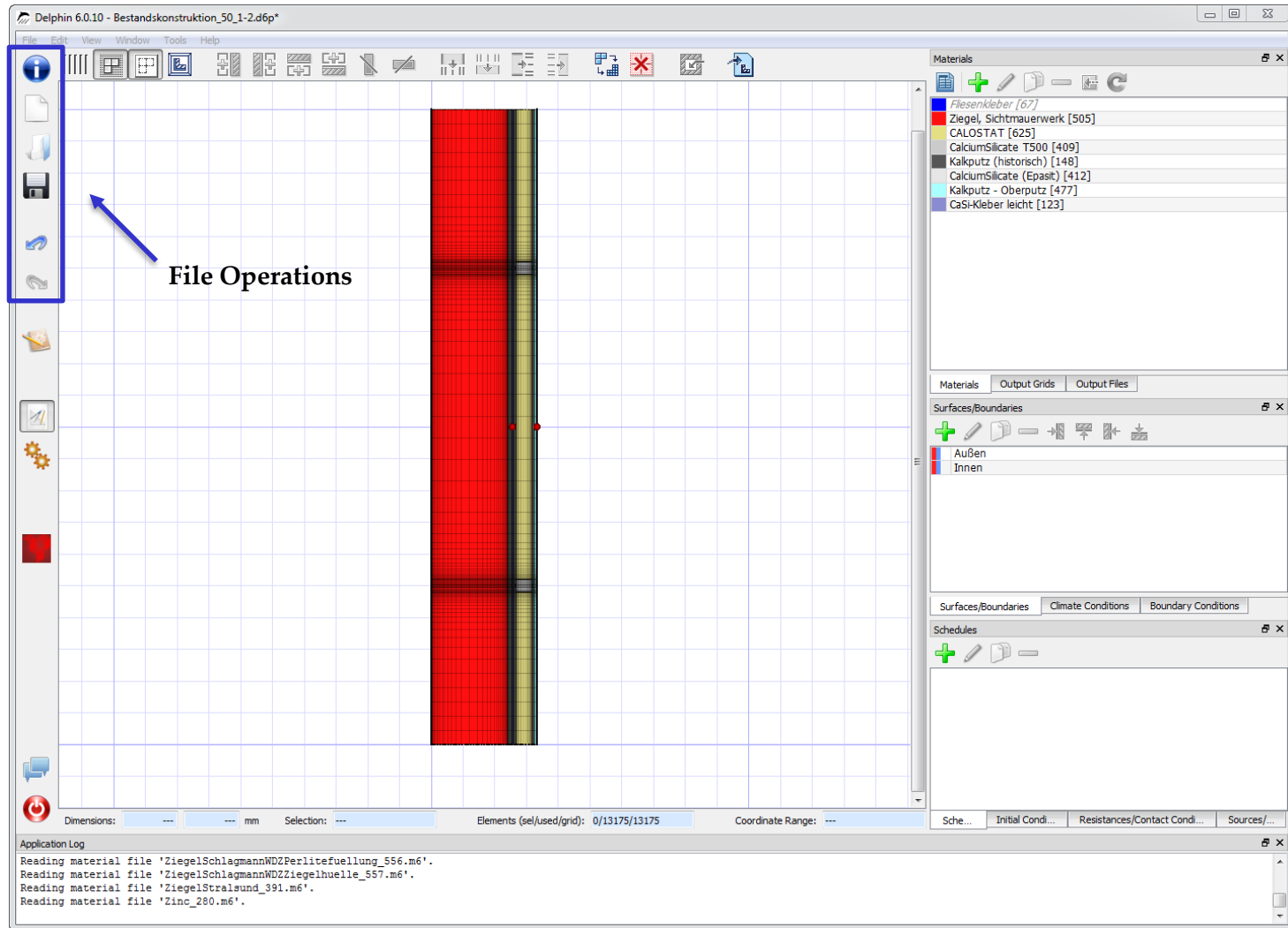
- Multiple languages
  - Switch with menu option Edit → Languages...
  - Currently: English, German, French
  - Translation is simple → Translators are welcome!
- Software runs natively on *Windows, MacOS* and *Linux*

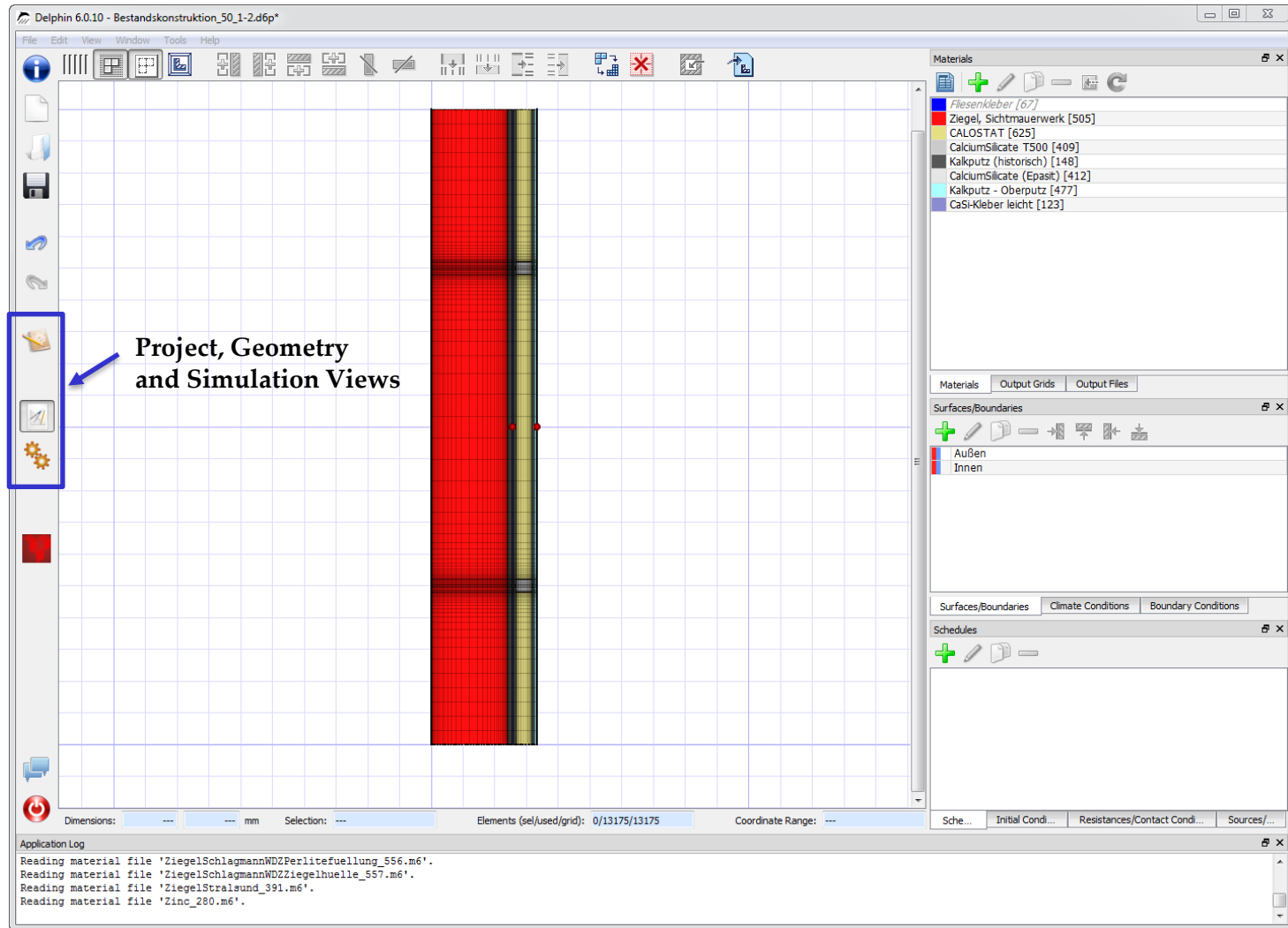


- On Mac OS X: Security → allow software from any sources

- Welcome page
  - Recently used projects (with preview)
  - Examples/Validation cases (with descriptions)
  - Current version, Update information, Web-content from Bauklimatik-Dresden.de

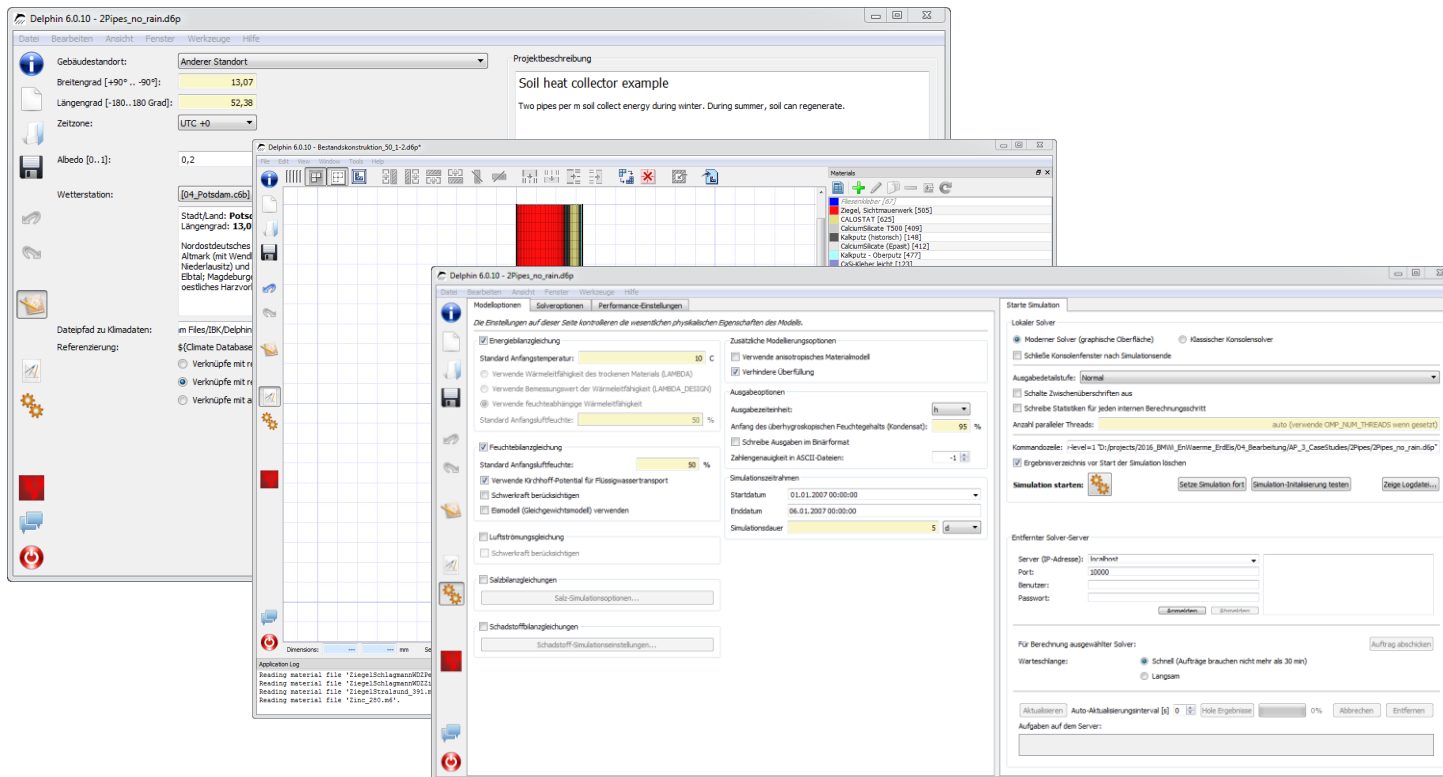


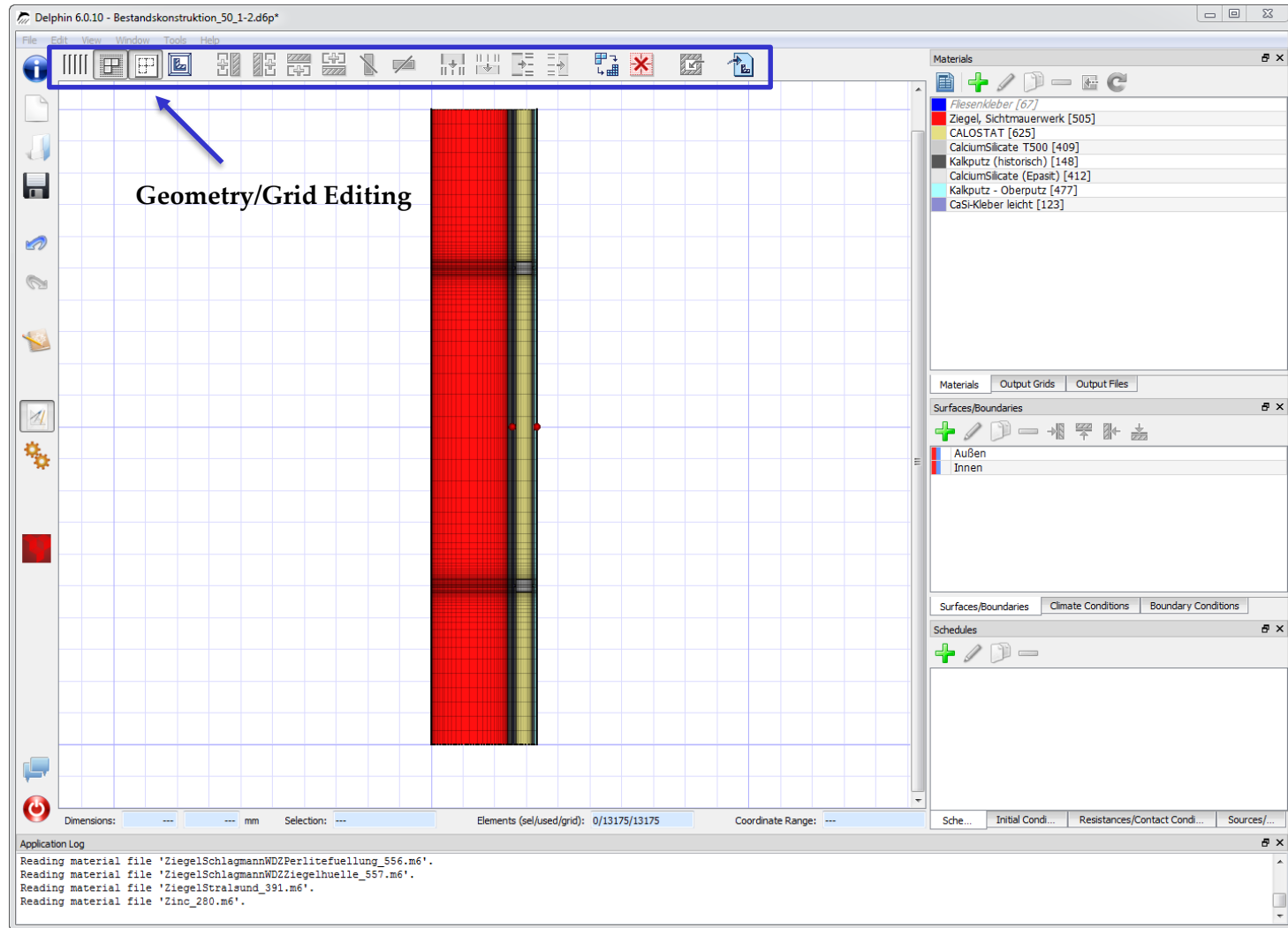


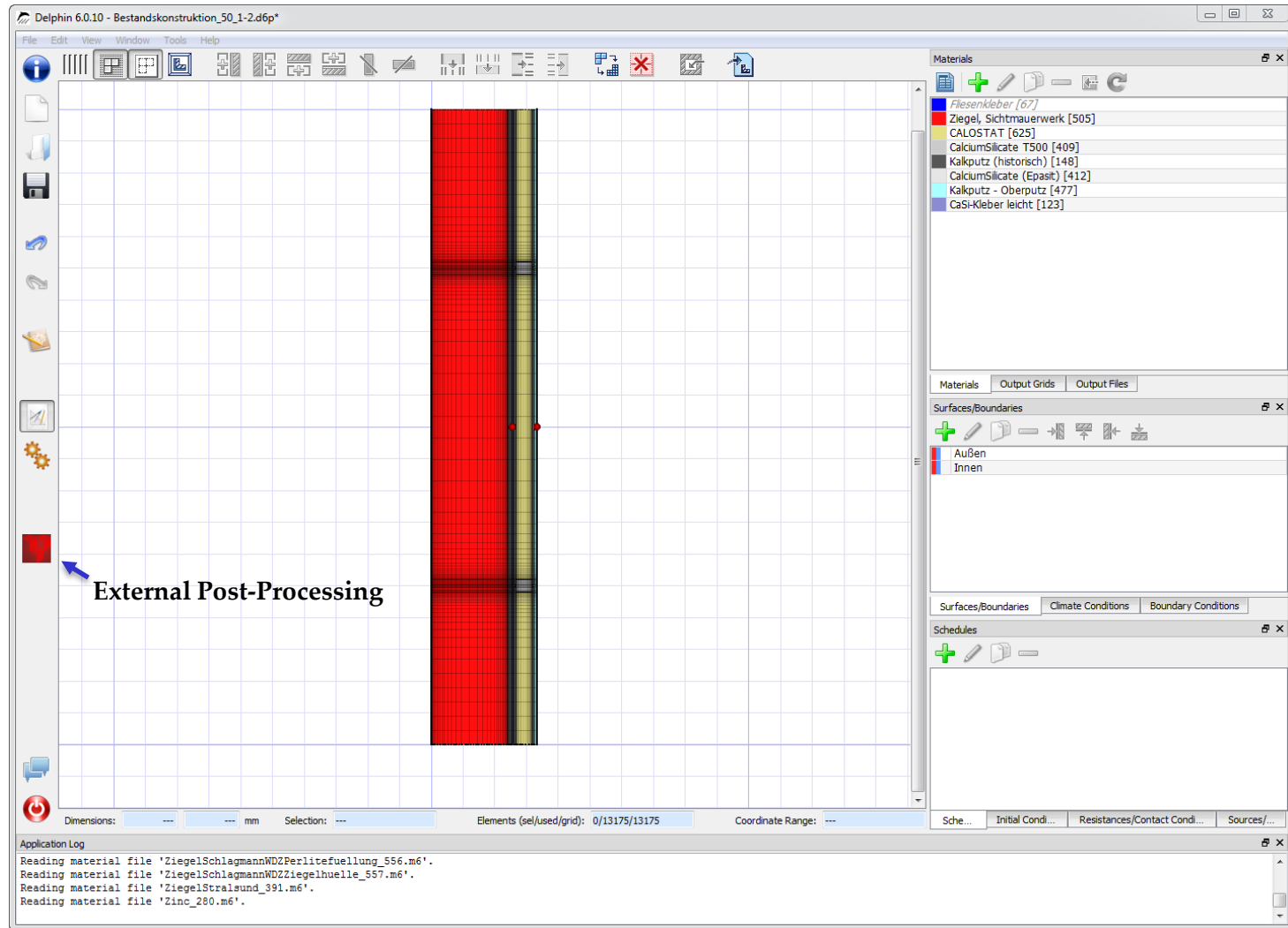


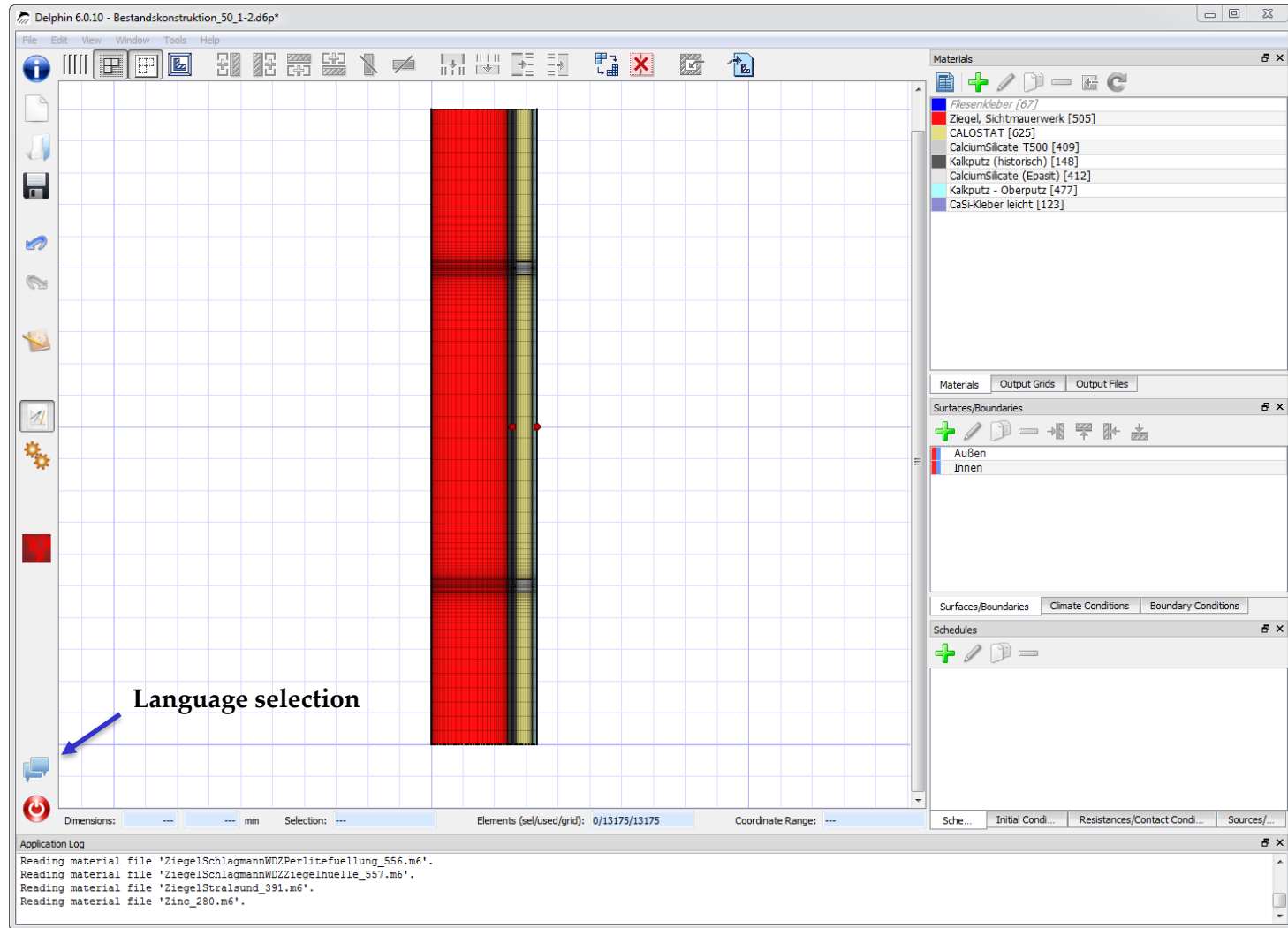


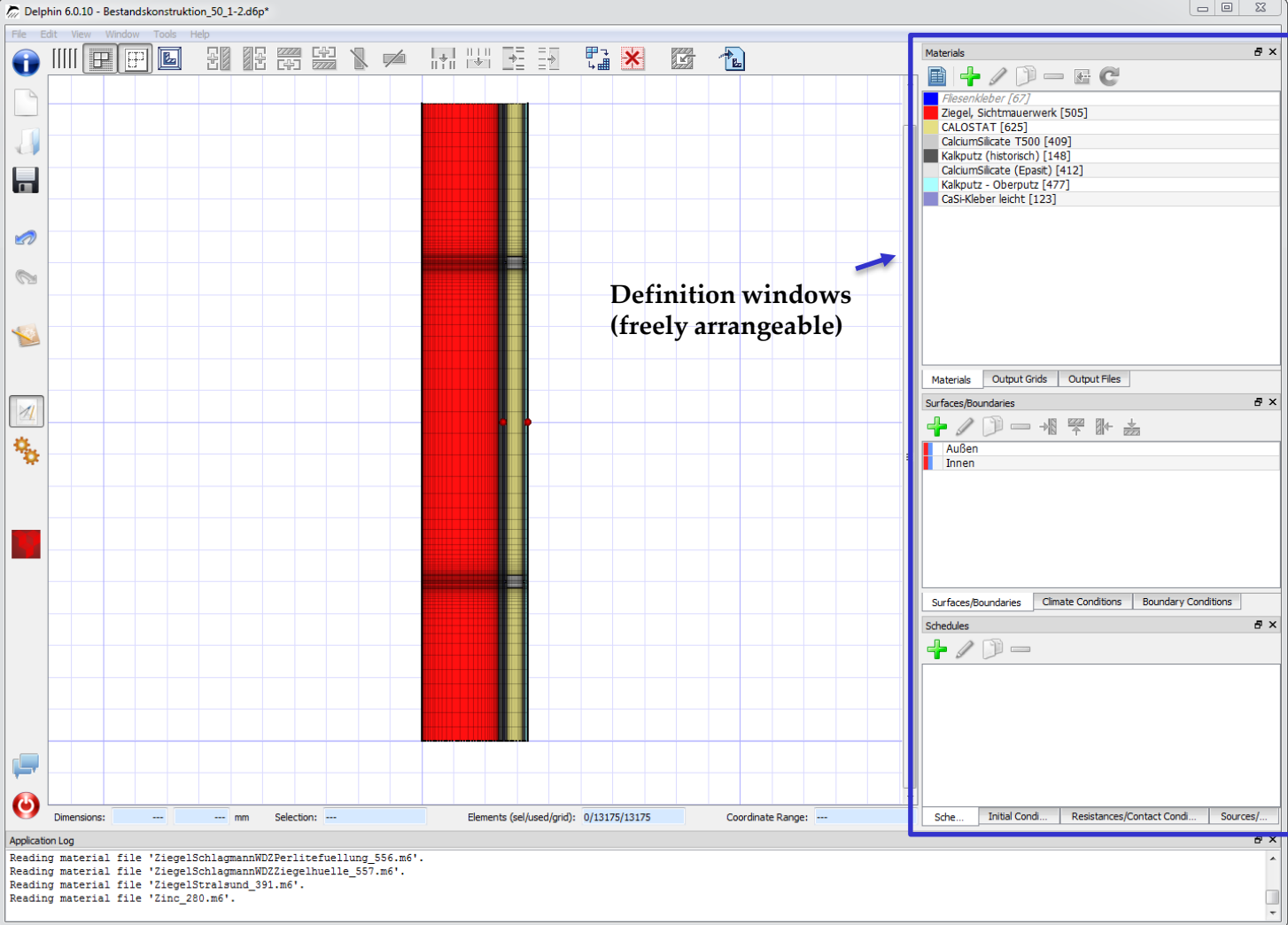
- 3 Views with project data
  - Project properties, location and climate
  - Construction/Geometry view (main modelling view)
  - Simulation view (physical model settings, solver options, simulation start)











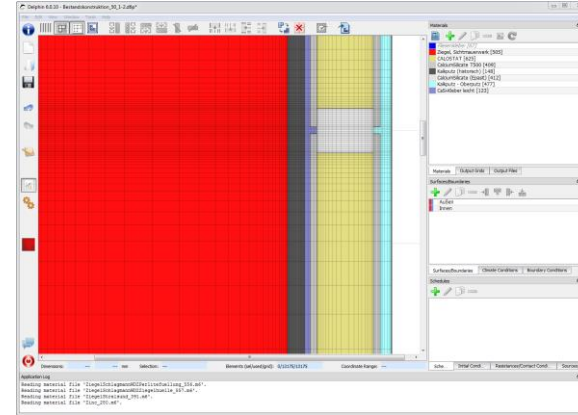
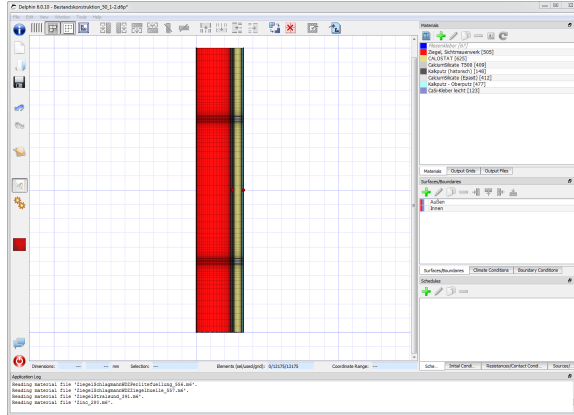
The screenshot displays the Delphin 6.0.10 software interface. The main window shows a 2D cross-section of a wall assembly on a blue grid. The wall consists of a red brick masonry section, a central vertical core, and a thin outer layer. A blue arrow points from the text "Definition windows (freely arrangeable)" to the right-hand side of the interface, where several floating windows are visible. These windows include:

- Materials:** A list of materials with their IDs: Fliesenkleber [67], Ziegel, Sichtmauerwerk [505], CALOSTAT [625], CalciumSilicate T500 [409], Kalkputz (historisch) [148], CalciumSilicate (Epast) [412], Kalkputz - Oberputz [477], and CaSi-Kleber leicht [123].
- Surfaces/Boundaries:** A window with tabs for Materials, Output Grids, and Output Files. It shows "Außen" (Outside) and "Innen" (Inside) surfaces.
- Schedules:** A window with tabs for Surfaces/Boundaries, Climate Conditions, and Boundary Conditions.
- Bottom Panel:** Includes an Application Log with the following text:

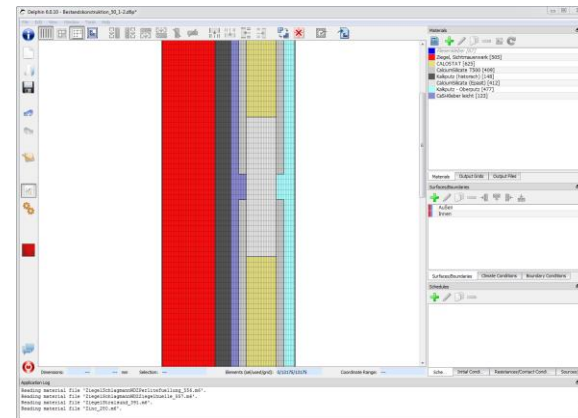
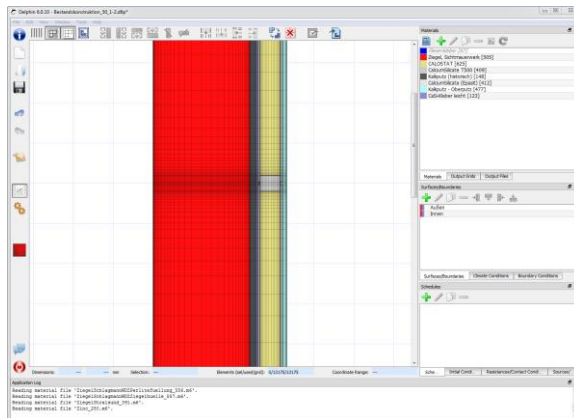
```
Reading material file 'ZiegelSchlagmannWDZPerlitefuellung_556.m6'.  
Reading material file 'ZiegelSchlagmannWDZiegelhuelle_557.m6'.  
Reading material file 'ZiegelStralsund_391.m6'.  
Reading material file 'Zinc_280.m6'.
```

At the bottom of the main window, there are status bars for Dimensions, Selection, Elements (sel/used/grid): 0/13175/13175, and Coordinate Range.

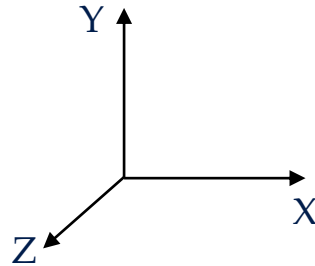
- Zooming via mouse scroll wheel



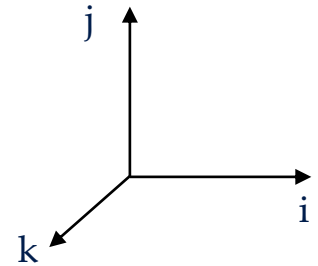
- Equidistant view toggle mode



- Coordinates

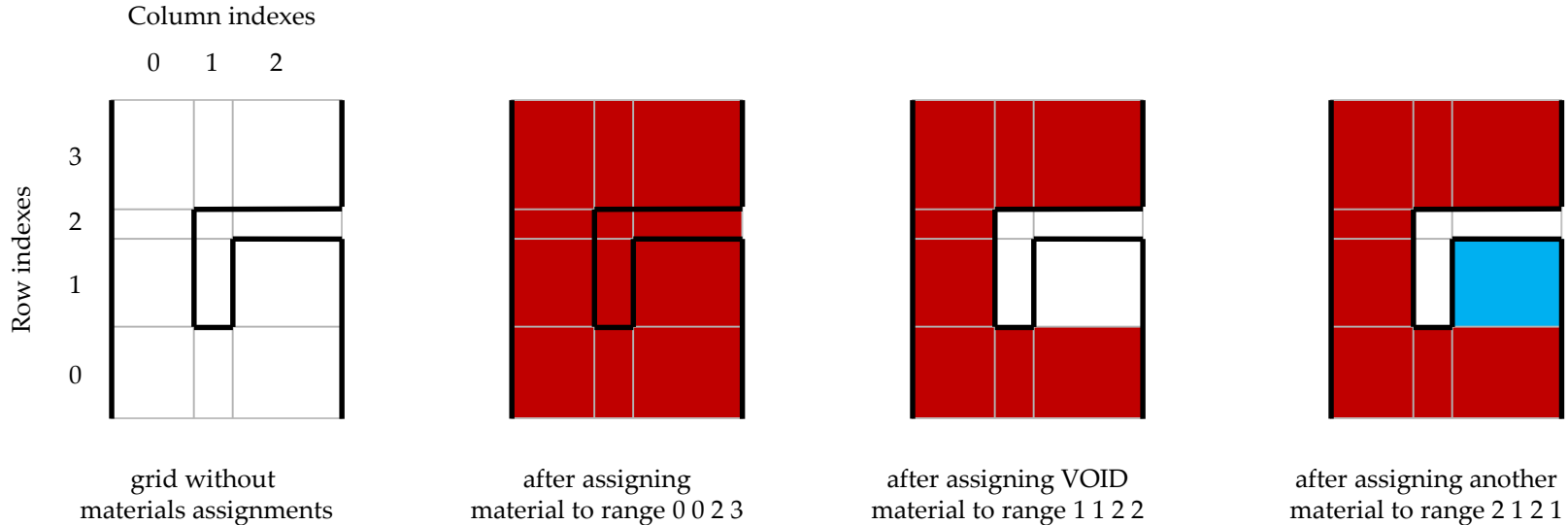


- Assignment/range indexes

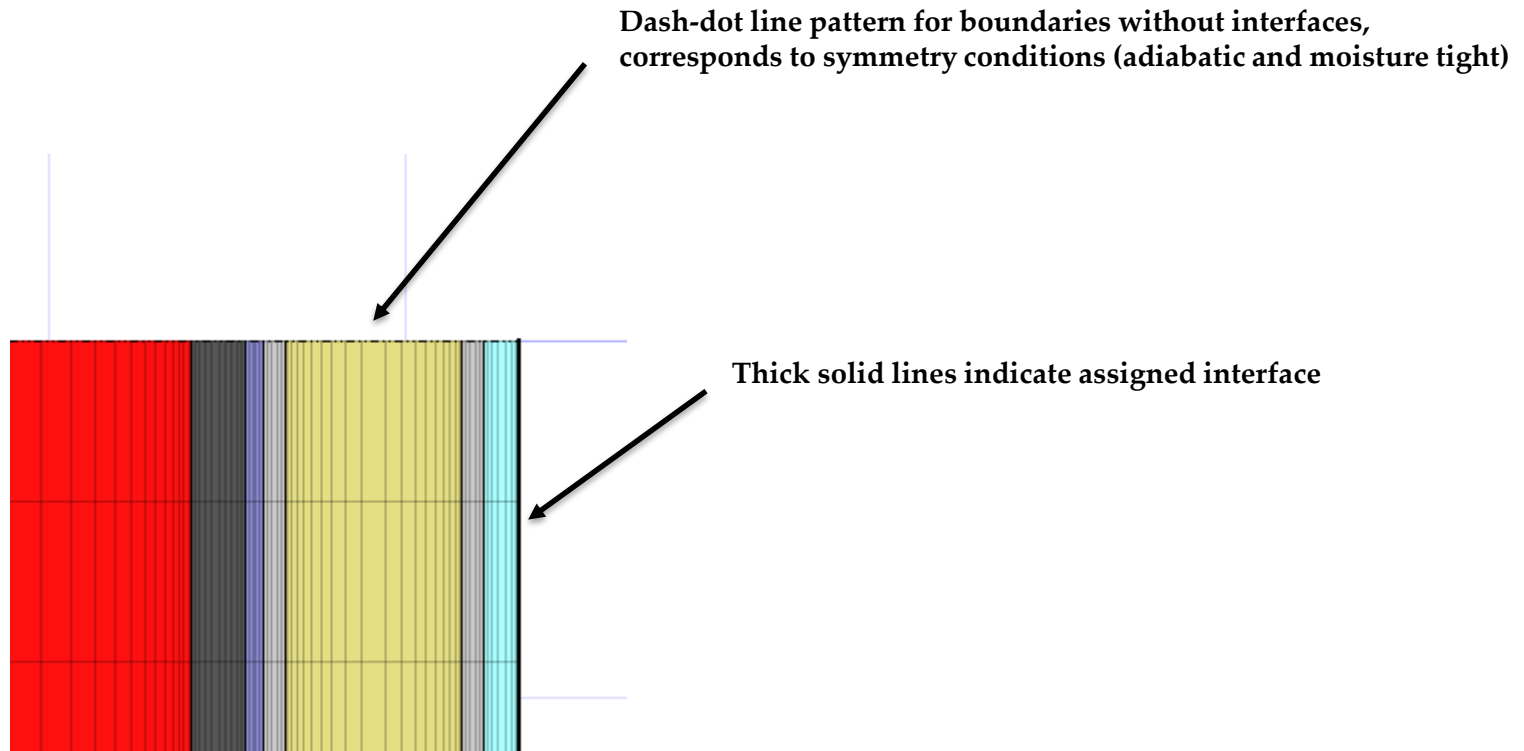


- Assignment order

➤ Later assignments override earlier assignments (applies to all assignments)

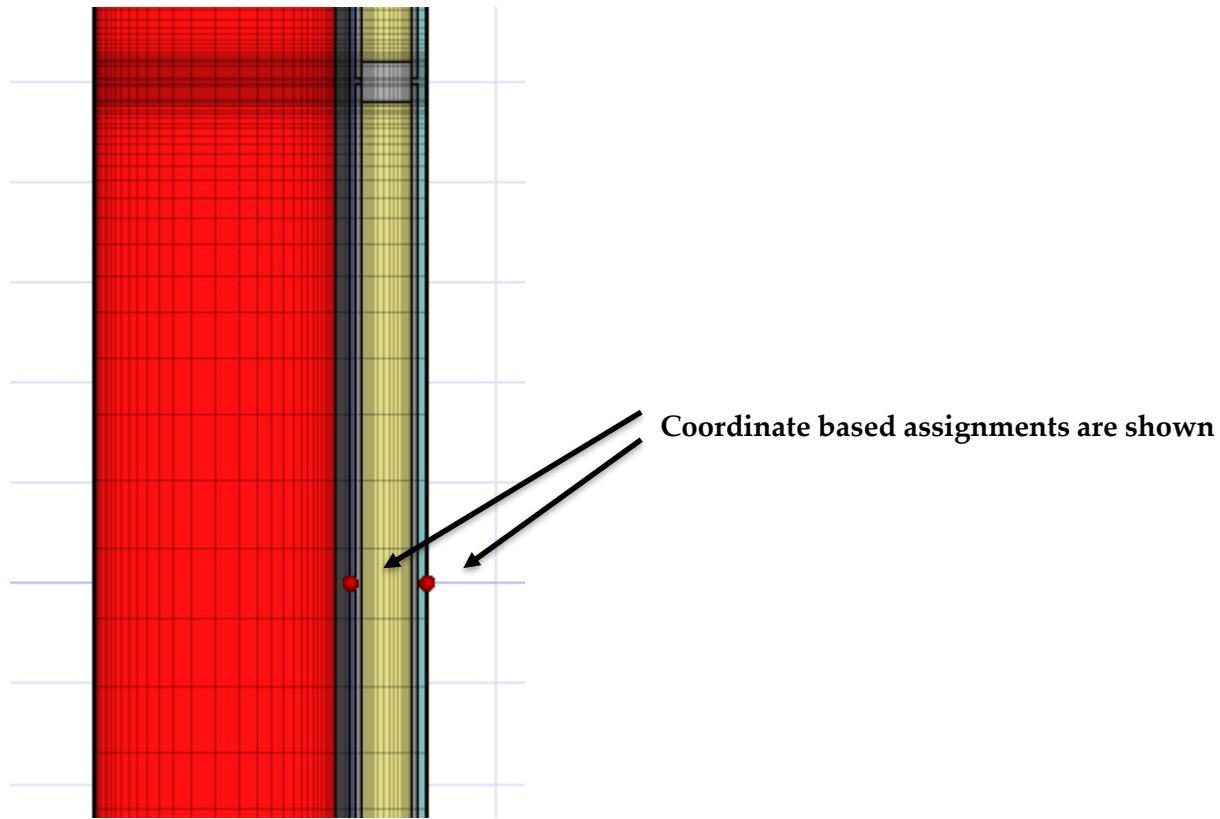


- Highlighting of edges/boundaries with assignments

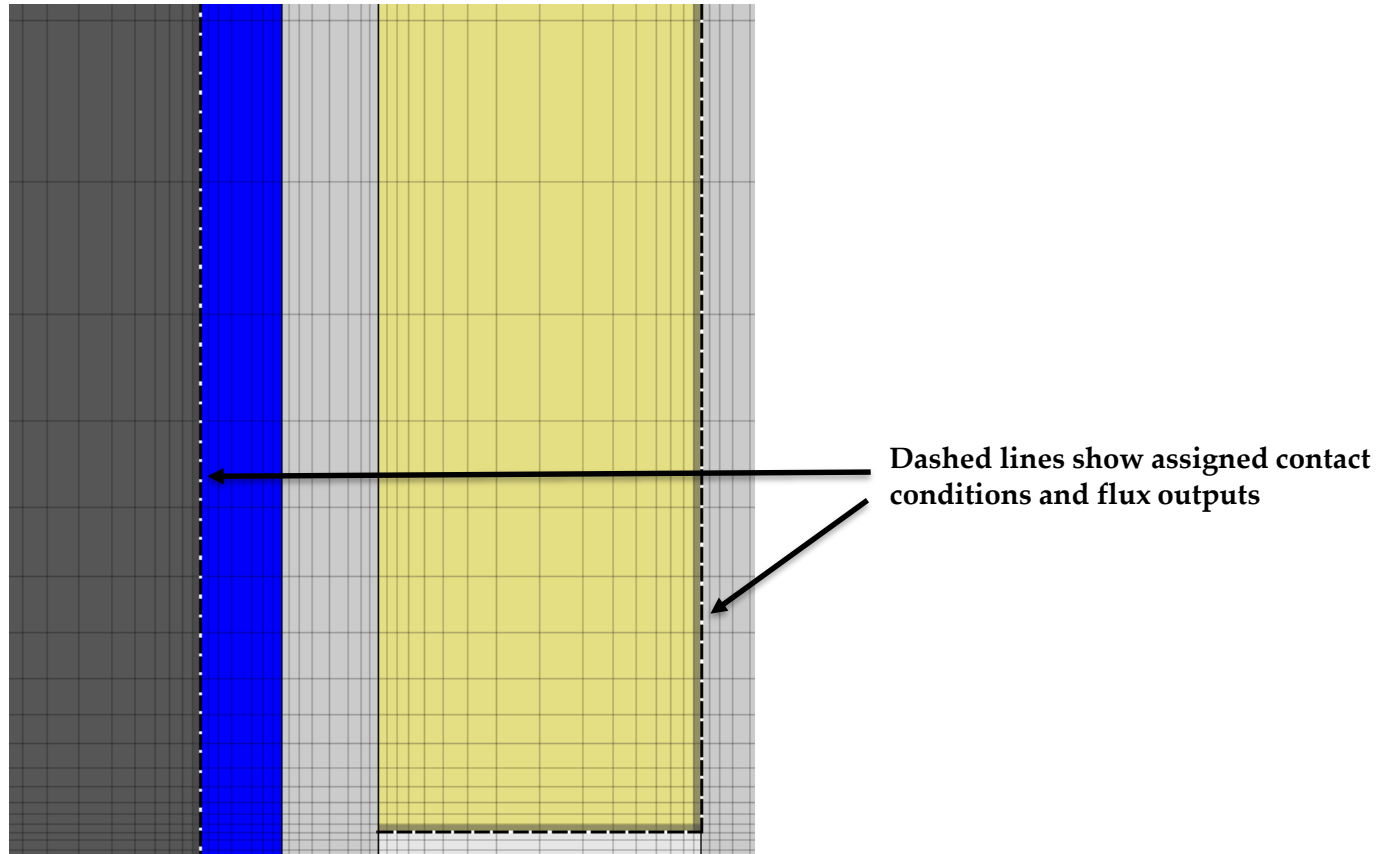




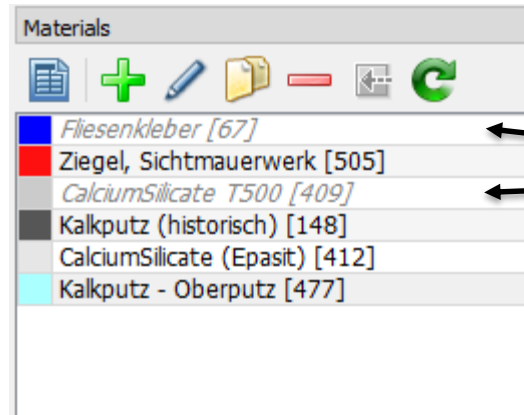
- Highlighting of coordinate outputs (sensors)



- Highlighting of side assignments

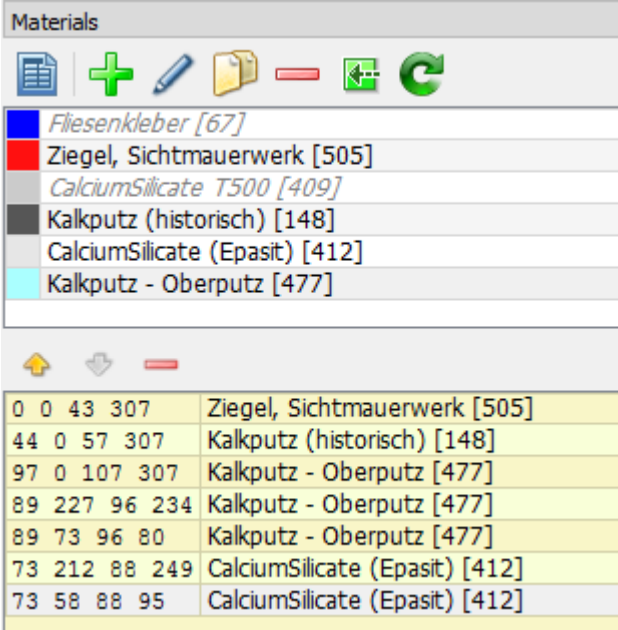


- Indication of used and unused definitions



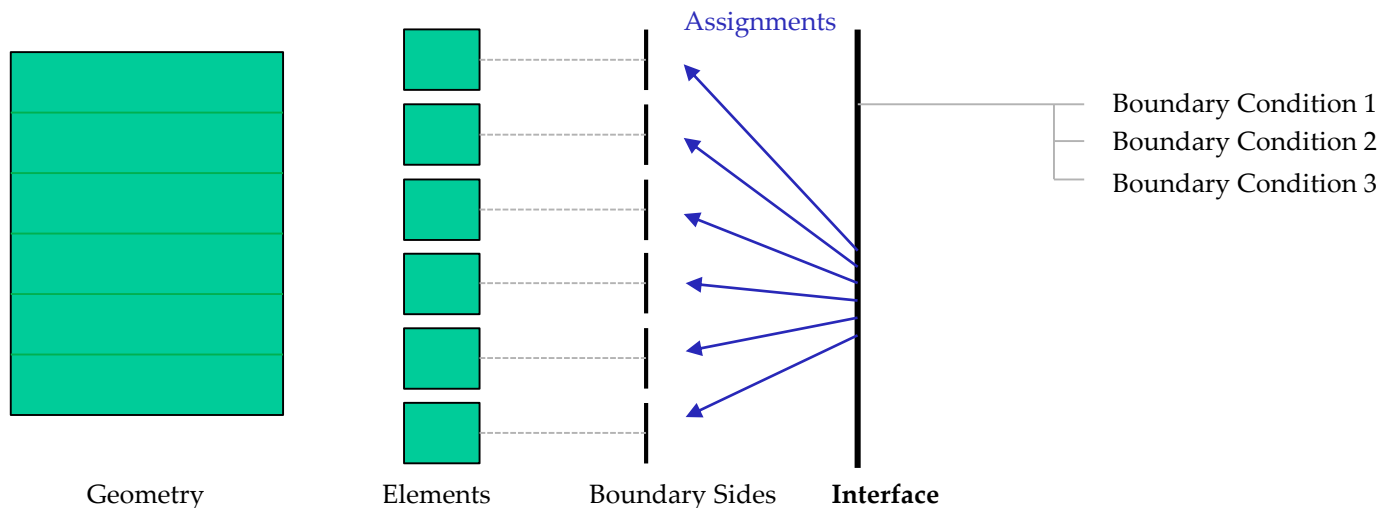
Gray italic text indicates an unused/not assigned definition

- Assignment lists are located alongside definition window  
(re-introduced from DELPHIN 4)

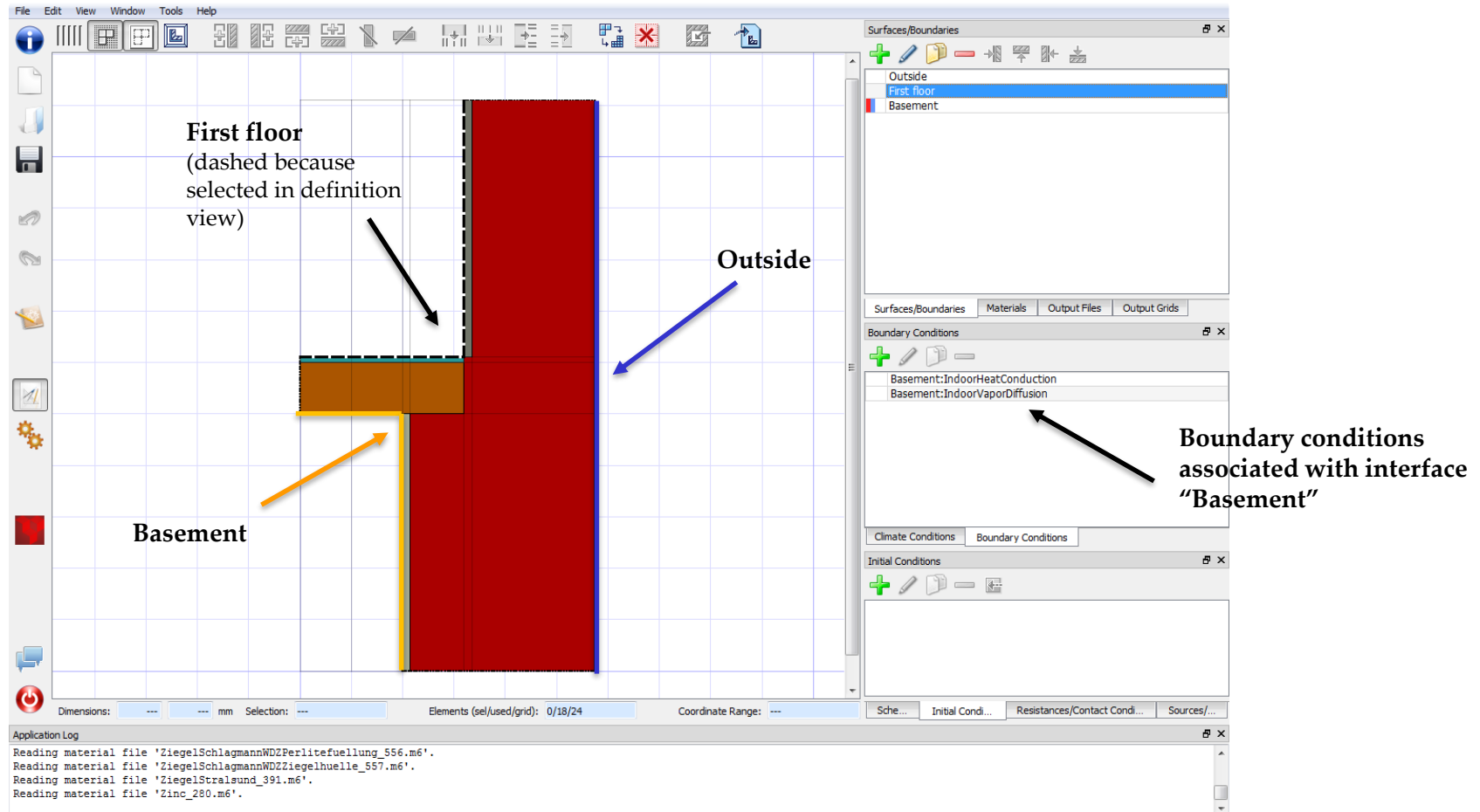


|    |     | Materials                     |                               |
|----|-----|-------------------------------|-------------------------------|
|    |     | Fliesenkleber [67]            |                               |
|    |     | Ziegel, Sichtmauerwerk [505]  |                               |
|    |     | CalciumSilicate T500 [409]    |                               |
|    |     | Kalkputz (historisch) [148]   |                               |
|    |     | CalciumSilicate (Epsit) [412] |                               |
|    |     | Kalkputz - Oberputz [477]     |                               |
|    |     | ↑ ↓ -                         |                               |
| 0  | 0   | 43 307                        | Ziegel, Sichtmauerwerk [505]  |
| 44 | 0   | 57 307                        | Kalkputz (historisch) [148]   |
| 97 | 0   | 107 307                       | Kalkputz - Oberputz [477]     |
| 89 | 227 | 96 234                        | Kalkputz - Oberputz [477]     |
| 89 | 73  | 96 80                         | Kalkputz - Oberputz [477]     |
| 73 | 212 | 88 249                        | CalciumSilicate (Epsit) [412] |
| 73 | 58  | 88 95                         | CalciumSilicate (Epsit) [412] |

- No embedded material data
  - Material files (\*.m6) are always referenced
  - Material list/definition window lists *Material References*
- *Interfaces* group several boundary conditions
  - Instead of assigning individual boundary conditions to several sides, interfaces are defined (e.g. outside, inside, basement, ...) and these are associated with boundary conditions
  - Support for *Engineering Interface Models* (predefined sets of boundary conditions and related climatic conditions)



- Interfaces – Example



The screenshot displays a software interface for modeling building interfaces. The main workspace shows a 3D model of a building with three distinct regions: a brown 'First floor' (dashed line indicating it is selected in the definition view), a red 'Basement', and a blue 'Outside' area. Annotations include an orange arrow pointing to the basement, a black arrow pointing to the first floor, and a blue arrow pointing to the outside. On the right, the 'Surfaces/Boundaries' panel lists 'Outside', 'First floor', and 'Basement'. Below it, the 'Boundary Conditions' panel shows 'Basement:IndoorHeatConduction' and 'Basement:IndoorVaporDiffusion', with a black arrow pointing to these entries. The 'Climate Conditions' panel is also visible. At the bottom, the 'Application Log' shows material file loading messages.

First floor  
(dashed because  
selected in definition  
view)

Outside

Basement

Boundary conditions  
associated with interface  
"Basement"

Surfaces/Boundaries

Outside  
First floor  
Basement

Boundary Conditions

Basement:IndoorHeatConduction  
Basement:IndoorVaporDiffusion

Climate Conditions

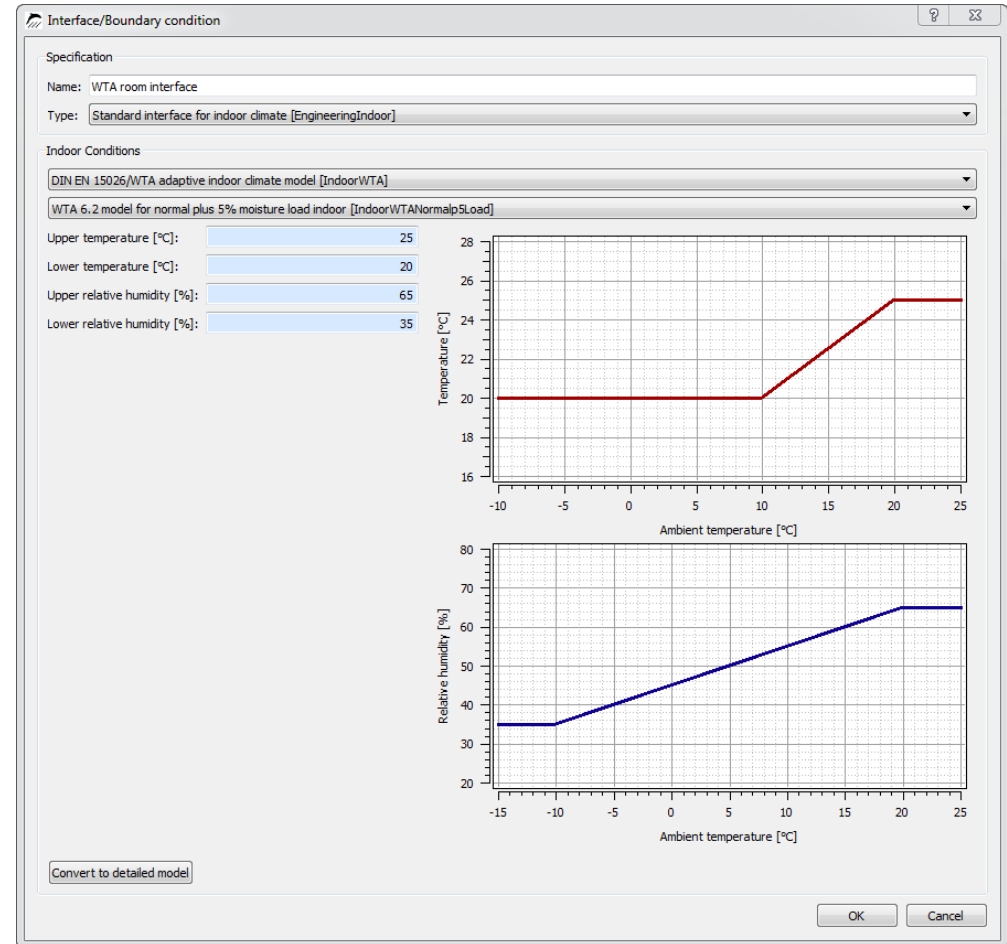
Boundary Conditions

Initial Conditions

Application Log

Reading material file 'ZiegelSchlagmannWDZPerlitefuellung\_556.m6'.  
Reading material file 'ZiegelSchlagmannWDZZiegelhuelle\_557.m6'.  
Reading material file 'ZiegelStralsund\_391.m6'.  
Reading material file 'Zinc\_280.m6'.

- Interfaces – Engineering Level
  - DIN indoor and outdoor climate
  - WTA model
  - Standard model
  
  - Boundary Conditions and Climate Conditions are created automatically during simulation setup
  
  - Engineering interface definitions can be converted to detailed model



- Output file definitions
  - Filename
  - *Physical Quantity*
  - Grid reference
  - Time and spatial handling (averaging/integration)
  - Value unit
- Grids
  - Define intervals and output steps
- Global options (for *all* files)
  - Binary/ASCII Format
  - ASCII-Format precision (rarely needed, for example for energy density integrals to compute overall gains/losses)
  - Output time unit (same for all output files)
  - Over-hygroscopic moisture content limit (as relative humidity)

Ausgabeoptionen

Ausgabezeiteinheit:

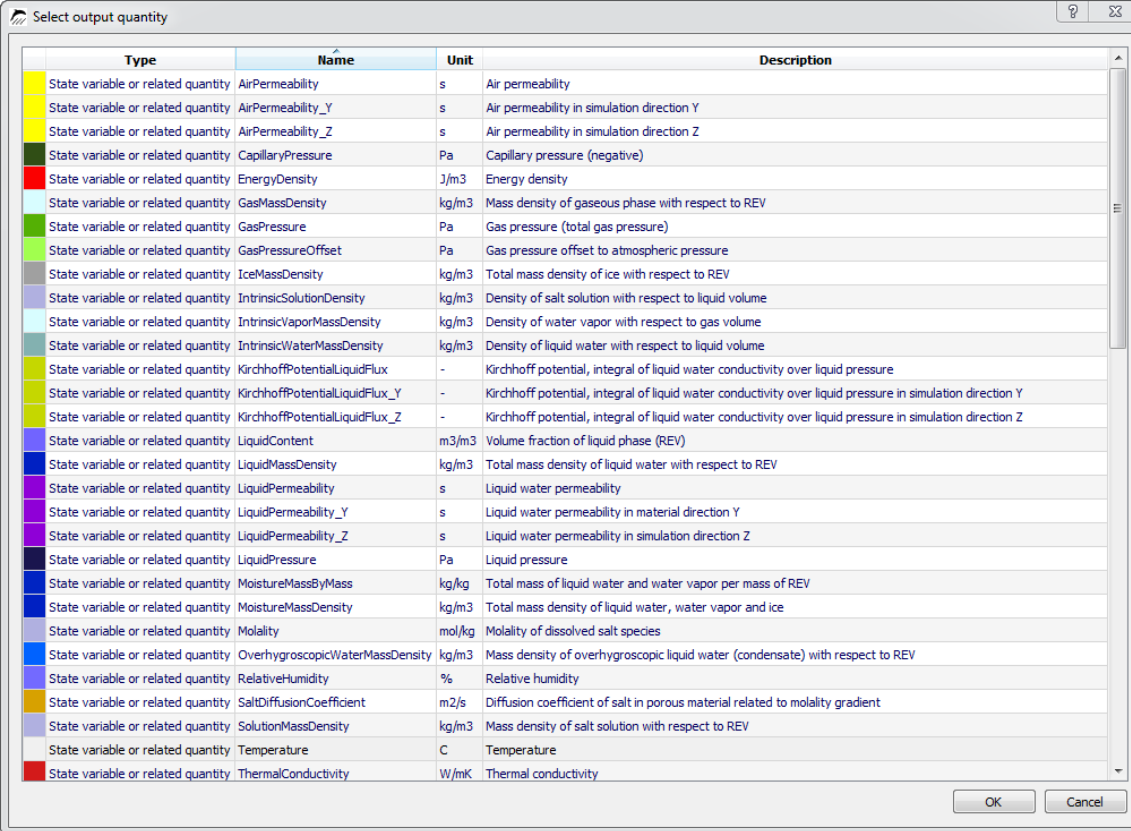
Anfang des überhygroskopischen Feuchtegehalts (Kondensat):  %

Schreibe Ausgaben im Binärformat

Zahlengenaugkeit in ASCII-Dateien:

- Physical Quantities

- Quantity defines also default unit and type (flux or field quantity)
- Anything calculated in DELPHIN is available as a quantity
- Includes transport coefficients (which can be monitored in output files)



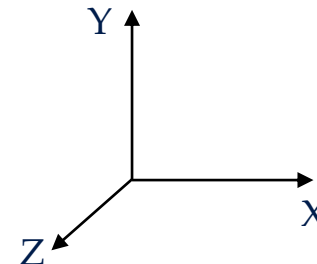
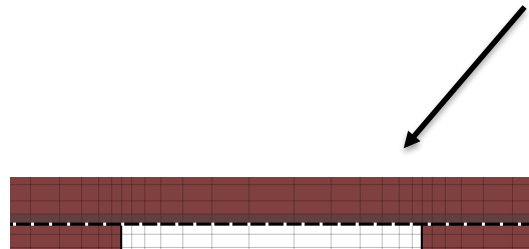
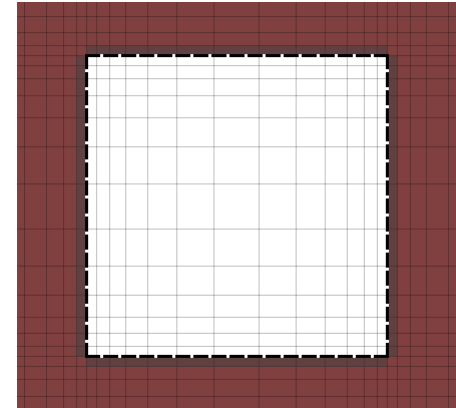
| Type                               | Name                            | Unit   | Description   |
|------------------------------------|---------------------------------|--------|---|
| State variable or related quantity | AirPermeability                 | s      | Air permeability  |
| State variable or related quantity | AirPermeability_Y               | s      | Air permeability in simulation direction Y  |
| State variable or related quantity | AirPermeability_Z               | s      | Air permeability in simulation direction Z  |
| State variable or related quantity | CapillaryPressure               | Pa     | Capillary pressure (negative)   |
| State variable or related quantity | EnergyDensity                   | J/m3   | Energy density  |
| State variable or related quantity | GasMassDensity                  | kg/m3  | Mass density of gaseous phase with respect to REV   |
| State variable or related quantity | GasPressure                     | Pa     | Gas pressure (total gas pressure)   |
| State variable or related quantity | GasPressureOffset               | Pa     | Gas pressure offset to atmospheric pressure   |
| State variable or related quantity | IceMassDensity                  | kg/m3  | Total mass density of ice with respect to REV   |
| State variable or related quantity | IntrinsicSolutionDensity        | kg/m3  | Density of salt solution with respect to liquid volume  |
| State variable or related quantity | IntrinsicVaporMassDensity       | kg/m3  | Density of water vapor with respect to gas volume   |
| State variable or related quantity | IntrinsicWaterMassDensity       | kg/m3  | Density of liquid water with respect to liquid volume   |
| State variable or related quantity | KirchhoffPotentialLiquidFlux    | -      | Kirchhoff potential, integral of liquid water conductivity over liquid pressure                           |
| State variable or related quantity | KirchhoffPotentialLiquidFlux_Y  | -      | Kirchhoff potential, integral of liquid water conductivity over liquid pressure in simulation direction Y |
| State variable or related quantity | KirchhoffPotentialLiquidFlux_Z  | -      | Kirchhoff potential, integral of liquid water conductivity over liquid pressure in simulation direction Z |
| State variable or related quantity | LiquidContent                   | m3/m3  | Volume fraction of liquid phase (REV)   |
| State variable or related quantity | LiquidMassDensity               | kg/m3  | Total mass density of liquid water with respect to REV  |
| State variable or related quantity | LiquidPermeability              | s      | Liquid water permeability   |
| State variable or related quantity | LiquidPermeability_Y            | s      | Liquid water permeability in material direction Y   |
| State variable or related quantity | LiquidPermeability_Z            | s      | Liquid water permeability in simulation direction Z   |
| State variable or related quantity | LiquidPressure                  | Pa     | Liquid pressure   |
| State variable or related quantity | MoistureMassByMass              | kg/kg  | Total mass of liquid water and water vapor per mass of REV  |
| State variable or related quantity | MoistureMassDensity             | kg/m3  | Total mass density of liquid water, water vapor and ice   |
| State variable or related quantity | Molality                        | mol/kg | Molality of dissolved salt species  |
| State variable or related quantity | OverhygroscopicWaterMassDensity | kg/m3  | Mass density of overhygroscopic liquid water (condensate) with respect to REV                             |
| State variable or related quantity | RelativeHumidity                | %      | Relative humidity   |
| State variable or related quantity | SaltDiffusionCoefficient        | m2/s   | Diffusion coefficient of salt in porous material related to molality gradient                             |
| State variable or related quantity | SolutionMassDensity             | kg/m3  | Mass density of salt solution with respect to REV   |
| State variable or related quantity | Temperature                     | C      | Temperature   |
| State variable or related quantity | ThermalConductivity             | W/mK   | Thermal conductivity  |



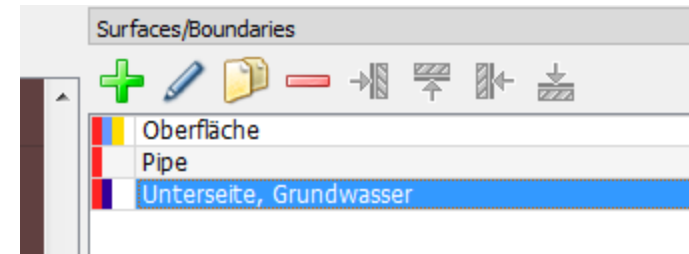
- Flux output sign conventions
  - Distinguish between boundary/surface fluxes and flux fields – **different sign conventions**
  - Fluxes are assigned to sides
  - One flux output (definition) can be assigned to several locations

- Rules

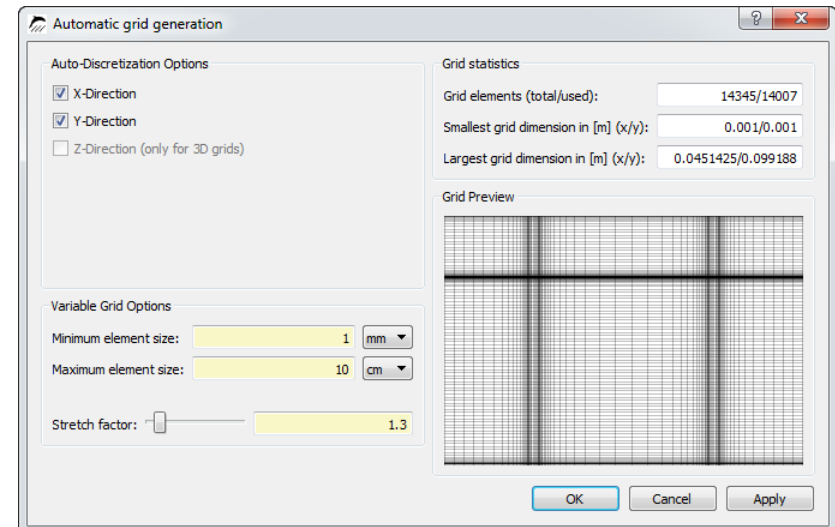
- When flux outputs are assigned only to boundary sides →  
Flux is *positive* when it flows *into* the construction  
i.e. a positive moisture flux increases the moisture content  
in the construction, a positive heat flux increases  
energy density (and temperature)
- When flux is assigned to at least one internal side,  
flux is *positive* when it flows into *positive coordinate* direction



- Schedules
  - Replace time limits for boundary and field conditions, can be specified like output intervals
- Interface – BC indication
  - Color bars indicate types of BC associated with an interface



- Intelligent Auto-Discretization
  - Clusters grid *only at boundaries where interfaces are assigned*
  - Recognizes and keeps field assignments (outputs/sources)



- Material Data Base
  - set of **m6** Material files (as in DELPHIN 5)
  - data files are read in separate thread – no longer delay when importing materials
- Climate Data
  - New format: **c6b** climate data container files for use in CCM (Climate Calculation Module)
  - Basically same content as EPW, but binary format (data protection), **epw** natively supported
  - Free Climate Data Editor (CCMEditor) tool available for editing/converting data
- Additional time series (climate data)
  - Still using **ccd** files as in DELPHIN 5
  - Now supporting **csv** files (tabulator separated data files):  
first column time points, second column values, description and units in first row

Example file:

| Time [d] | Temperature [C] |
|----------|-----------------|
| 0.0      | 10.0            |
| 0.02083  | 9.0             |
| 0.041667 | 8.7             |
| 0.0625   | 7.4             |

Model Options | Solver Options | Performance Options

The settings on this page control basic properties of the physical model.

Energy Balance Equation

Default initial temperature:  C

Use thermal conductivity of dry material (LAMBDA)

Use design value of thermal conductivity (LAMBDA\_DESIGN)

Use moisture-dependent thermal conductivity

Default initial relative humidity:  %

Moisture Balance Equation

Default initial relative humidity:  %

Use Kirchhoff potential for liquid flux calculation

Use gravity

Use equilibrium ice model

Air Mass Balance Equation

Use gravity

Salt Balance Equations

Pollutant Balance Equations

Additional Modeling Options

Use anisotropic material transport model

Prevent overfilling

Output options

Output time unit:

Over-hygroscopic moisture limit (condensate):  %

Write binary output files

Number precision in ASCII files:

Simulation Time Frame

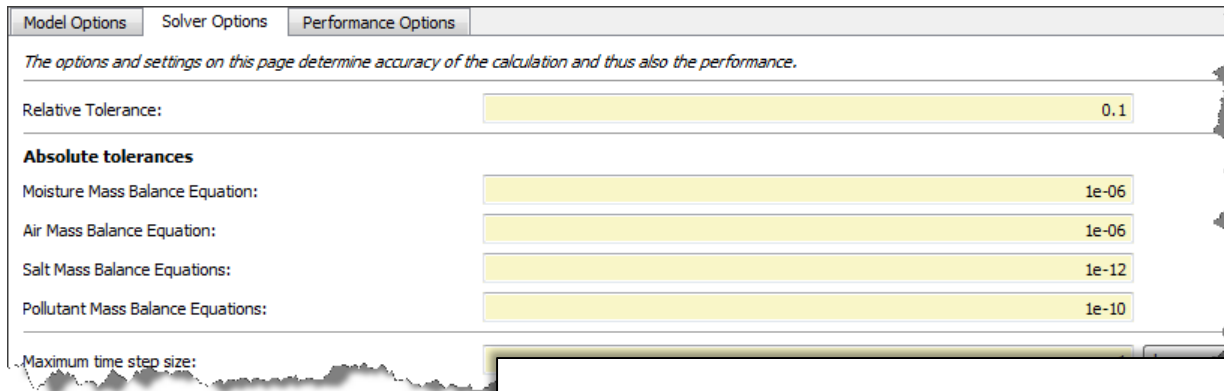
Start date:

End date:

Duration:

## First page: Model options

- Contains settings, that define physical model and naturally give different results



## Second page: Solver options

- Tolerances control error test – to how many digits shall my *conserved quantities* be accurate  
Mind: there is a non-linear relationship between conserved quantities and analysed properties (e.g. relative humidity)
- Settings have an influence on model results
- Smaller tolerances **slow down** simulation but can help increase robustness!

Model Options | Solver Options | Performance Options

*The options in this page only have an impact on simulation performance, not on results.*

Integrator: CVODE [CVODE]

Maximum Method Order (1-5): 5

Non-linear Iteration Convergence Coefficient: 1e-07

Linear Equation System Solver: Sparse direct solver (KLU) [KLU]

System band width (direct band solver): auto

Maximum Dimension for Krylov Subspace: 30

Linear Iteration Convergence Coefficient: 0.1

Preconditioner: Automatic selection [Auto]

System band width (band preconditioner): auto

Level of fill-in (ILU): auto

Initial time step: 1 min

Time step size limit (model consistency): 0.0001 s

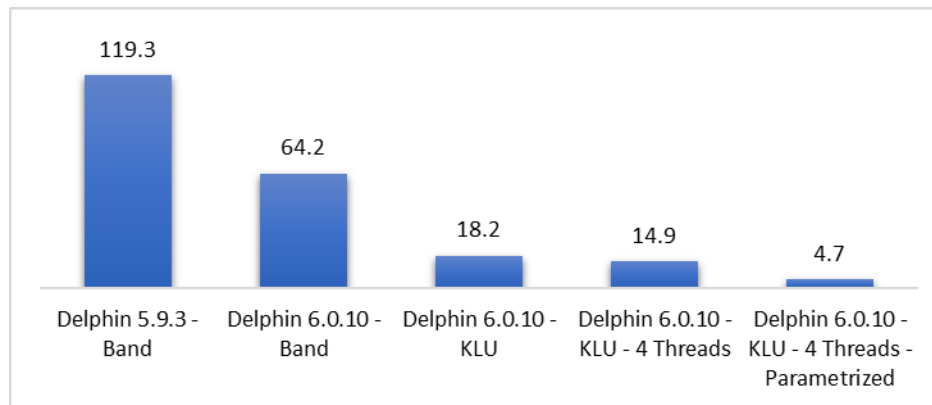
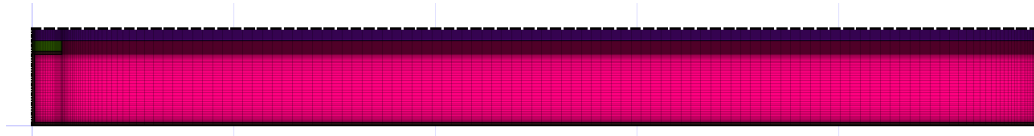
## Third page: Performance options

- Numerical settings only influence simulation speed (differences in order of rounding errors possible)

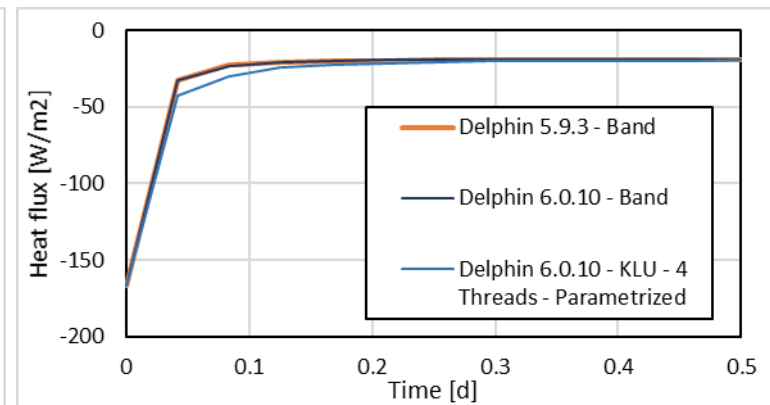
- Time integrators available
  - Explicit Euler (for debugging purposes)
  - Runge Kutta 47 (Dormand-Prince), explicit solver
  - Implicit Euler (for testing numerically tricky problems)
  - **CVODE** (default, as in DELPHIN 5)
  - Alternating-Direct-Implicit (ADI), good for certain 2D/3D problems, research code
- Linear equation system solvers (for use within implicit solvers)
  - Banded (general 1D simulations, small 2D simulations)
  - Block-Tridiagonal (VOC/Salt simulations in 1D)
  - **Sparse direct** (KLU solver, for thermal problems in 2D/3D)
  - **GMRES** and **BiCGStab** (for general 2D/3D cases) – Krylov-Subspace methods!
- Preconditioners (for Krylov-Subspace solvers)
  - Banded
  - **ILU** (incomplete LU factorization)
  - ... others are research/test implementations
- Physical model evaluation done in parallel (**OpenMP parallelization**)

See presentation and workshop from BauSIM 2016 for details

- Example 1 – EN ISO 10211 – Case 2
  - Energy balance only (thermal bridge problem)
  - 36666 Elements, 189 half-bandwidth (rectangular 194 x 189 grid)



Simulation time [s]

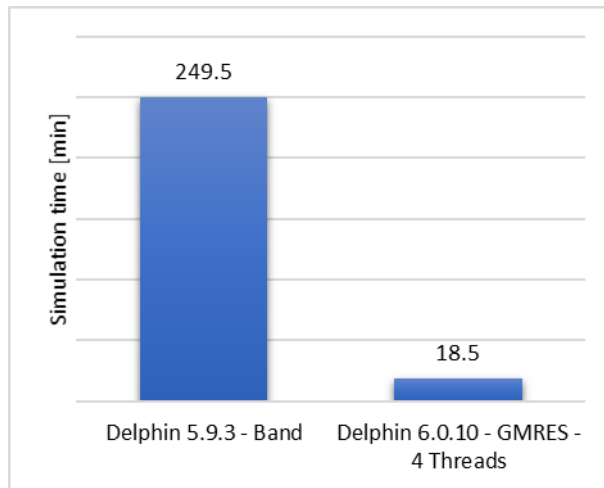
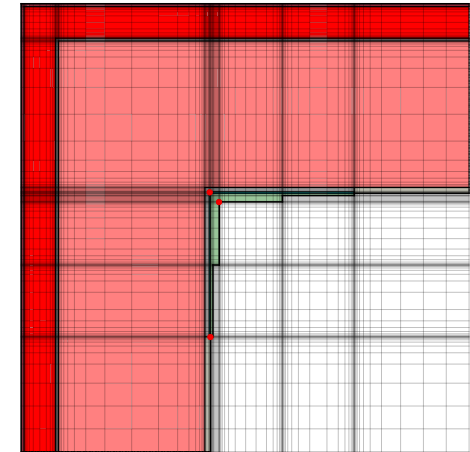


Bottom heat flux density [W/m<sup>2</sup>]

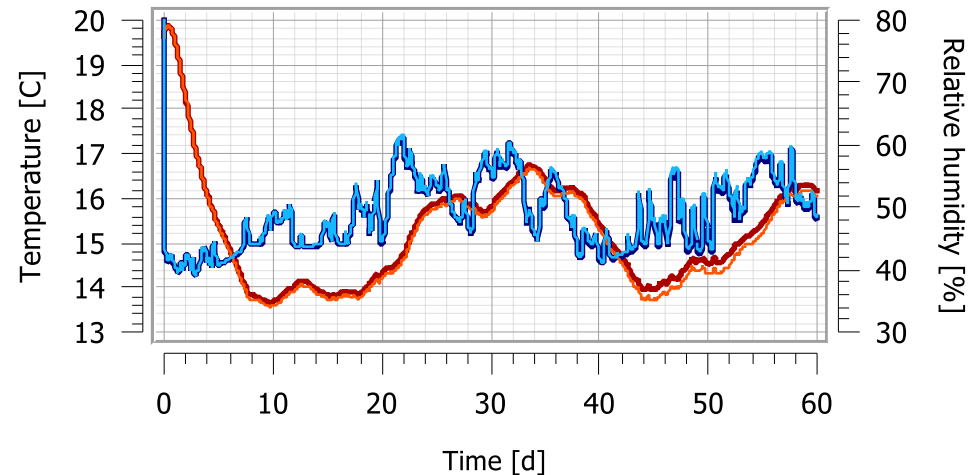
- Variants
  - Band solver vs. KLU (in DELPHIN 6)
  - Serial/parallel code (1 vs. 4 threads)
  - Parameters for steady-state result (transient accuracy does not matter)



- Example 2 – Corner
  - Hygrothermal simulation
  - 10931 Elemente (21862 Unknowns)
- Variants
  - Serial banded solver in DELPHIN 5 (half-bandwidth 223)
  - Parallel GMRES solver in DELPHIN 6 (4 threads), ILU preconditioner, colored Jacobian (14 colors)



Simulation time [min], first 60 days of simulation



- Temperature [Delphin 5]   ■ RelHum [Delphin 5]
- Temperature [Delphin 6]   ■ RelHum [Delphin 6]

- Send projects to remote (powerful) server and collect results

Remote Solver Server

Server (IP-Address):

Port:

User:

Password:

- Project input files are collected and exported into project package (\*.d6pp)
- Project package is sent to server, scheduled in either *fast* or *slow* queue (*fast* jobs are automatically aborted after 30 minutes if not yet finished)
- Once completed, results are archived as 7zip file and retrieved from server
- Results are extracted in projects directory just as if simulated locally → ready for PostProcessing

- Only limited lifetime licenses
  - Much reduced license costs
  - Annual license duration with support and free updates/upgrades
  - Activation provided for work and private computer (linked to person/company)
  - Activation needs to be updated every year (license renewal)
- License/support renewal/extension:
  - Always for 1 year after last license expired, includes free updates/upgrades and support
  - Cannot skip renewal intervals, after approximately 4 years same price as new license
- Pricing:

|                           |                         |
|---------------------------|-------------------------|
| Commercial license:       | 800 € initial + 600 €/a |
| Academic license:         | 600 €/a                 |
| Student/teaching license: | --- €/a                 |

*all prices excluding VAT*



# New features and optimizations in the hygrothermal transport model DELPHIN 6

Dr. Andreas Nicolai

**Thank You! Questions?**

