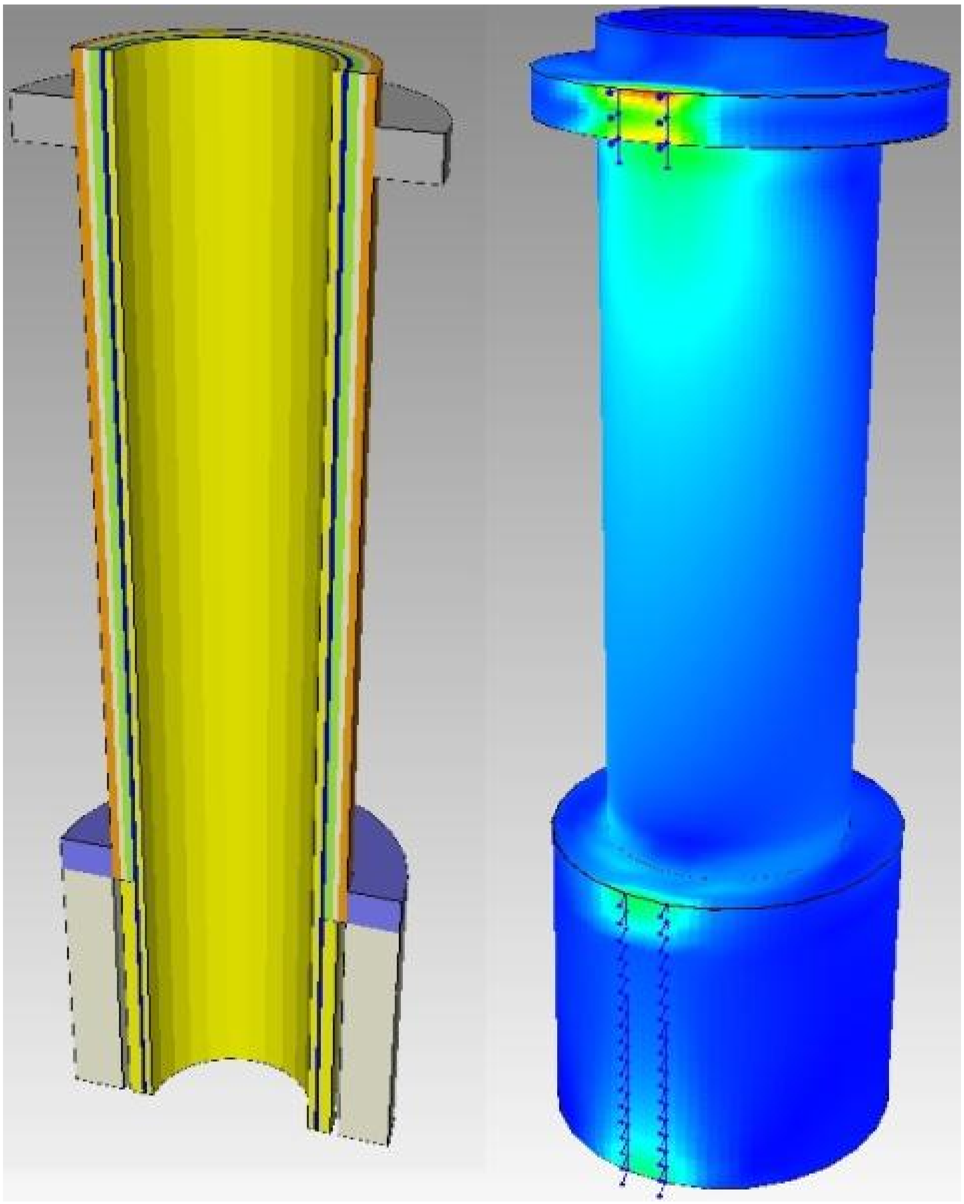
Part 32: 3D-Mesh Generator SOLIDGEN for Heat-Exchanger and Battery-Structures

With the new 3D mesh generator SOLIDGEN (MEANS-Update from July 2023) Cylinders and Quaders can be extruded from the 2D view in depth.
Likewise, entire cylinder groups (see battery pack) can be generated in relatively small and precise hexahedron meshes, which are otherwise only possible with the common tetrahedron mesh generators (e.g. NETGEN or GMSH) with a great deal of modeling and time expenditure.

Heat-Exchanger made up of 22,542 hexahedra and 24,674 nodes

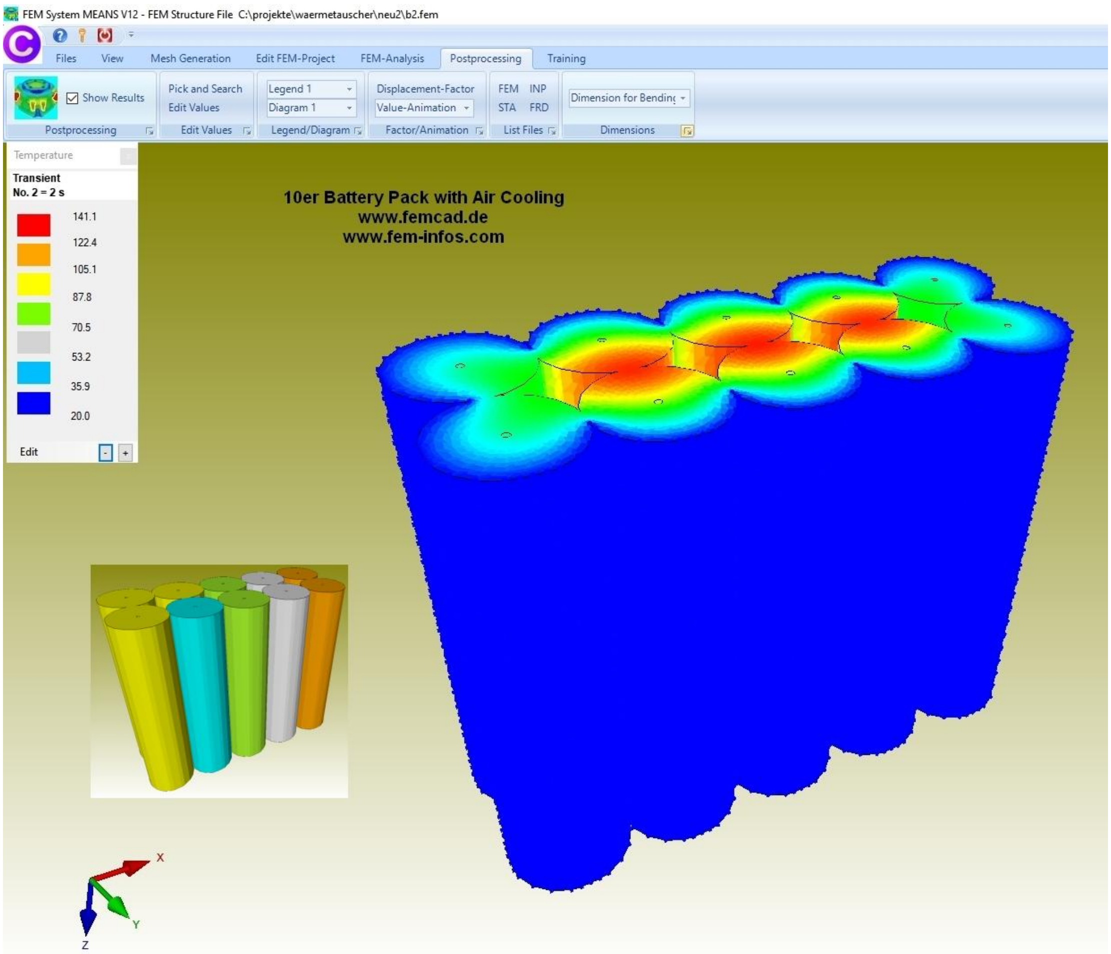
Structure consists of 3 pipes, 2 isulations, 1 layer of concrete and 3 layers of air



Battery-Pack

A 10 battery pack consisting of 10 cylinders is generated with SOLIDGEN and calculated with MEANS and the Add-On TEMPERATURE with air cooling. Cooling is very important because the batteries connected in series can overheat, leak or age very quickly due to the higher current output. If only one battery fails, the entire power storage device is short-circuited and, in extreme cases, can even explode. Since large temperature differences also produce higher deformations and stresses, the battery pack should be cooled down as gently and evenly as possible.

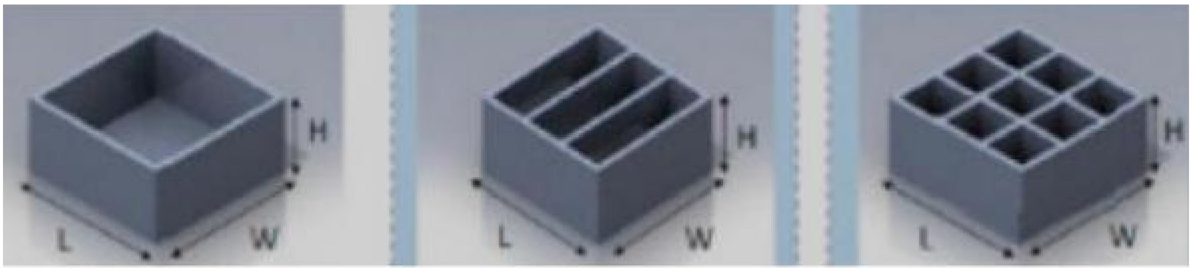
FEM model made up of 26,680 hexahedra and 34,424 nodes



16 Battery Pack with three different Cooling Systems

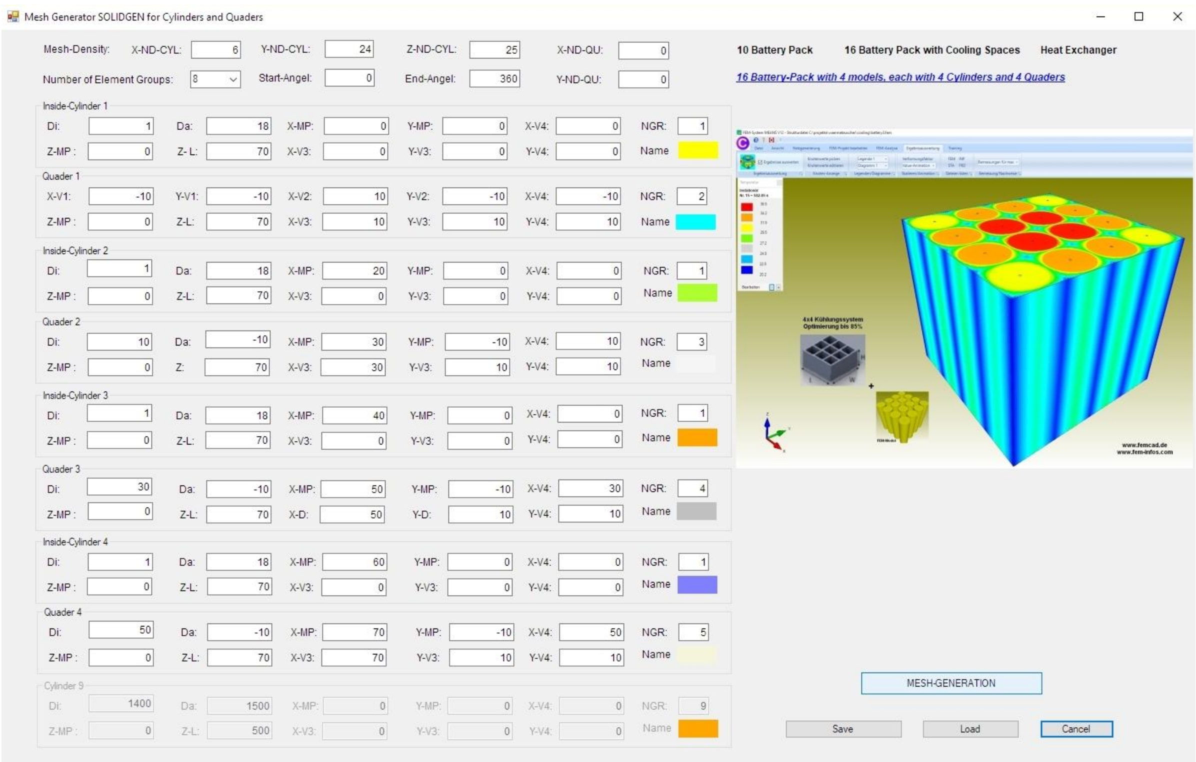
In the following, the unsteady temperature distributions on a 16 Battery Pack calculated with the following three Cooling Systems:

all outside surfaces	+ all horizontal surfaces	+ all vertical surfaces
1x1 Cooling	**4x1 Cooling**	**4x4 Cooling**

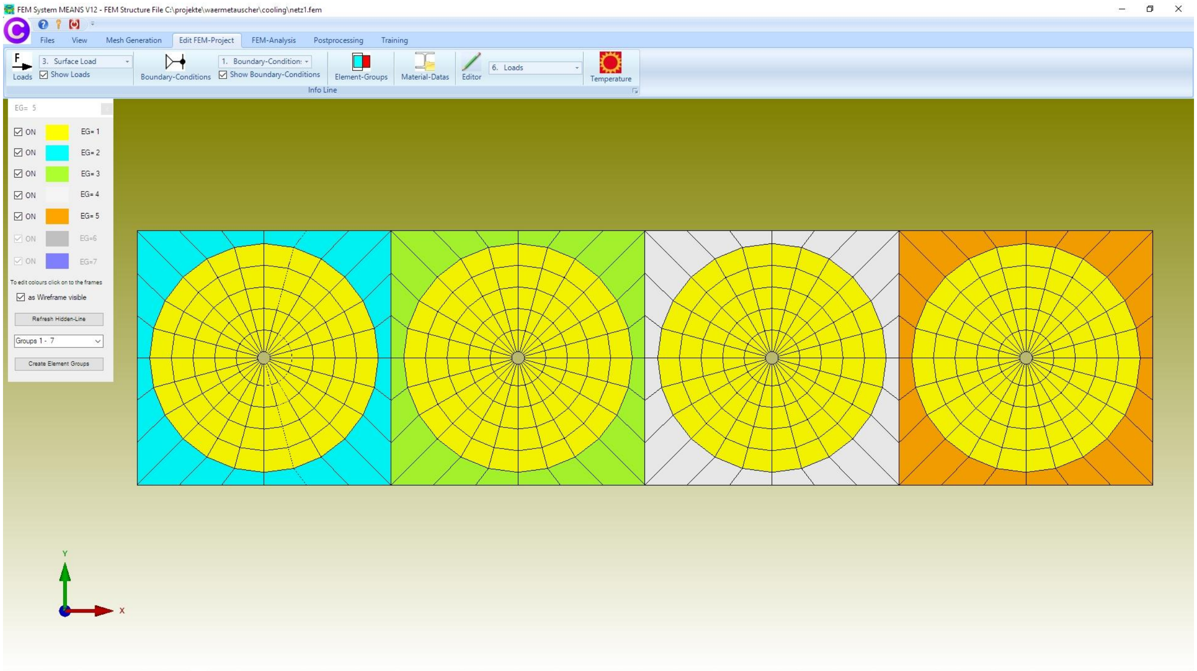


Mesh Generation with SOLIDGEN

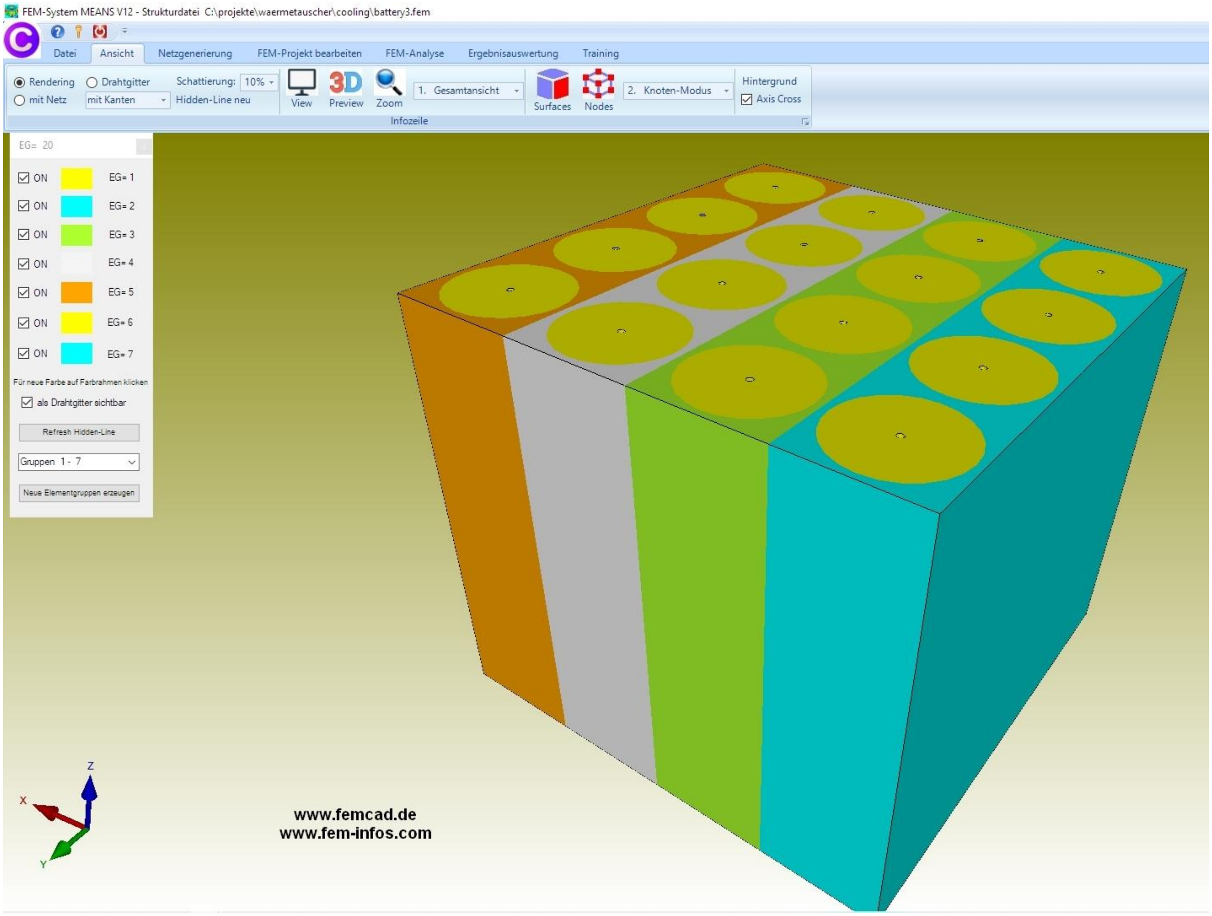
First, 4 cylinders and 4 cuboids with the diameters, centres, widths and heights are entered in a user-friendly and clear SOLIDGEN form.



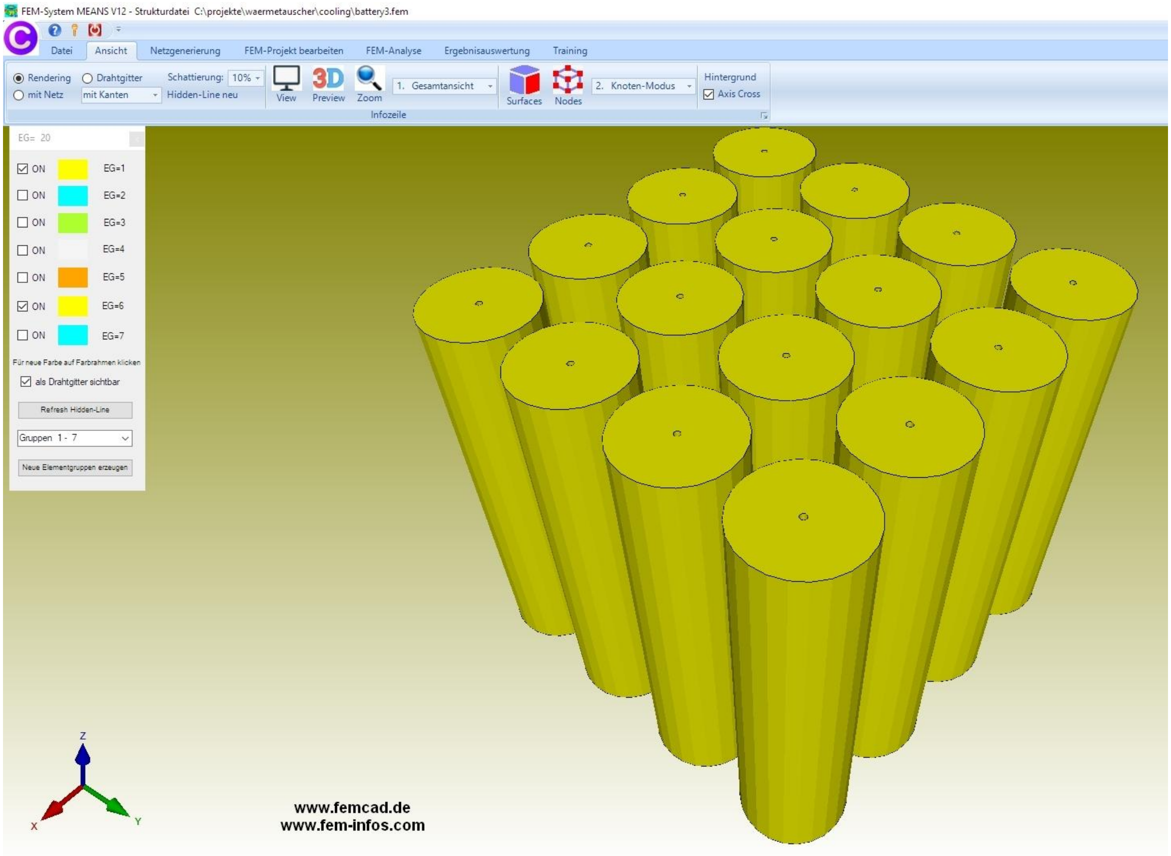
Then the 2D QUAD mesh is generated and extruded into a hexahedron mesh with the Z height and Z length.



In the last step, 4 meshes are offset by 20 mm in the y-direction and loaded together to a FEM model with 54 303 Hexahedrons, 65 171 nodes and 20 element groups.

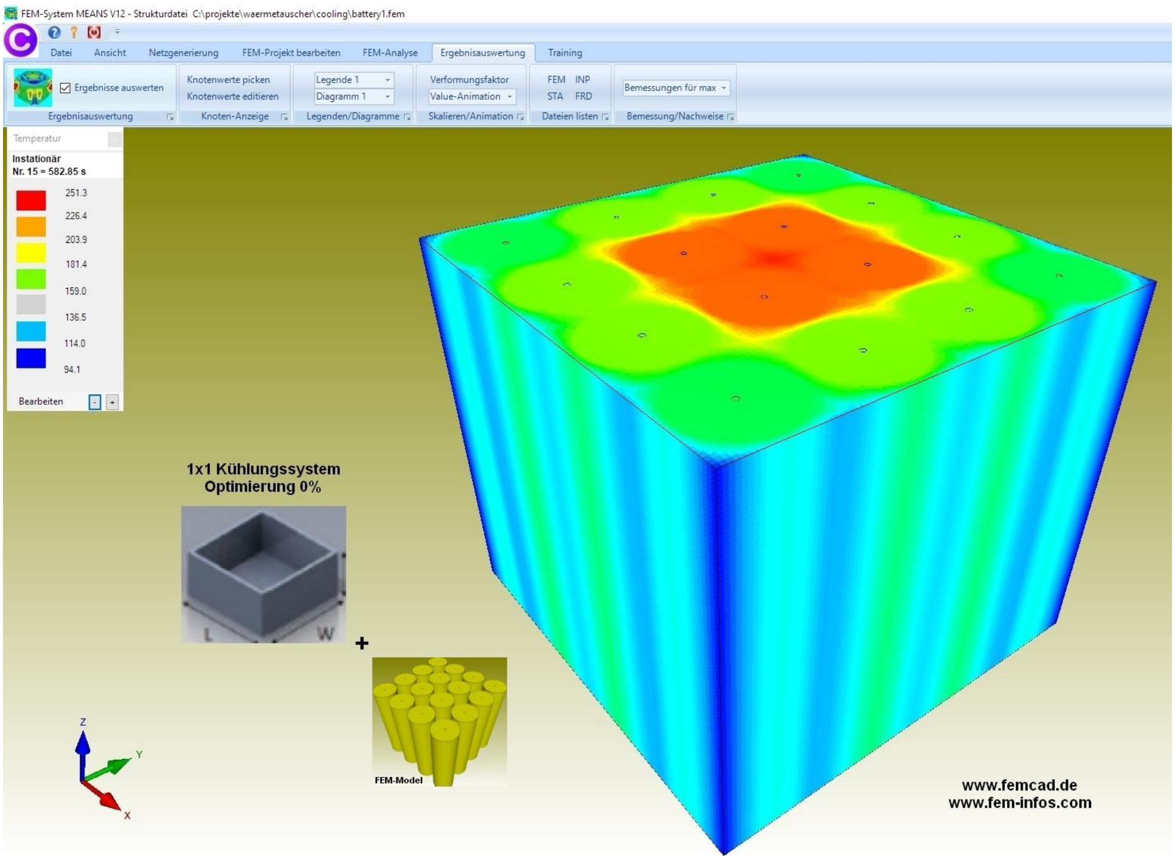


FEM model with 16 Cylinders and without Cuboids



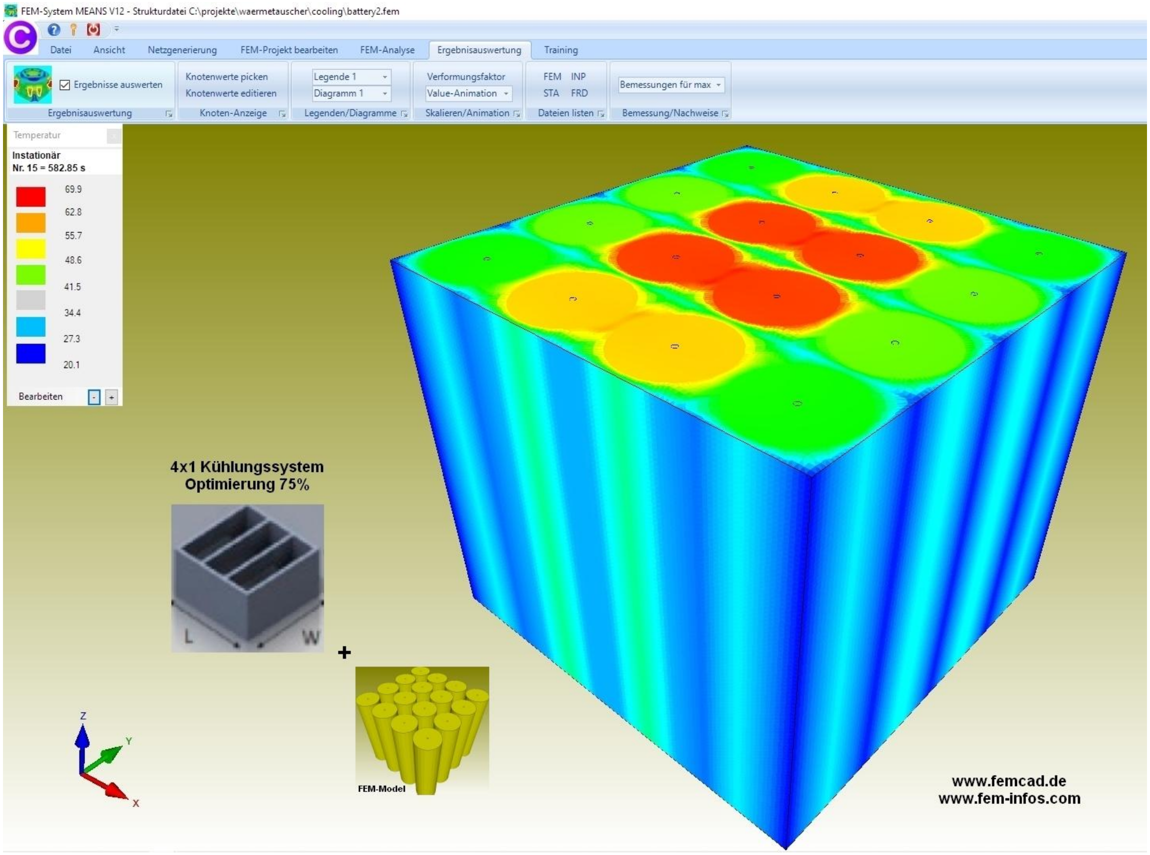
1x1 Cooling System after 15 Time-Steps and 585 seconds

max. Temperature = 251.3° C; min. Temperature = 94.1° C



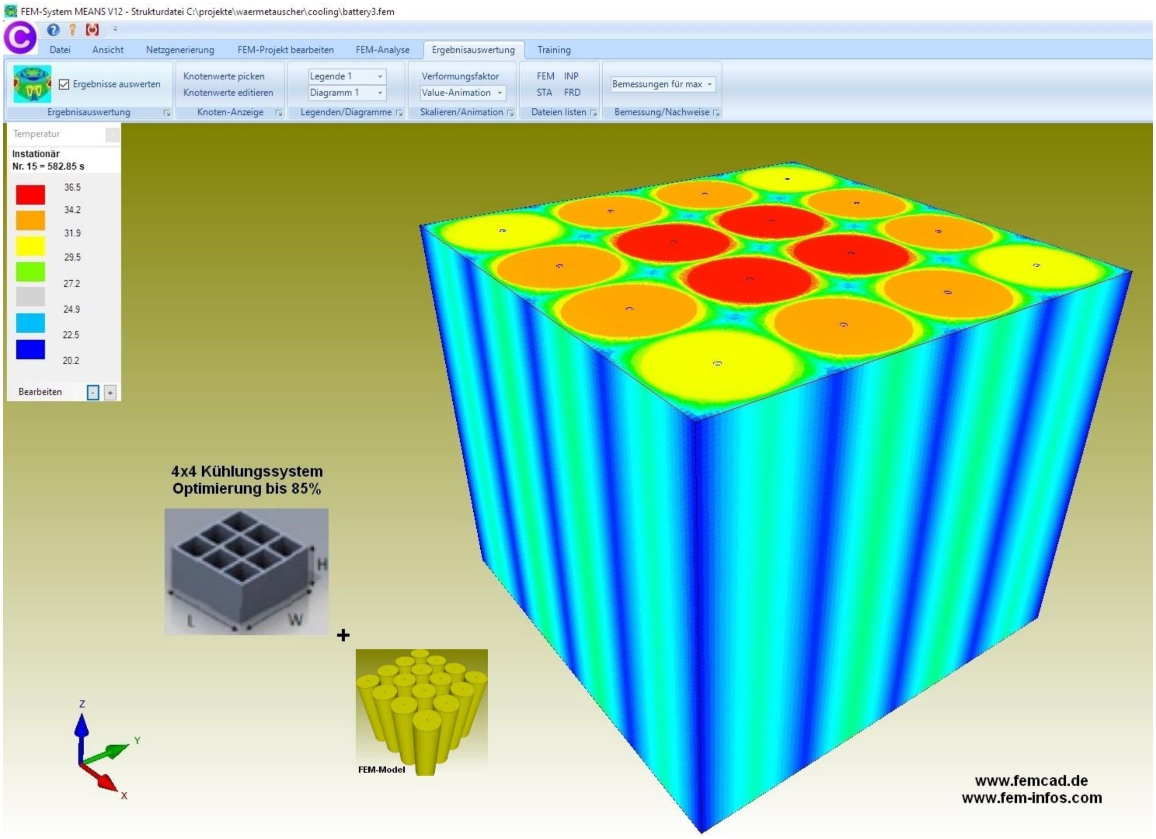
4x1 Cooling System after 15 Time-Steps and 585 seconds

max. Temperature = 69.9° C; min. Temperature = 20.1° C



4x4 Cooling System after 15 Time-Steps and 585 seconds

max. Temperature = 36.5° C; min. Temperature = 20.2° C



SOLIDGEN form

Select the "Mesh Generation" tab and the "SOLIDGEN" menu to display the SOLIDGEN form to generate battery structures from cylinders and cuboids:

- Cylinders, up to 9 cylinders can be generated
- Cylinder contacting the other, e.g. 10 battery pack with Y-ND-CYL = 20
- Cylinder in a cuboid, e.g. 16 battery pack with Y-ND-CYL = 24
- Cuboid, e.g. for layered structures, e.g. underfloor heating (in future)

Several meshes can be connected to a main mesh with a FEM Merge.
To generate a 2D mesh with circle and rectangle enter the following in the SOLIDGEN form:

Mesh densities:

X-ND-CYL: Number of nodes in X-direction or radius
Y-ND-CYL: number of nodes around the circumference (the larger the more circular)
Z-ND-CYL: Number of nodes in the Z direction
X-ND-QU: Number of nodes in the X-direction in a cuboid
Y-ND-QU: Number of nodes in the Y-direction in a cuboid

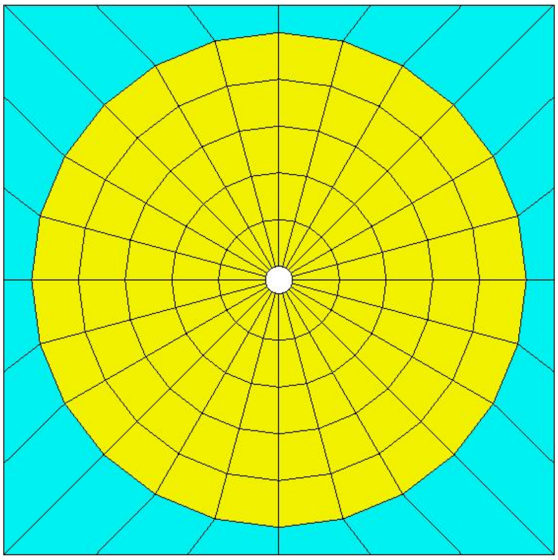
Cylinder datas:

Inside diameter Di = 1 mm (here small hole to avoid pentahedron)
Outer diameter Da = 18 mm
X-MP = X-Center
Y-MP = Y-Center
Z-MP = Z center point for cylinders or Z starting point for cuboids
Z-L = length in Z direction (for 2D = 0)

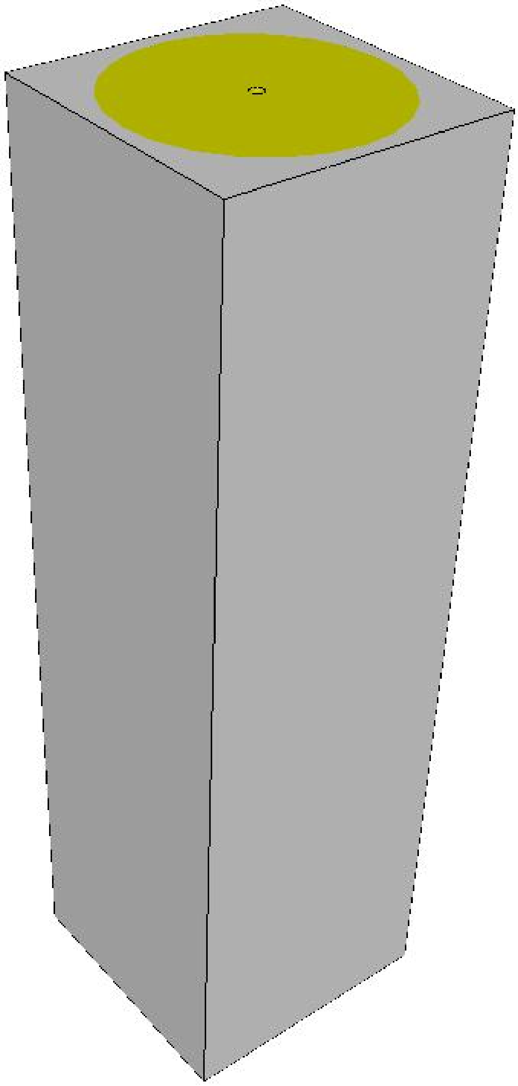
Cuboid datas:

X-V1 = X point 1
Y-V1 = Y point 1
X-V2 = X point 2
Y-V2 = Y point 2
X-V3 = X point 3
Y-V3 = Y point 3
X-V4 = X point 4
Y-V4 = Y point 4

Select the "Mesh Generation" menu to generate a 2D mesh of 140 QUA4S elements and 168 nodes with Z-L = 0.

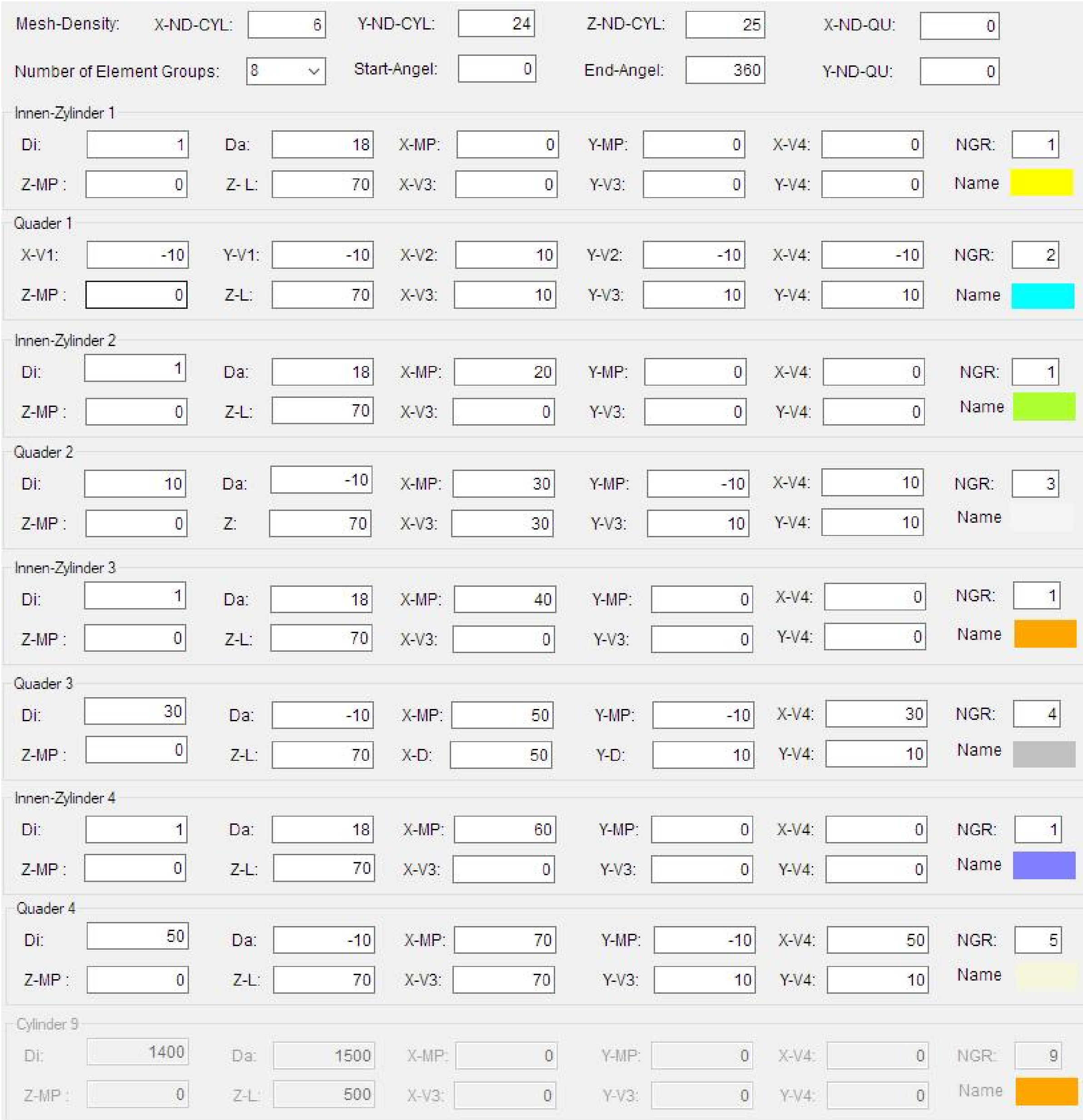


Select the "Mesh Generation" menu to generate a 3D mesh of 3456 HEX8 solids and 6400 nodes with Z-L = 70.



Creation of the 4x1 model

Click on "16 battery pack" and the datas for 4 cylinders and 4 cuboids will be displayed and select the "Mesh Generation" menu.

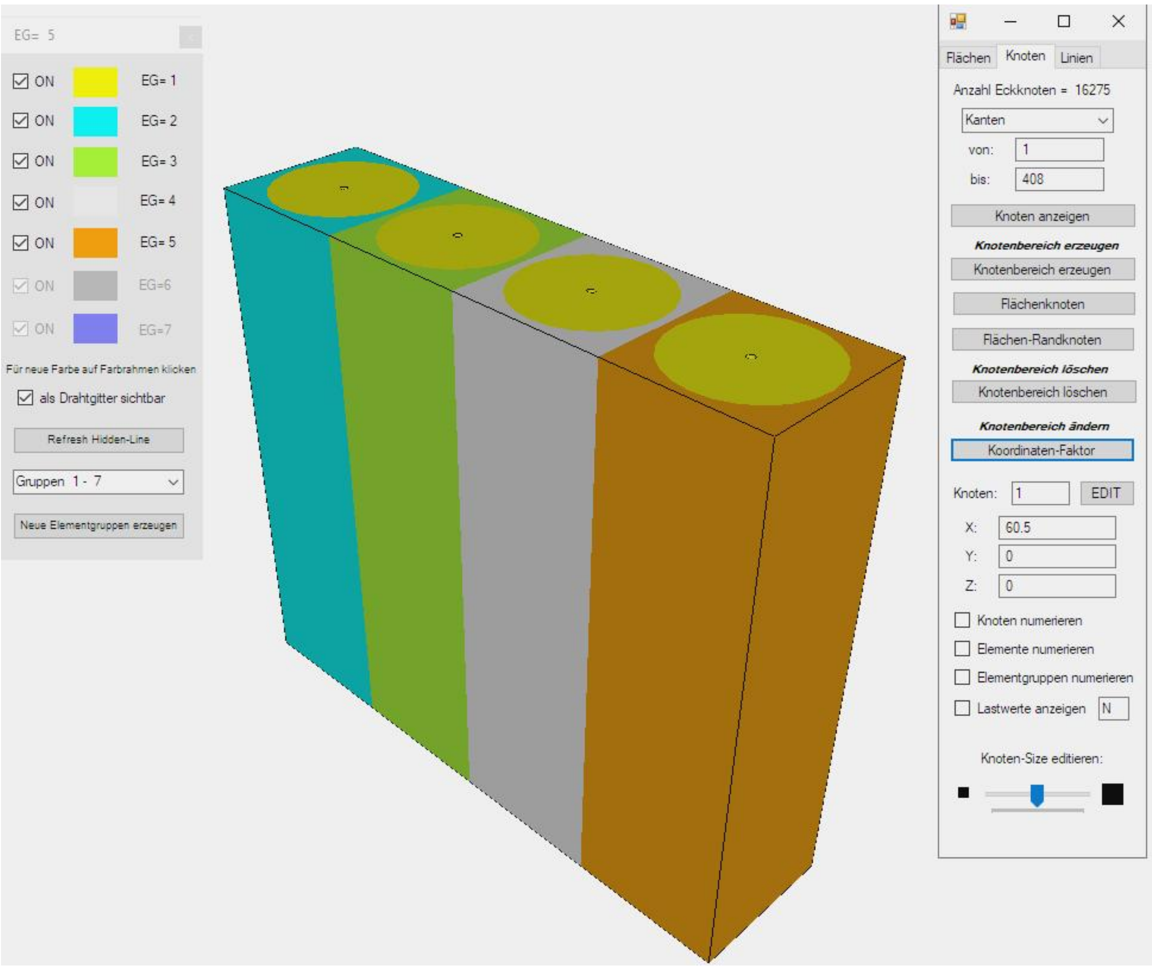


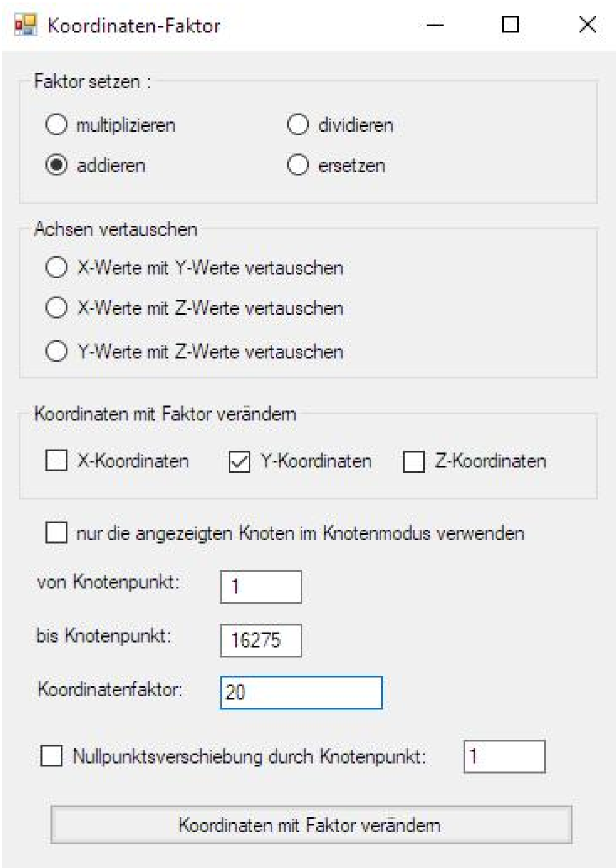
A FEM mesh of 13 824 HEX8 elements, 16 275 nodes and 5 element groups. Save the model under the name "Part1.fem".

Coordinate factor

In the right menu, select the "Nodes" and "Coordinate Factor" tabs and add the model by 20 mm in the Y direction as shown in the image.

The coordinate factor can also be started via the "Edit FEM project" and "Node coordinates" tabs.


EG= 5
ON EG= 1
ON EG= 2
ON EG= 3
ON EG= 4
ON EG= 5
ON EG=6
ON EG=7
Für neue Farbe auf Farbrahmen klicken
als Drahtgitter sichtbar
Refresh Hidden-Line
Gruppen 1 - 7
Neue Elementgruppen erzeugen
Flächen Knoten Linien
Anzahl Eckknoten = 16275
Kanten
von: 1
bis: 408
Knoten anzeigen
Knotenbereich erzeugen
Knotenbereich erzeugen
Flächenknoten
Flächen-Randknoten
Knotenbereich löschen
Knotenbereich löschen
Knotenbereich ändern
Koordinaten-Faktor
Knoten: 1 EDIT
X: 60.5
Y: 0
Z: 0
Knoten numerieren
Elemente numerieren
Elementgruppen numerieren
Lastwerte anzeigen N
Knoten-Size editieren:

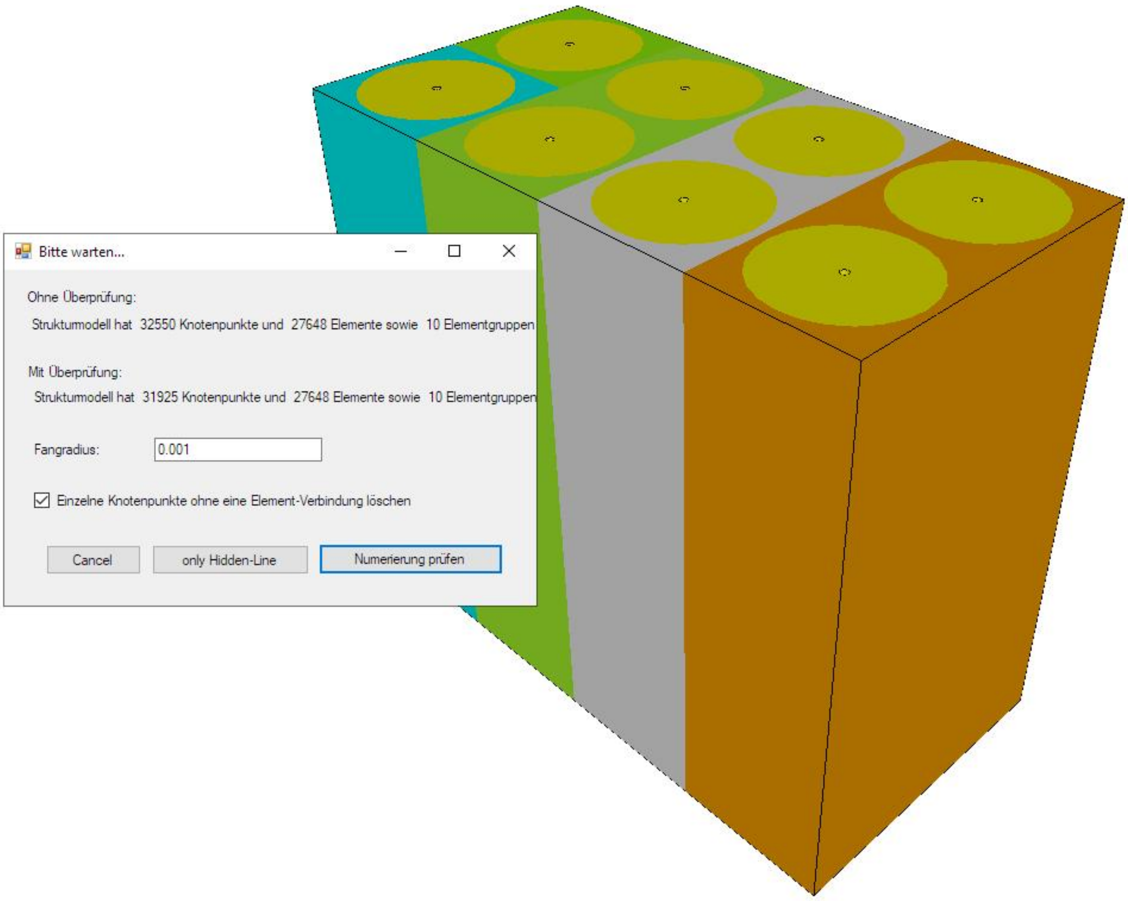

Koordinaten-Faktor
Faktor setzen :
multiplizieren
dividieren
addieren
ersetzen
Achsen vertauschen
X-Werte mit Y-Werte vertauschen
X-Werte mit Z-Werte vertauschen
Y-Werte mit Z-Werte vertauschen
Koordinaten mit Faktor verändern
X-Koordinaten
Y-Koordinaten
Z-Koordinaten
nur die angezeigten Knoten im Knotenmodus verwenden
von Knotenpunkt: 1
bis Knotenpunkt: 16275
Koordinatenfaktor: 20
Nullpunktsverschiebung durch Knotenpunkt: 1
Koordinaten mit Faktor verändern

FEM-Merge

Then load the saved model "Part1.fem" to the current model using the "FEM Merge“ menu and delete the overlayed nodes with a node check radius of "0.001".

Creation of the 4x2 model

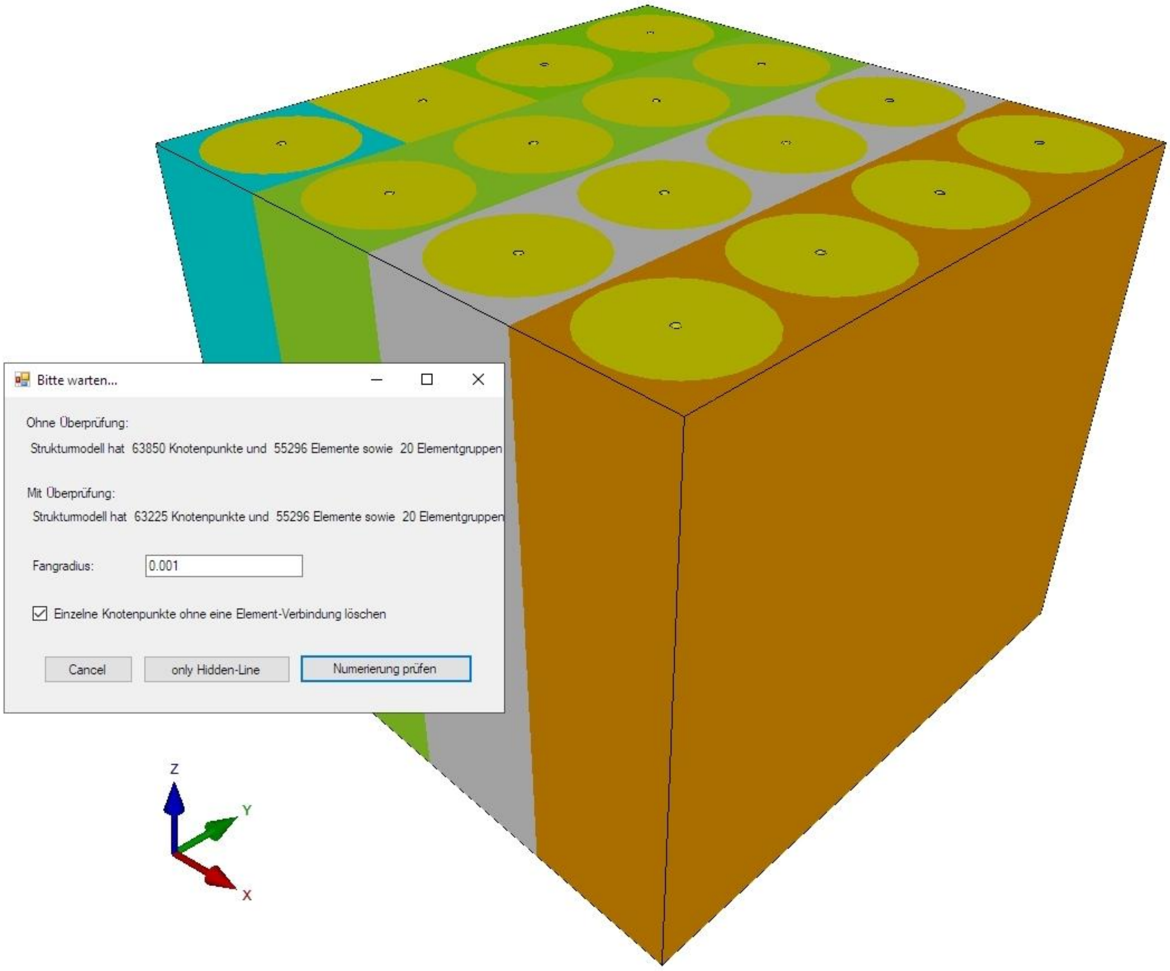
After creating the hidden line, save the model as "Part2.fem" for the next FEM-Merge .



Creation of the 4x4 model

Now add the Y coordinates by 40 mm again with "Coordinate Factor".
and merge the two models via the FEM-Merge and delete the overlayed nodes with a model check and the snap radius "0.001".

An FEM mesh is obtained from 62235 nodes, 55296 hexahedron elements and 20 element groups.



Calculation of convection

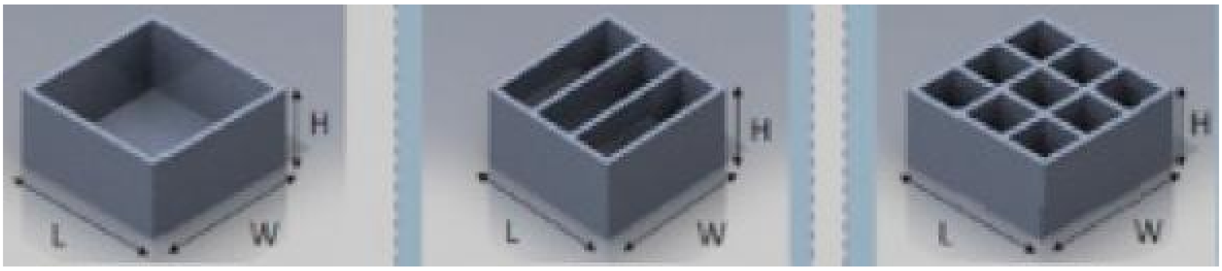
The 16 battery pack is air-cooled, from the literature a heat transfer coefficient of 120 W/m²K is selected for “strongly moving” at an ambient temperature of 20°C.

Luft an der Wand		Wärmeübergangs-koeffizient α (W/(m²*K))
Luft senkrecht zur Metallwand [6]	ruhend	3,5...35
Luft senkrecht zur Metallwand [6]	mäßig bewegt	23...70
Luft senkrecht zur Metallwand [6]	kräftig bewegt	58...290

Generation of the air cooling with a convection

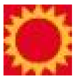
The batteries are cooled over the outer and inner walls with a medium air flow.

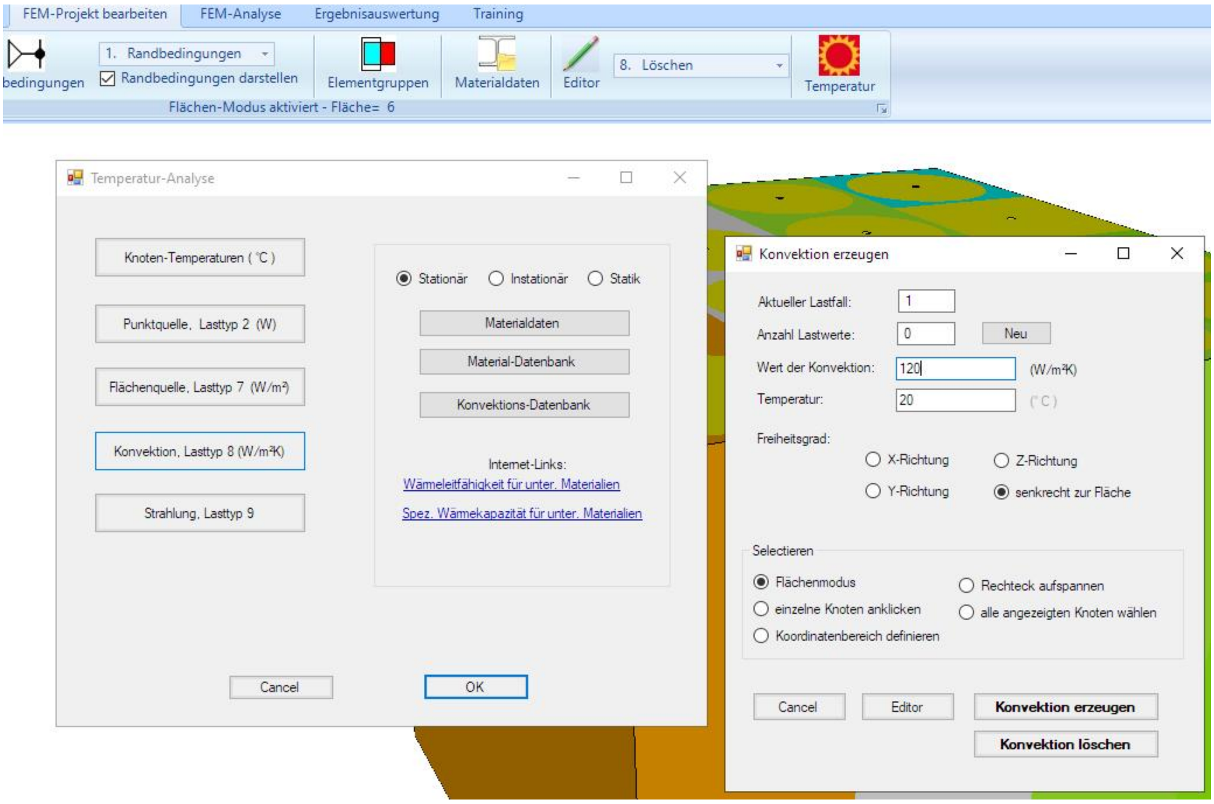
The following three cooling systems are available:



Outside cooling + horizontal cooling + vertical cooling

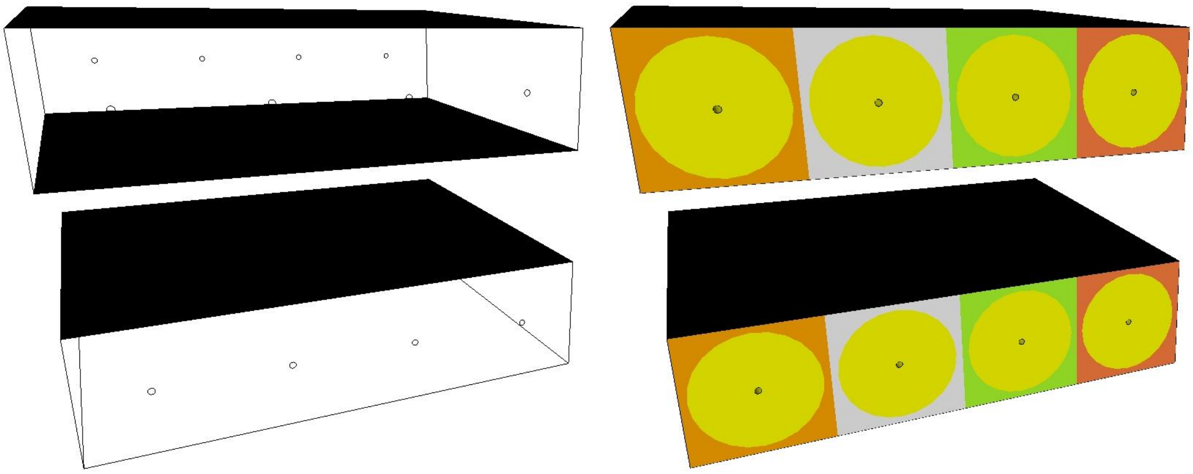
Convection of the outer walls

Select the "Edit FEM project" tab and the icon  and select the "Convection, load type 8 (W/m²K)" menu. Then, in the new window, select "Surface mode" and click on the 4 outer surfaces 1, 6, 11 and 16 to generate the convection of 120 W/m²K at an ambient temperature of 20°C.

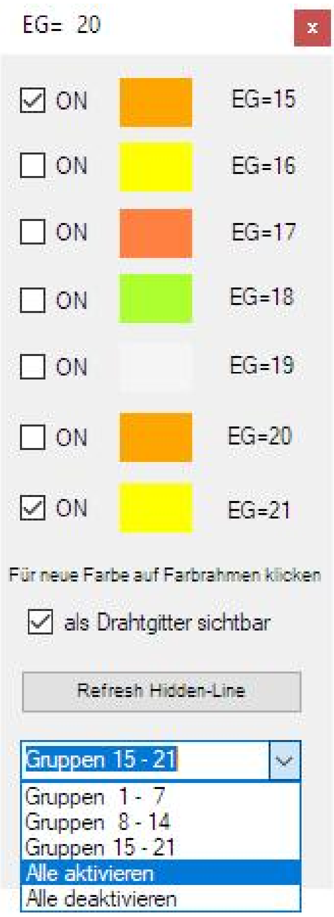


Convection of the horizontal walls

For the horizontal interior surfaces, the element groups 6, 7, 8, 9 and 10 as well as the rows 16, 17, 18, 19 and 20 are hidden and a new surface model must be created in "surface mode". Now the horizontal surfaces are on the outside and can be selected as convection surfaces.

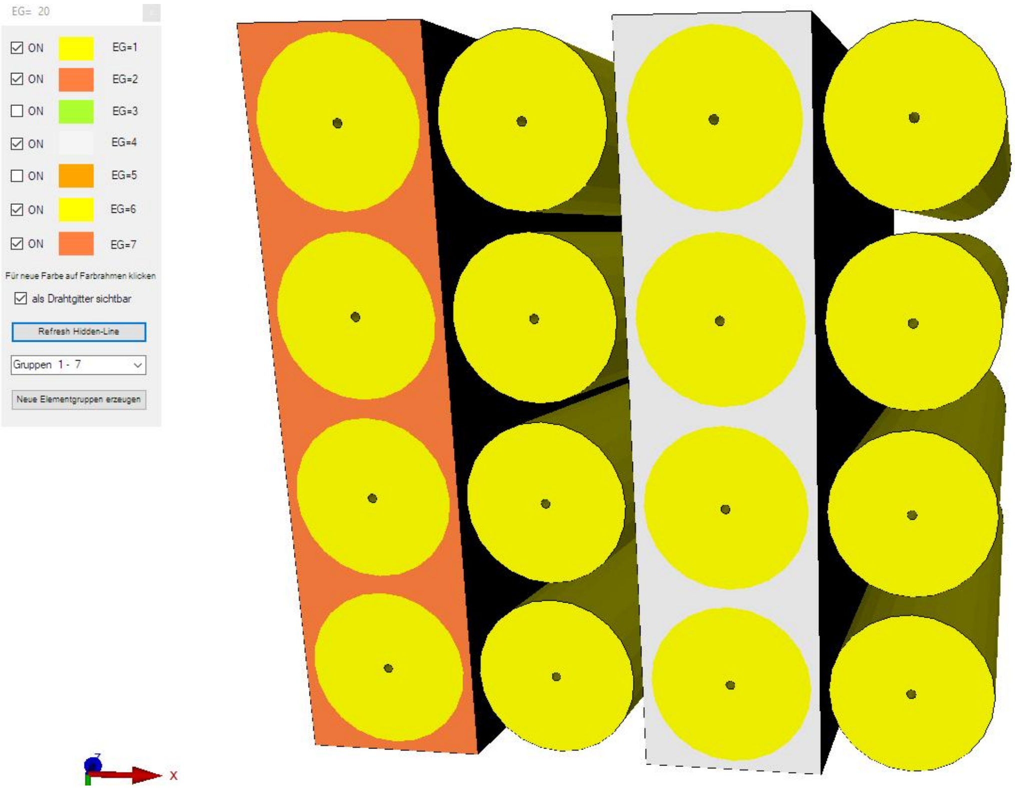


With "Activate all" and the "Refresh Hidden-Line" menu, all 20 element groups are displayed again:

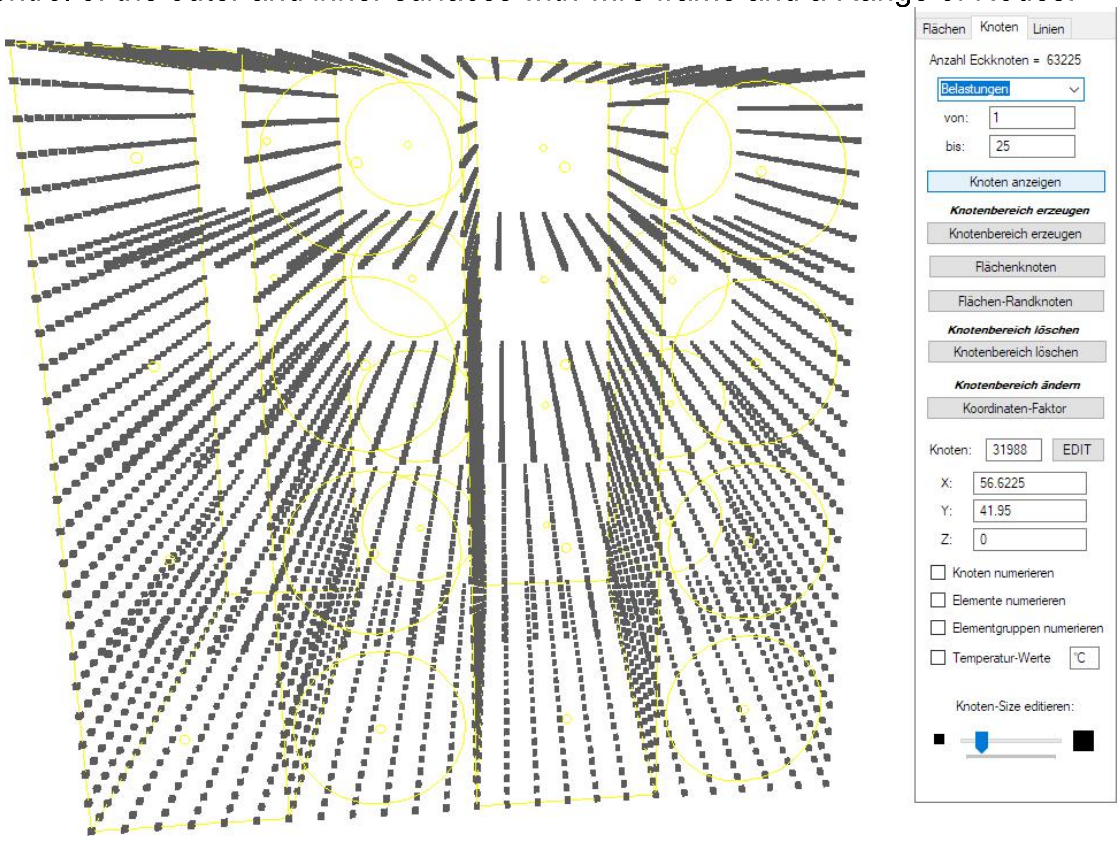


Convection of vertical walls

In order to be able to select these surfaces, the element groups 3, 8, 13 and 18 as well as 5, 10, 15 and 20 must be hidden. Then a new surface model must be created and the 3 vertical walls must be loaded with convection.



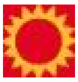
Control of the outer and inner surfaces with wire frame and a Range of Nodes:



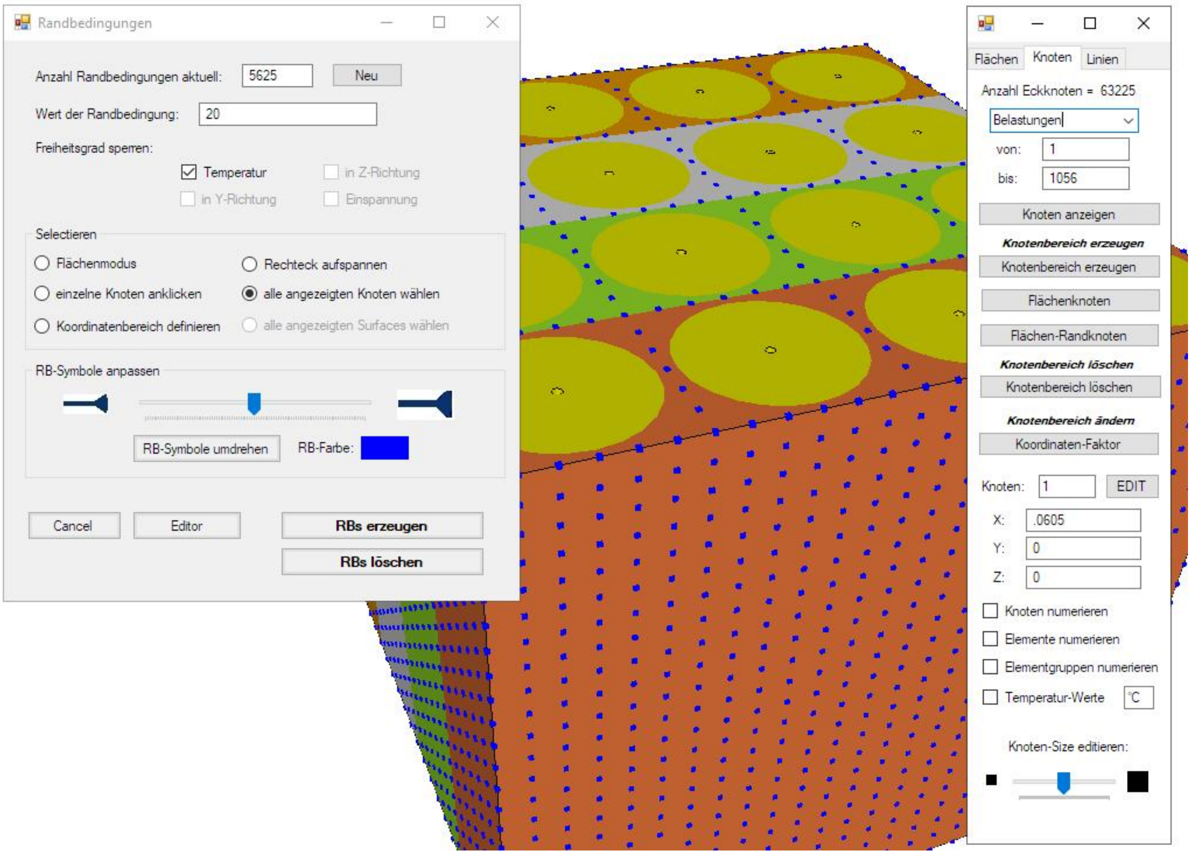
Input of a coolant cooling

In order to simulate coolant cooling, the convection surfaces have to be converted into temperature boundary conditions with a node temperature of 20°C.

Use the "View" and "Node Mode" tabs to display all nodes of the convection load.

Then select the temperature icon  and create the temperature boundary conditions with the selection "Select all displayed nodes".

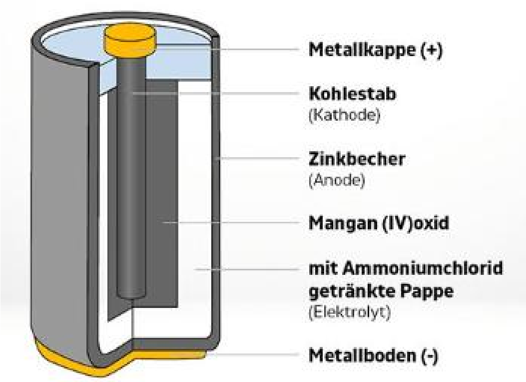
Then the convection must be deleted with "Edit FEM project", "Editor" and "Delete".



Entering the material data

Batteries mainly consist of zinc-carbon or lithium-graphite material compounds with a liquid electrolyte and a coated separator.

Zinc-carbon battery



Lithium-graphite battery

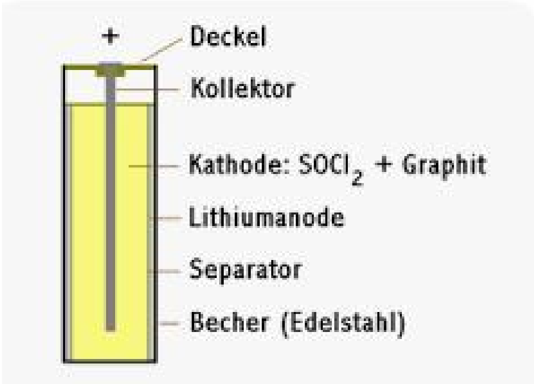


Table-2.1: 21700 Lithium-ion cell specification

Item	Specification*
Rated discharge capacity (1C-rate)	3,2Ah
Nominal Voltage	3,56 V
Rated Discharge energy	11,4 Wh
Density	2560 kg/m3

Heat Capacity	1000 J/(kg*K)
Radial Thermal Conductivity	1 W/(m2K)
Axial Thermal Conductivity	25 W/(m2K)
Tangential Thermal Conductivity	25 W/(m2K)
Internal Resistace	50 mΩ

Table-2.2: The physical and initial conditions are as shown in the table below:

Battery Initial Temperature	20 oC
Coolant Inlet Temperature	20 oC
Coolant Inlet Velocity	0.1 -1m/s
Heat Generation	0.5-2.5 w/Cell
Cell conductivity	Kr = 1 w/m*k Ka = 25 w/m*k

Quelle:

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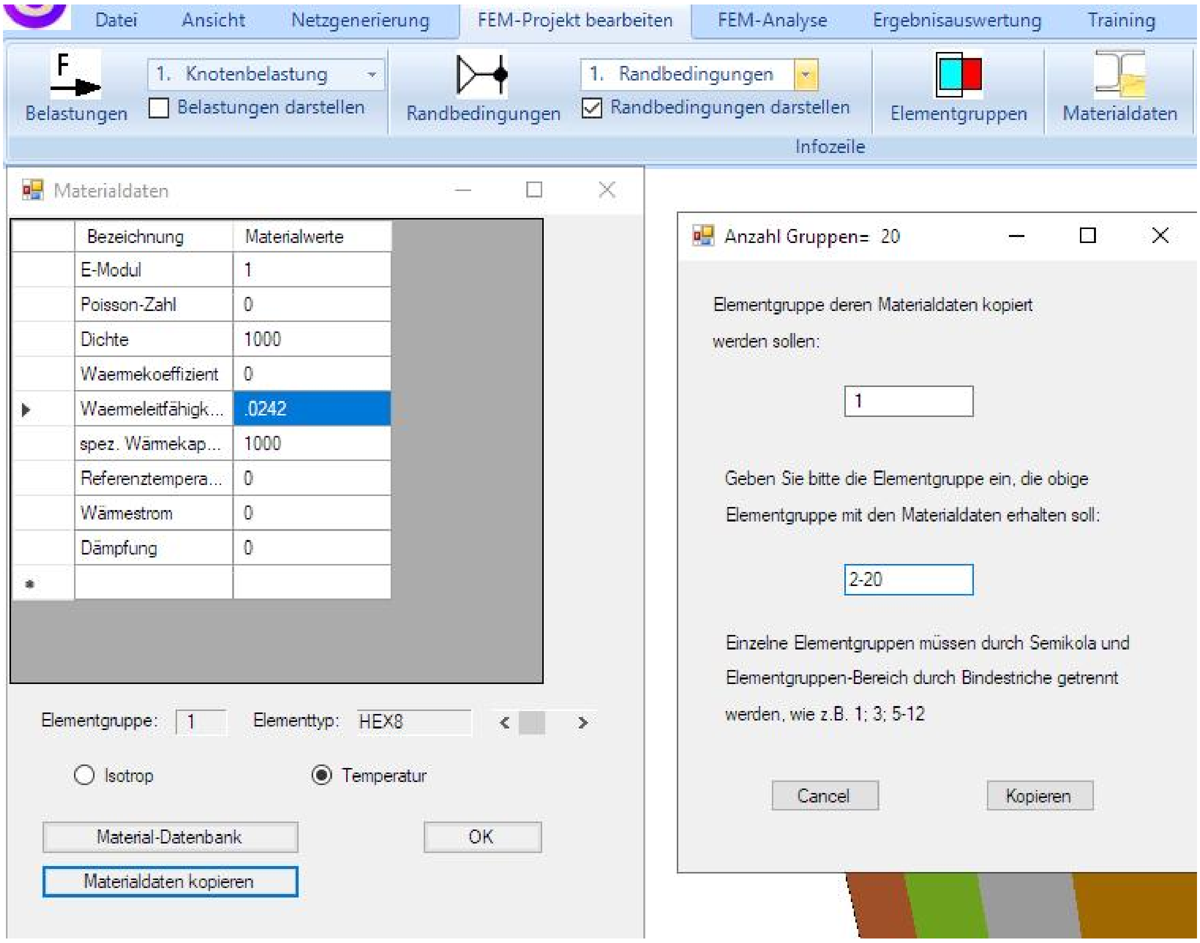
Element group Air

Airflow and coolant are assumed to flow around the cylindrical battery cells through air gaps with a thermal conductivity of 0.0242 W/mK.
Enter the material data of air with tab "Edit FEM project" and "Material data" in element group 1. Then copy them to the element groups from 2-20 with "Copy material data".

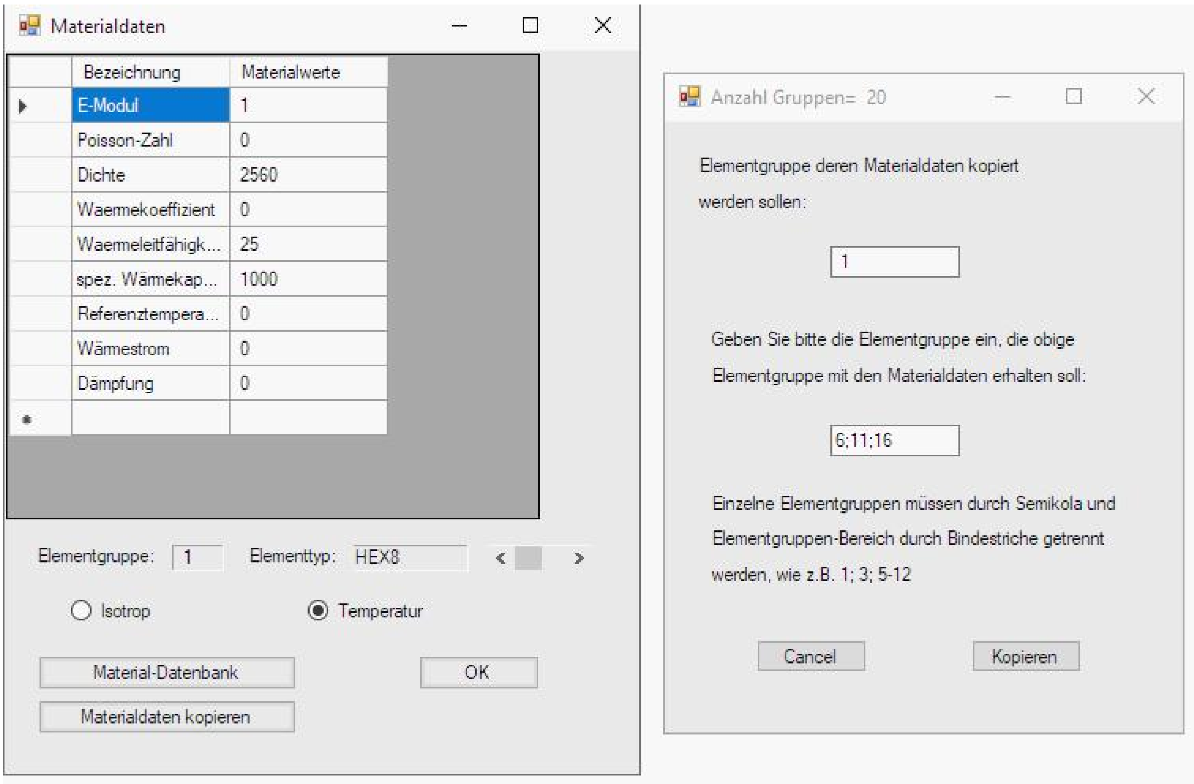


Element group Battery

The following material data are taken from Table 2.1:

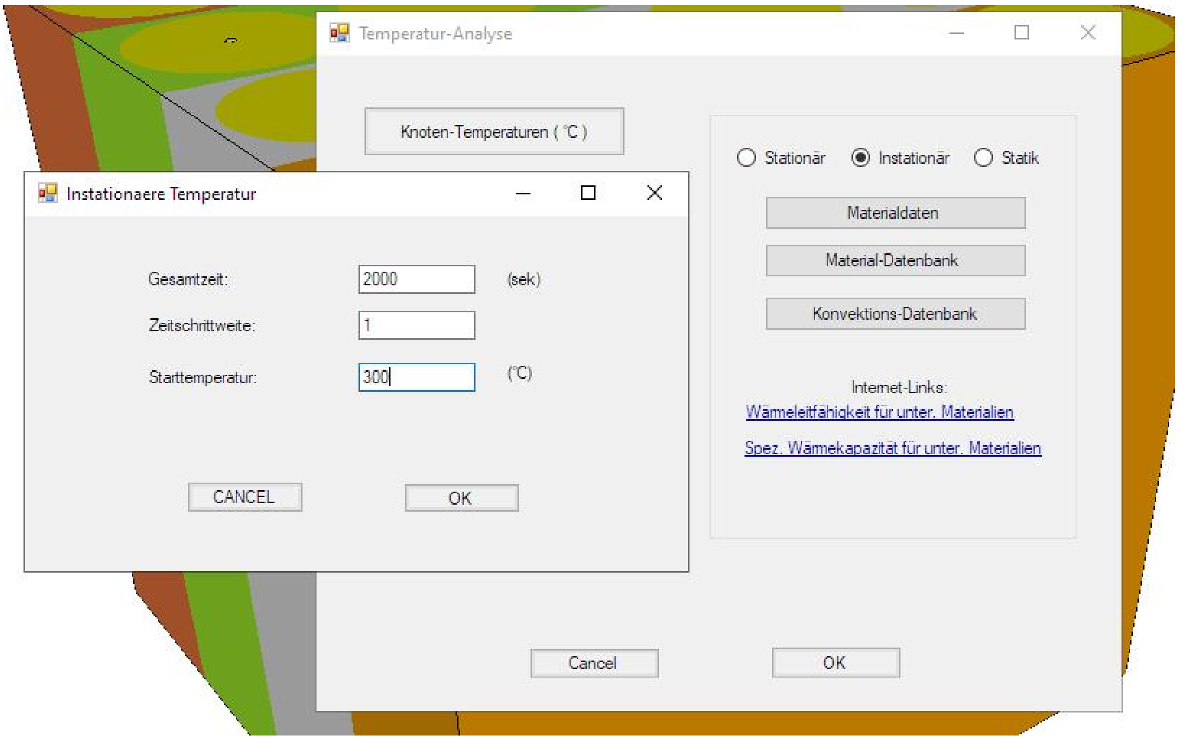
Thermal conductivity = 25 W/mK
Specific heat capacity = 1000 J/kgK
Density = 2560 kg/m³

Enter these values in element group 1 and copy them to element groups 6, 11, 16.



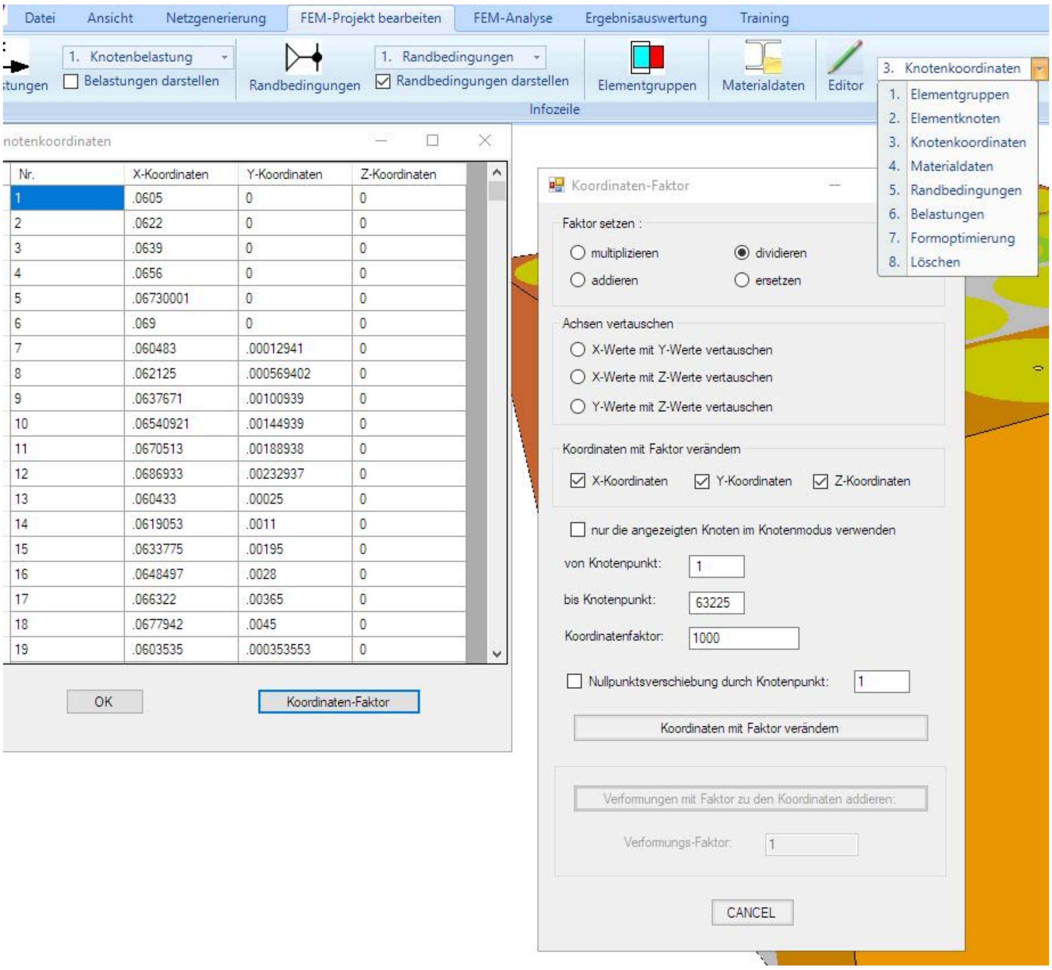
Input total time, time step and start temperature

The parameters for a transient temperature analysis are entered via the temperature icon  : Total time = 2000 sec, time step = 1 and start temperature = 300 °C.



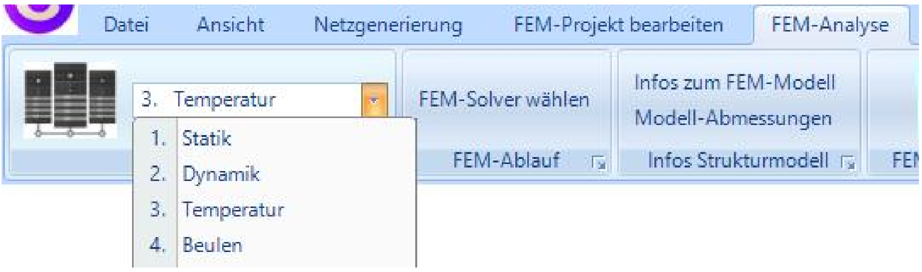
Change coordinates from millimeters to meters

The coordinates are generated in millimeters and must be converted to meters using the "Edit FEM project" and "Node coordinates" tabs.



FEM Analysis

Save the two FEM models under any name and use the Quick Solver to calculate the node temperatures and heat flow density with the "FEM Analysis" and "Temperature" tabs.

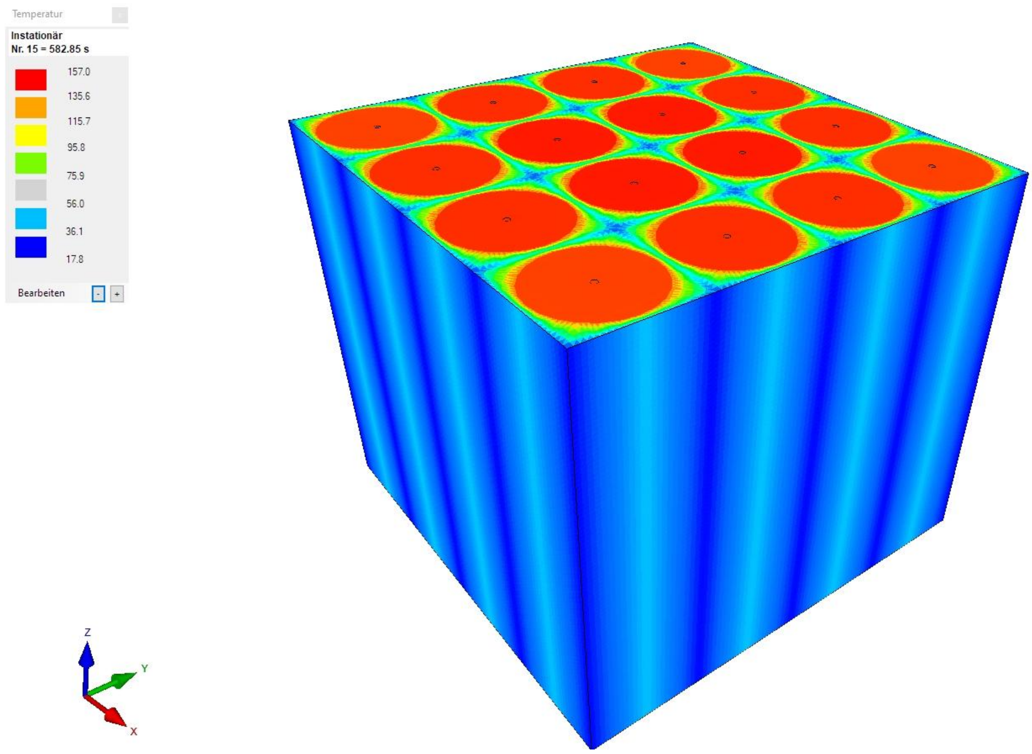


Postprocessing

After the FEM analysis, evaluate the temperature distributions for convection and coolant for time step 15 with the "Postprocessing" tab.

Air cooling after 582 seconds

max. Temperature = 157 °C; min. Temperature = 17.8° C



Coolant cooling after 582 seconds

max. Temperature = 134.1° C; min. Temperature = 20° C