APPROACH TO DEFINE THE AERODYNAMIC FREE AREA FOR NATURAL SMOKE VENTS IN A CFD SIMULATION ENVIRONMENT

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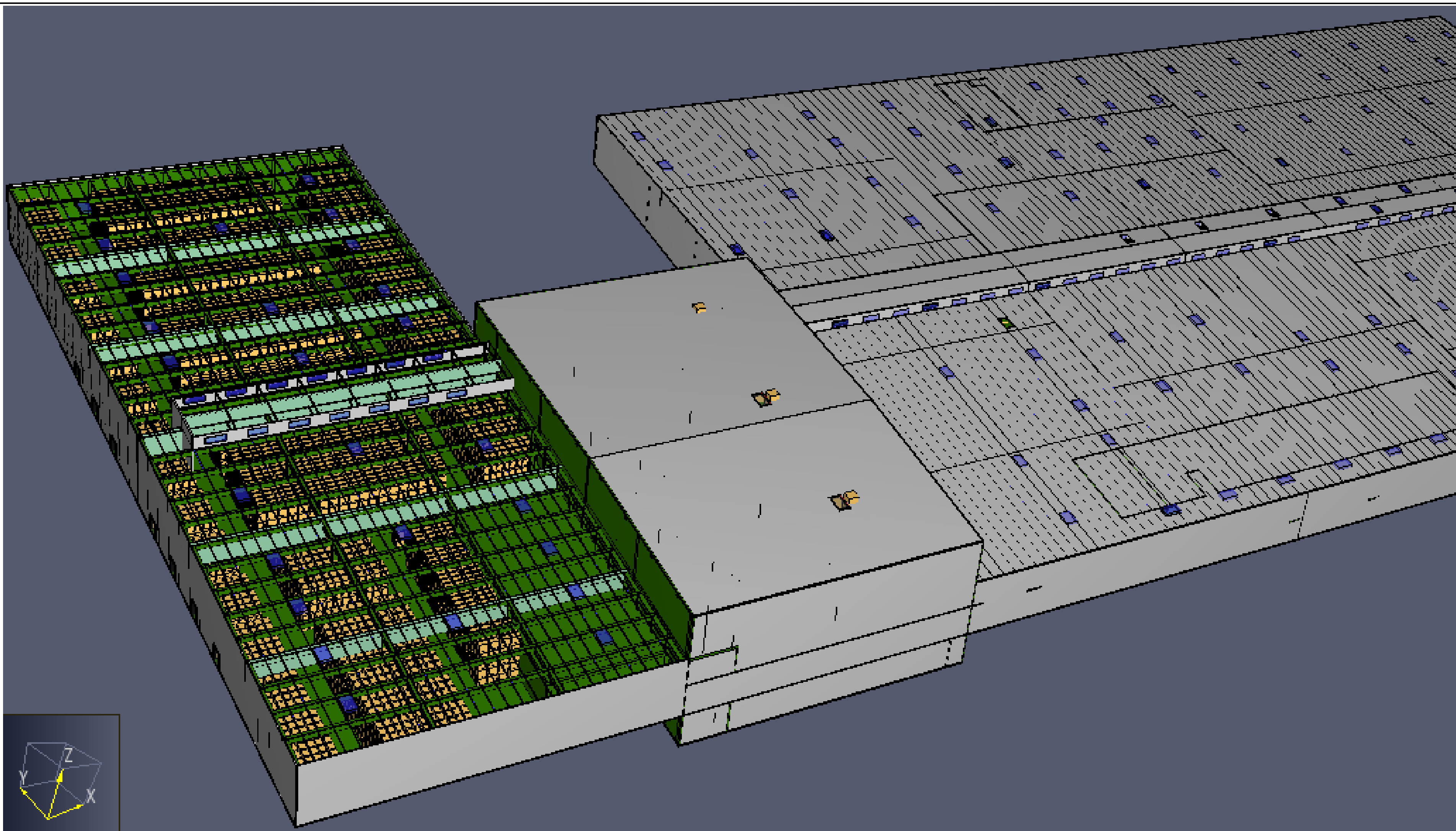
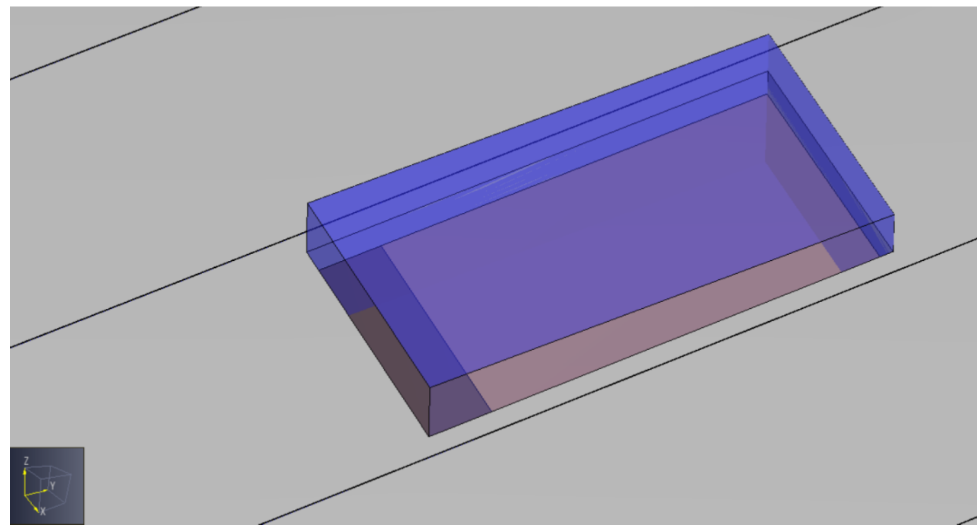
GOALS OF THE RESEARCH



Lagre scale project – PyroSim model of a tyre factory in Hungary, total floor area: 64.000 m2

GOALS OF THE RESEARCH

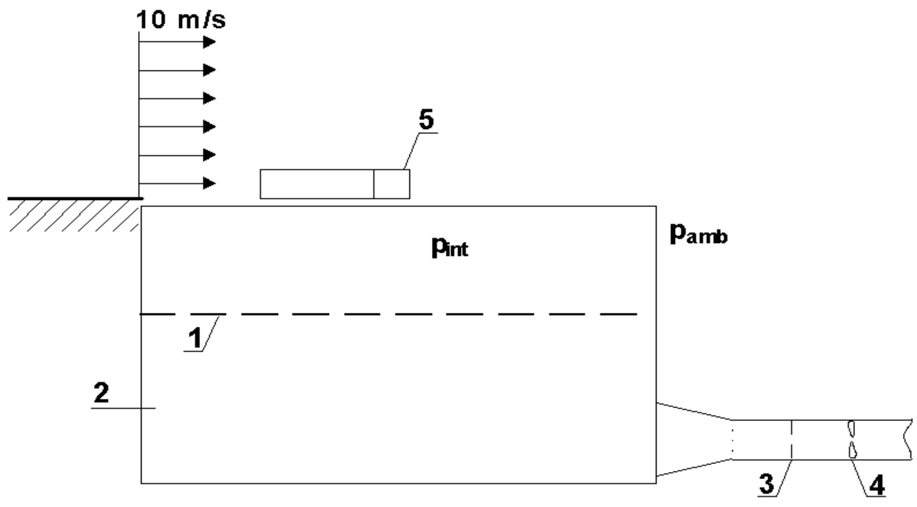
- natural smoke and heat exhaust from buildings is one of the key application fields of CFD simulations;
- natural smoke and heat exhaust vents (NSHEV) are modelled in FDS/Pyrosim by "Hole" elements, whose sizes are essential in the findings of simulation;
- questions:
  - is an FDS/Pyrosim environment suitable to simulate the standard test of natural smoke and heat vents?
  - what is the appropriate size of the ‚Hole' element?
  - How is it influenced by the installation details?



top view of a 2.700x3.200 mm heat and smoke vent in a flat roof in CFD/PyroSim environment (real vent is on the top image); grid: 50x50 cm – is it OK when a simple ‚Hole' element is used adjusted to the grid?

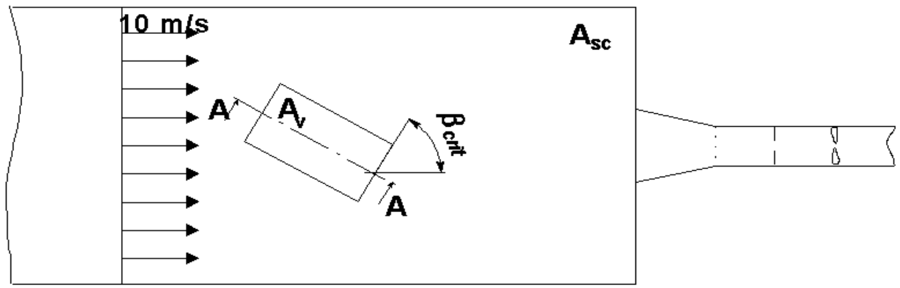
AERODYNAMIC FREE AREA OF NHSEVs – TEST METHOD

- coefficient of discharge (c_v) is determined by a test according to EN 21101-2
- test may be performed on full scale or reduced scale models
- at reduced scale models, flow similarity shall be achieved
- the Reynolds number for a reduced scale and a full scale vent must be the same
- To achieve the same Reynolds number, usually a model of 1/6 or higher scale is necessary, but lower scales (down to 1/10) may also be used



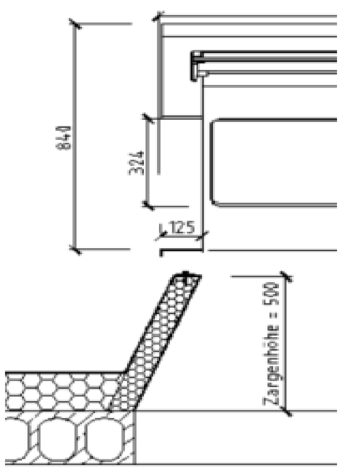
Test method:

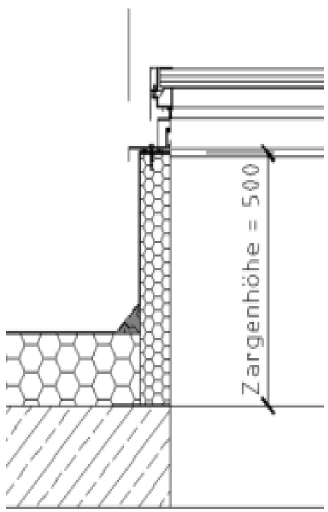
- the roof vent is placed over a settling chamber,
- There is a stationary and uniform flow inside the setting chamber approaching the roof vent
- side wind simulator exposing the natural smoke and heat vent

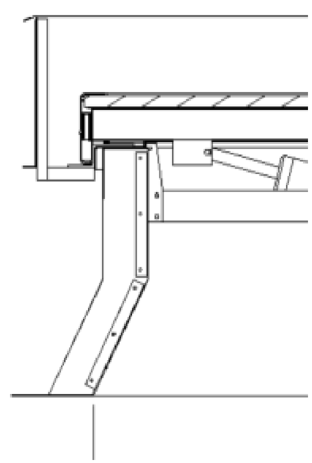
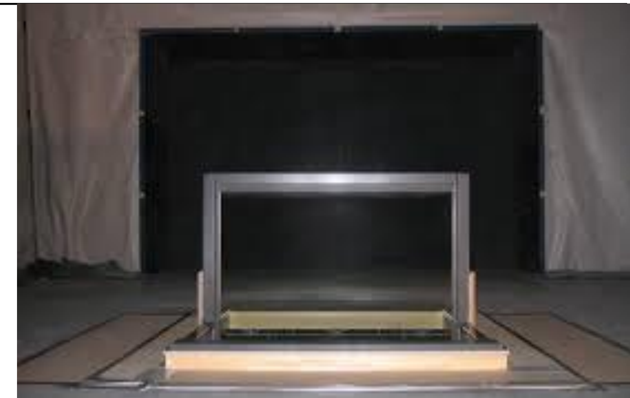


PROBLEMS BETWEEN THE TEST AND THE REAL INSTALLATION OF THE NATURAL SMOKE AND HEAT VENTS

- individual aerodynamic free areas resulted for each natural smoke and heat vent are comparable, but natural flat roof smoke and heat vents are installed differently from the test
- the settling chamber is usually made of a kind of construction panel of a mere few centimeter thickness
- flat roofs, however, the structure under the natural smoke and heat vent (supporting structure, heat insulation or slope forming for waterproofing, etc.) is at least from 30 to 50 cm or may be even more

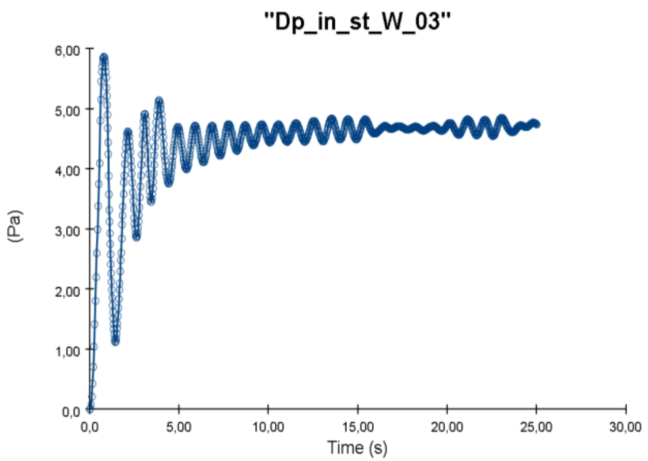


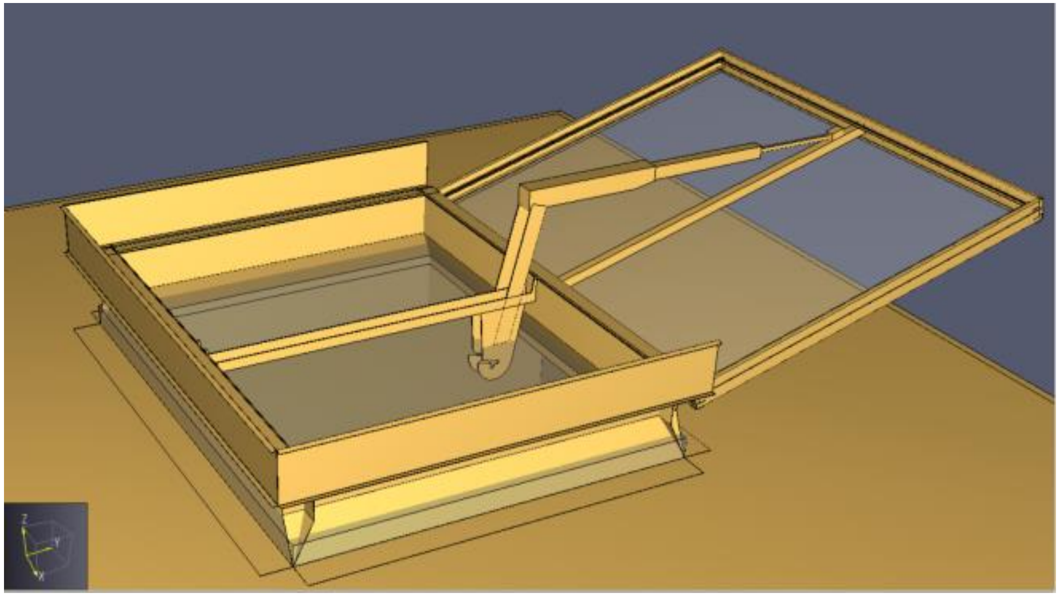


MODELLING A HEAT AND SMOKE VENTILATOR WITH FDS/PYROSIM

- single-wing smoke and heat ventilator of 2,000 x 2,500 mm with wind baffles was tested
- its geometrical opening area is 5.0 m^2 while the aerodynamic free area of 3.15 m^2, therefore the coefficient of discharge c_v= 0,63
- test environment has been built in FDS/Pyrosim environment according to EN 12101-2, Annex B
- grid spacings are: basically 5 cm (6,25 – 12,5 cm)





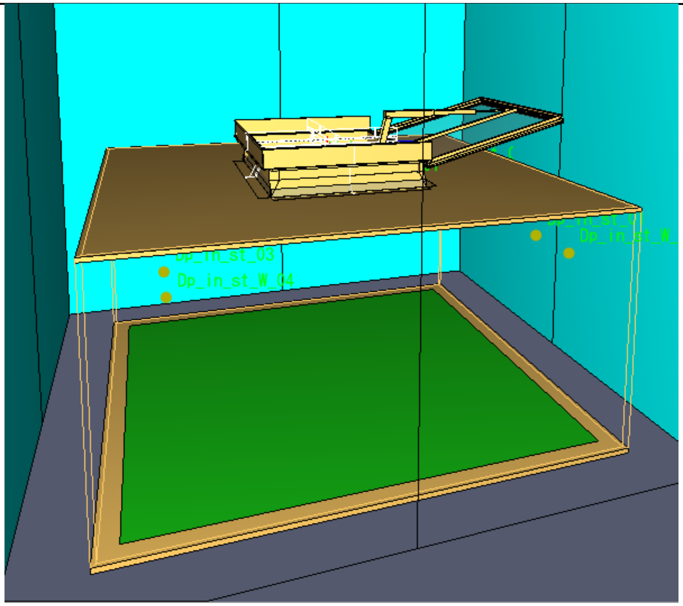
- mass flow was changed during the simulation so as for the overpressure developing in the settling chamber to be between 3-12 Pa in 6 simulation cases.
- simulation time: 25 s

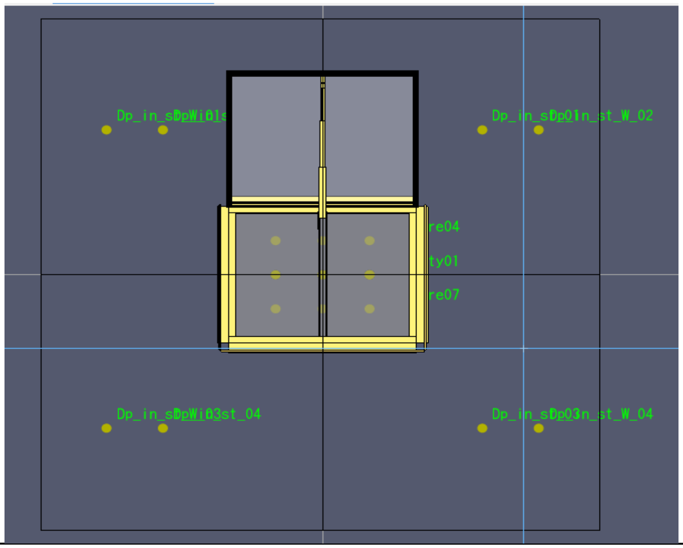
AERODYNAMIC FREE AREA IN A CFD ENVIRONMENT

- aerodynamic free area and the flow coefficient for natural smoke and heat vents also include the other loss of flow such as **friction** and **reduction of the geometric cross-section** in addition to the phenomenon "vena contracta";
- on the right side of the equation derives from the ideal (non-friction) Bernoulli equation, describing the ideal mass flow resulted from the particular pressure difference through an opening;
- relationship between the non-friction and real flow is created by the coefficient of discharge (C_v).

$$\dot{m}_{ing} = C_v \cdot A_v \cdot v \cdot \rho_{air} = C_v \cdot A_v \cdot \rho_{air} \sqrt{\frac{2\Delta p_{int}}{\rho_{air}}}$$

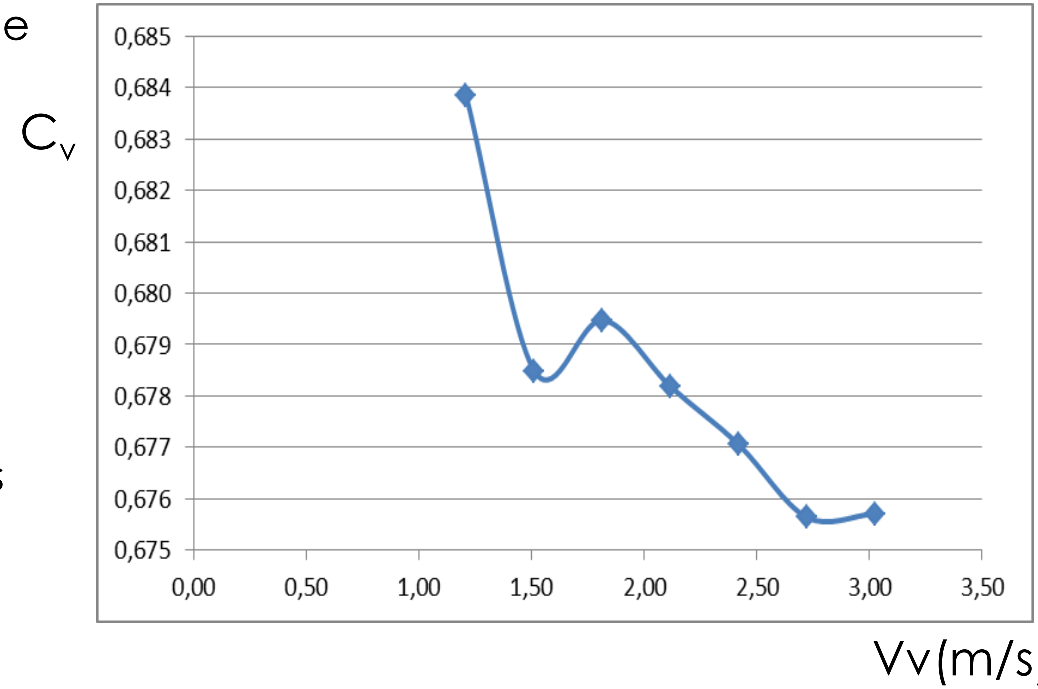
$$C_v = \frac{\dot{m}_{ing}}{A_v \cdot \sqrt{2\rho_{air} \cdot \Delta p_{int}}}$$





SIMULATION RESULTS – WITHOUT SIDE WIND

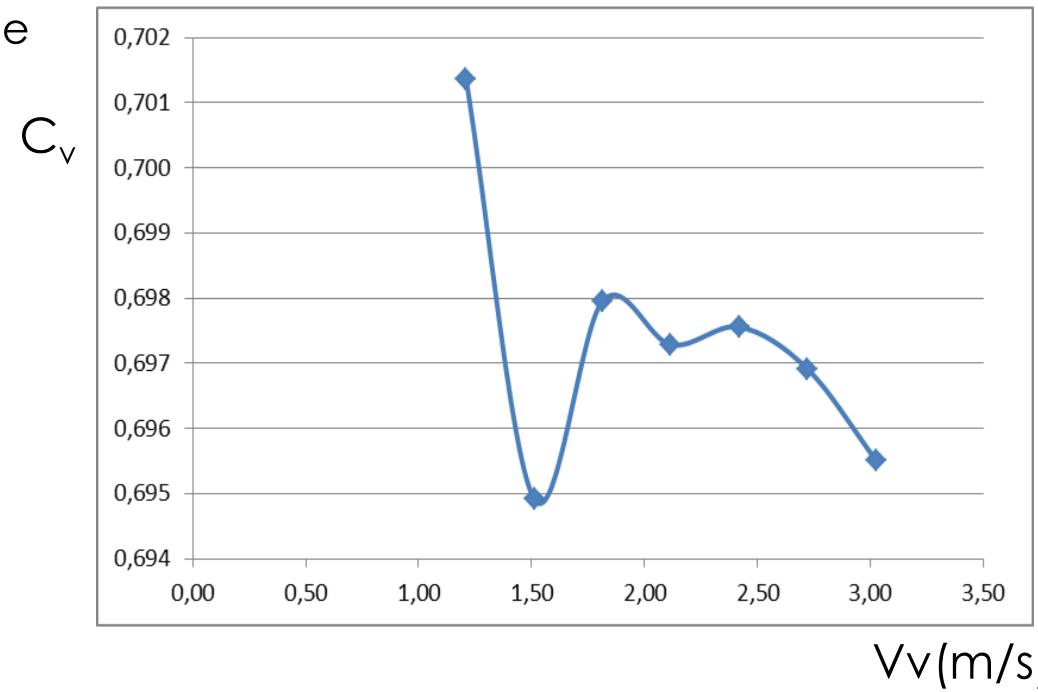
- right: change in the C_v value in the function of the average speed calculated for the nominal vent area
- below: simulation findings for a construction according to the standard test
- the value of the C_v factor according to standard conditions amounted to 0,677, but the manufacturer did not published the test results without side-wind



File name	MESH cm	Asupp (m2)	vsupp (m/s)	tamb (°C)	ro (kg/m3)	m' (kg/s)	Av (m2)	Vv_average (m/s)	nu (Pa s)	Dv_e (m)	Re_v	Dp_int (Pa)	Cv_0
AM200x250_M05_0_020mps_a	5,0	30,25	0,20	20	1,2042	7,2852	5,0	1,21	1,841E-05	2,0	1,58E+05	1,885058	0,68383
AM200x250_M05_0_025mps_a	5,0	30,25	0,25	20	1,2042	9,1065	5,0	1,51	1,841E-05	2,0	1,98E+05	2,992006	0,67849
AM200x250_M05_0_030mps_a	5,0	30,25	0,30	20	1,2042	10,9278	5,0	1,82	1,841E-05	2,0	2,37E+05	4,295935	0,67948
AM200x250_M05_0_035mps_a	5,0	30,25	0,35	20	1,2042	12,7491	5,0	2,12	1,841E-05	2,0	2,77E+05	5,869612	0,67818
AM200x250_M05_0_040mps_a	5,0	30,25	0,40	20	1,2042	14,5704	5,0	2,42	1,841E-05	2,0	3,17E+05	7,692027	0,67705
AM200x250_M05_0_045mps_a	5,0	30,25	0,45	20	1,2042	16,3917	5,0	2,72	1,841E-05	2,0	3,56E+05	9,775878	0,67564
AM200x250_M05_0_050mps_a	5,0	30,25	0,50	20	1,2042	18,2129	5,0	3,03	1,841E-05	2,0	3,96E+05	12,06646	0,67571

SIMULATION RESULTS – WITHOUT SIDE WIND, WITH REAL FLOOR SLAB THICKNESS

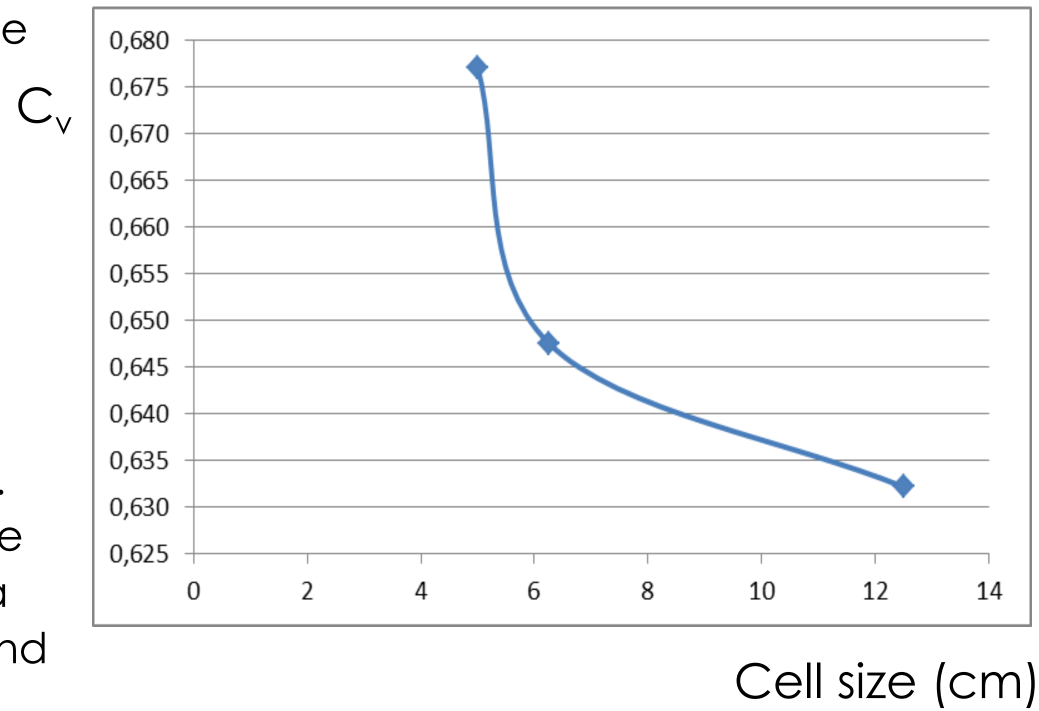
- right: change in the C_v value in the function of the average speed calculated for the nominal vent area
- below: simulation findings for a construction according to the standard test
- a slight increase in the effective geometrical area was seen



File name	MESH cm	Asupp (m2)	vsupp (m/s)	tamb (°C)	ro (kg/m3)	m' (kg/s)	Av (m2)	Vv_average (m/s)	nu (Pa s)	Dv_e (m)	Re_v	Dp_int (Pa)	Cv_0
AM200x250_M05_0_020mps_a_m1	5,0	30,25	0,20	20	1,2042	7,2852	5,0	1,21	1,841E-05	2,0	1,58E+05	1,792026	0,70136
AM200x250_M05_0_025mps_a_m1	5,0	30,25	0,25	20	1,2042	9,1065	5,0	1,51	1,841E-05	2,0	1,98E+05	2,852227	0,69491
AM200x250_M05_0_030mps_a_m1	5,0	30,25	0,30	20	1,2042	10,9278	5,0	1,82	1,841E-05	2,0	2,37E+05	4,071446	0,69796
AM200x250_M05_0_035mps_a_m1	5,0	30,25	0,35	20	1,2042	12,7491	5,0	2,12	1,841E-05	2,0	2,77E+05	5,552409	0,69728
AM200x250_M05_0_040mps_a_m1	5,0	30,25	0,40	20	1,2042	14,5704	5,0	2,42	1,841E-05	2,0	3,17E+05	7,246455	0,69756
AM200x250_M05_0_045mps_a_m1	5,0	30,25	0,45	20	1,2042	16,3917	5,0	2,72	1,841E-05	2,0	3,56E+05	9,188287	0,69691
AM200x250_M05_0_050mps_a_m1	5,0	30,25	0,50	20	1,2042	18,2129	5,0	3,03	1,841E-05	2,0	3,96E+05	11,38916	0,69552

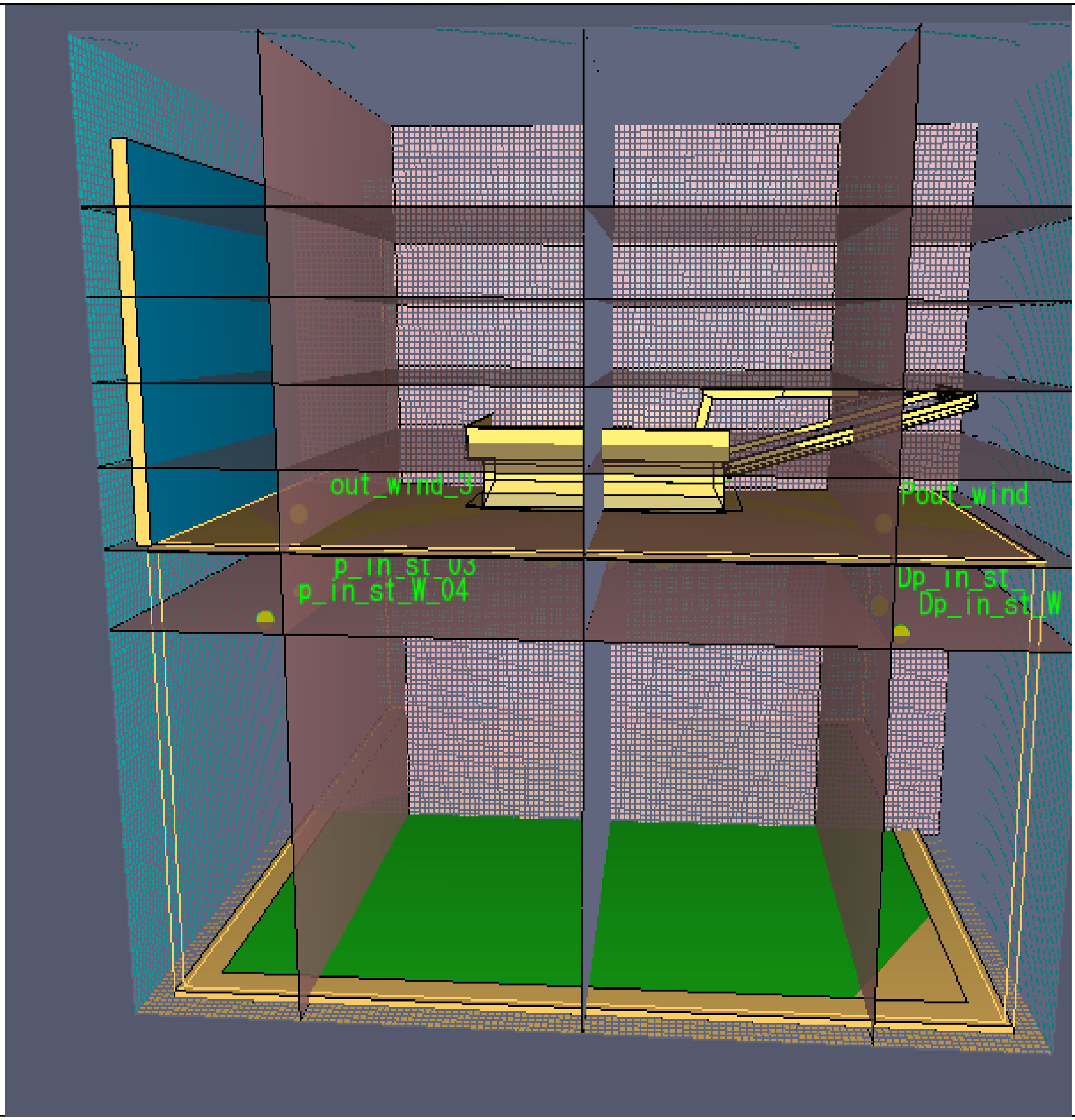
SIMULATION RESULTS – WITHOUT SIDE WIND, WITH REAL FLOOR SLAB THICKNESS, WITH VARIOUS GRIDS

- right: change in the C_v value in the function of the average speed calculated for the nominal vent area
- below: simulation findings for a construction according to the standard test
- the effective geometrical cross-section increases by grid spacing.
- the reduction of grid spacing – the increase in cell size – to achieve a reasonable running time will amend the results in favour of safety



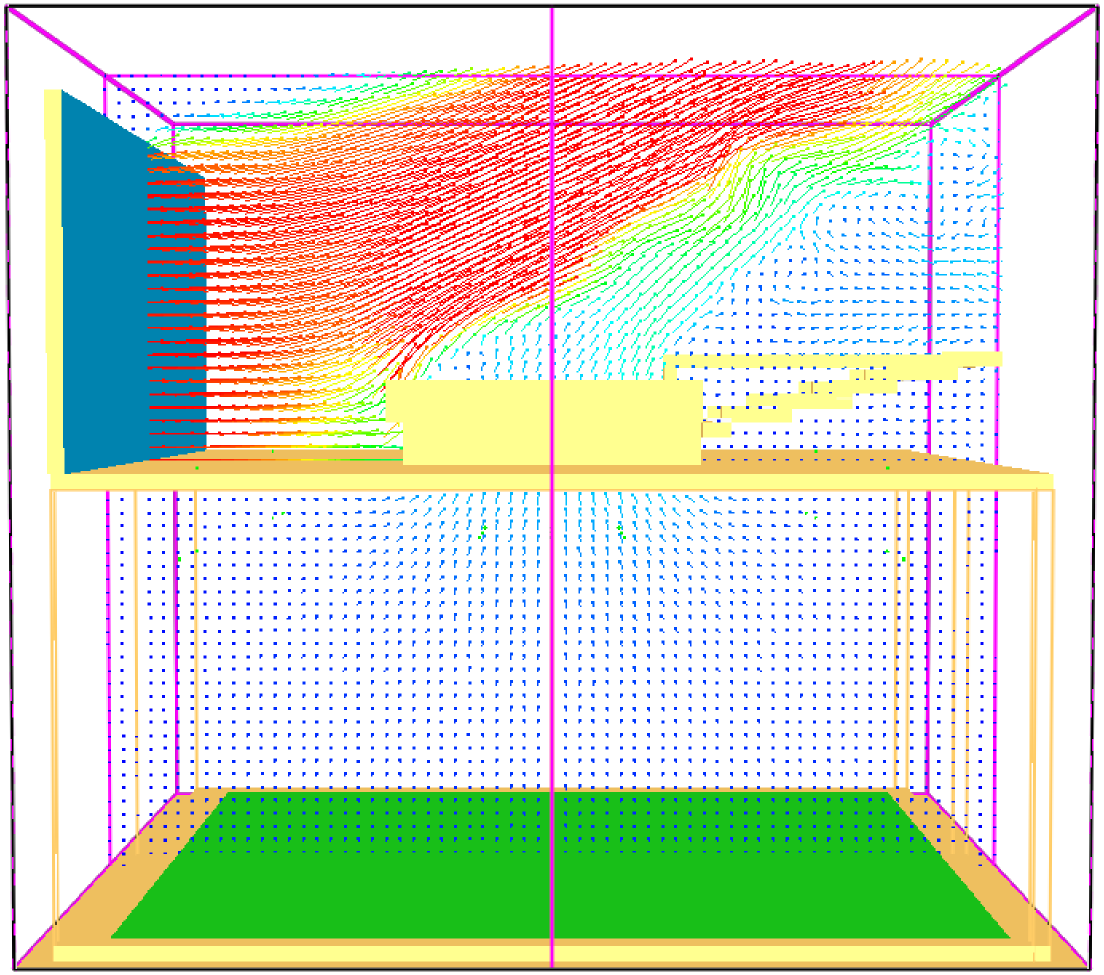
File name	MESH cm	Asupp (m2)	vsupp (m/s)	tamb (°C)	ro (kg/m3)	m' (kg/s)	Av (m2)	Vv_average (m/s)	nu (Pa s)	Dv_e (m)	Re_v	Dp_int (Pa)	Cv_0
AM200x250_M12_5_04mps_b	12,5	30,25	0,40	20	1,2042	14,5704	5,0	2,42	1,841E-05	2,0	3,17E+05	8,822784	0,63218
AM200x250_M06_25_04mps_c	6,25	30,25	0,40	20	1,2042	14,5704	5,0	2,42	1,841E-05	2,0	3,17E+05	8,408846	0,64755
AM200x250_M05_0_040mps_a	5,0	30,25	0,40	20	1,2042	14,5704	5,0	2,42	1,841E-05	2,0	3,17E+05	7,692027	0,67705

SIMULATION RESULTS – WITH SIDE WIND



- left: the model used for testing the side wind with slices
- tangential speed component was used in addition to using blow-in from two directions perpendicular to each other
- the pressure conditions prevailing in the setting chamber depend on the assumed wind direction, but the extreme value of this function is highly influenced by the mass flow passing through the vent

SIMULATION RESULTS – WITH SIDE WIND



- left: the model used for testing the side wind with slices
- tangential speed component was used in addition to using blow-in from two directions perpendicular to each other
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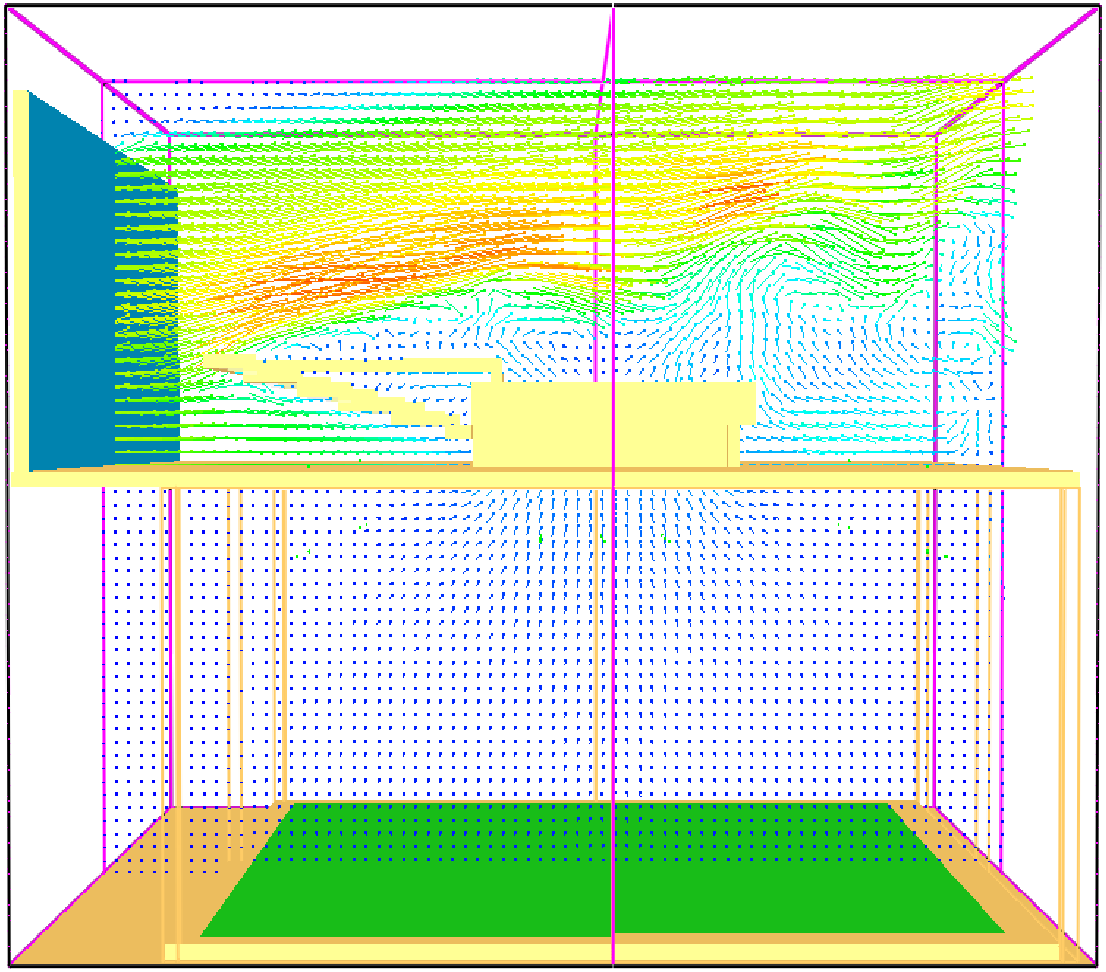
SIMULATION RESULTS – WITH SIDE WIND



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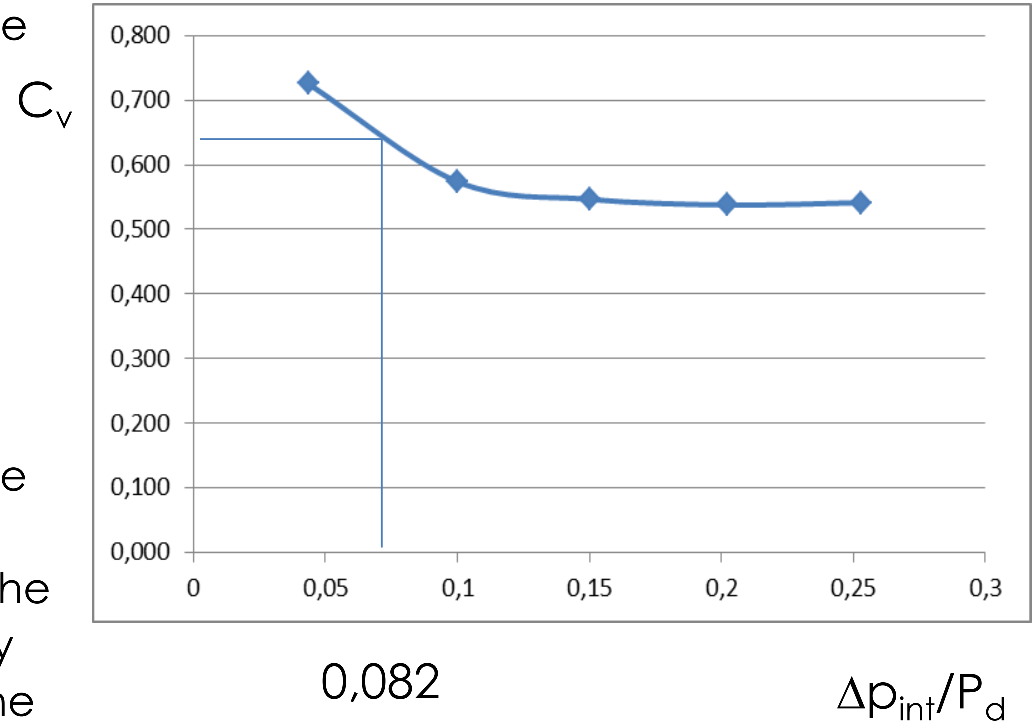
SIMULATION RESULTS – WITH SIDE WIND

- right: change in the C_v value in the function of $\Delta p_{int}/P_d$ (the aerodynamic free area depends significantly from the value of $\Delta p_{int}/P_d$
- below: simulation findings for a construction with side wind
- in the setting chamber, minor air speeds generate negative C_v values, so the exhaust effect of the wind became dominant
- simulation result is C_v=0.622; with the value measured by the laboratory (C_v=0,63), it may be stated that the simulation is very accurate



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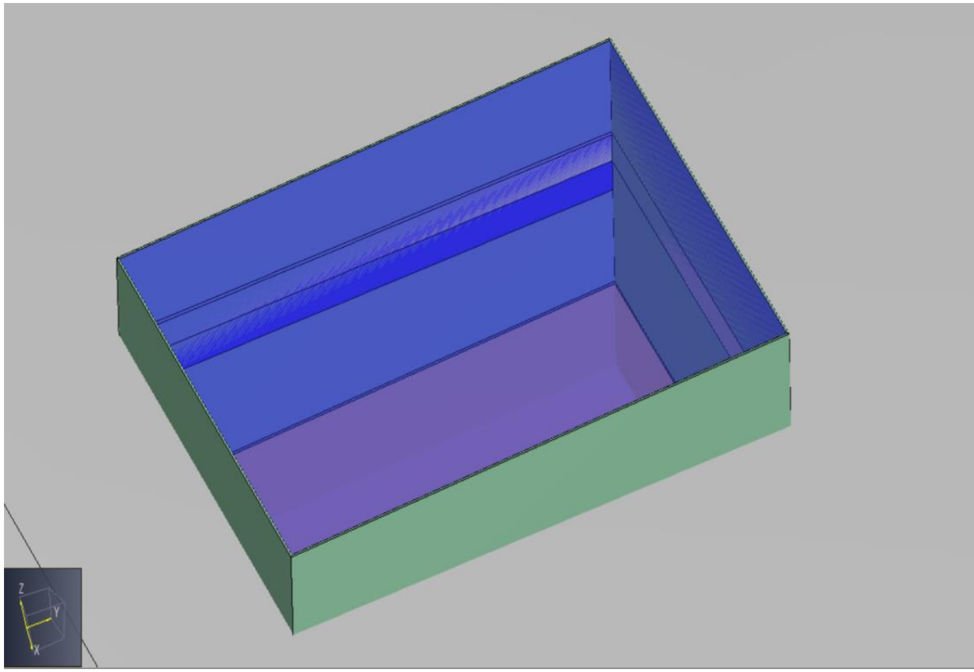
AM200x250_M05_0_010mps_a_SW2	5,0	30,25	0,10	20	1,2042	3,6426	5,0	0,61	1,841E-05	2,0	7,92E+04	-12,47206		10,00	60,21	0,30	9,03121	-0,20715
AM200x250_M05_0_020mps_a_SW2	5,0	30,25	0,20	20	1,2042	7,2852	5,0	1,21	1,841E-05	2,0	1,58E+05	-0,172716		10,00	60,21	0,30	9,03121	-0,00287
AM200x250_M05_0_025mps_a_SW2	5,0	30,25	0,25	20	1,2042	9,1065	5,0	1,51	1,841E-05	2,0	1,98E+05	2,617494	0,72540	10,00	60,21	0,30	9,03121	0,043474
AM200x250_M05_0_030mps_a_SW2	5,0	30,25	0,30	20	1,2042	10,9278	5,0	1,82	1,841E-05	2,0	2,37E+05	6,02182	0,57391	10,00	60,21	0,30	9,03121	0,100017
AM200x250_M05_0_035mps_a_SW2	5,0	30,25	0,35	20	1,2042	12,7491	5,0	2,12	1,841E-05	2,0	2,77E+05	9,038569	0,54651	10,00	60,21	0,30	9,03121	0,150122
AM200x250_M05_0_040mps_a_SW2	5,0	30,25	0,40	20	1,2042	14,5704	5,0	2,42	1,841E-05	2,0	3,17E+05	12,18757	0,53788	10,00	60,21	0,30	9,03121	0,202424
AM200x250_M05_0_045mps_a_SW2	5,0	30,25	0,45	20	1,2042	16,3917	5,0	2,72	1,841E-05	2,0	3,56E+05	15,21505	0,54158	10,00	60,21	0,30	9,03121	0,252708

SUMMARY 1.

- we have established that though the CFD technique is very laboursome with respect to defining the C_v value, but regarding its accuracy, it may be compared with laboratory tests
- key establishment of our research is that for roof smoke and heat vents, the "Hole" element used in the simulation model shall be set by the geometrical cross-section of the vent to be used
- in order to simulate friction, footing of the natural smoke and heat vent as well as the floor thickness including the heat insulation shall be represented in the model environment

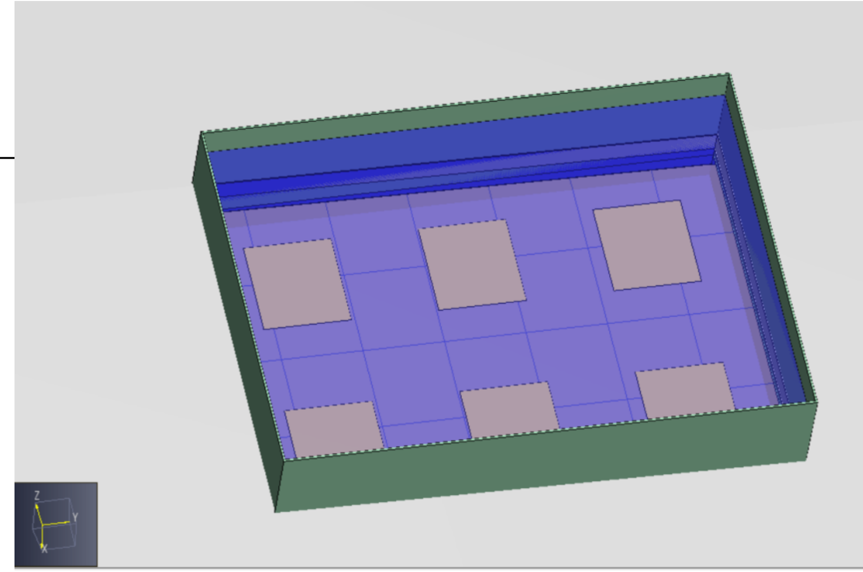


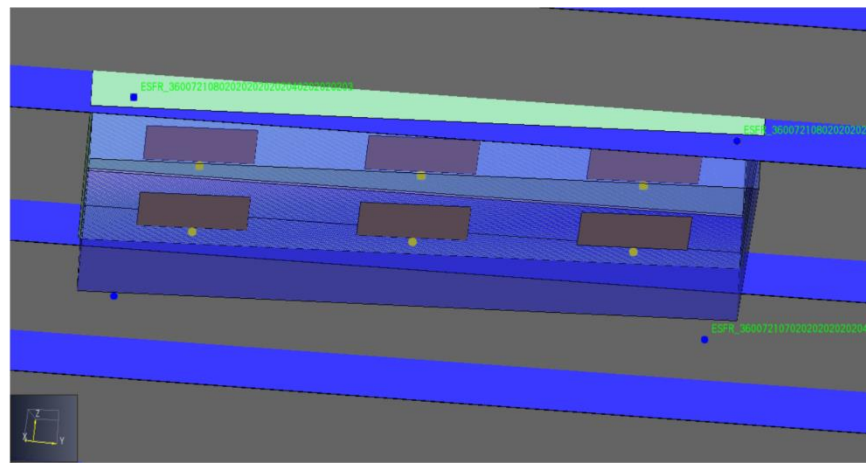
2.700x3.200 mm heat and smoke ventilator modelled with 2.500x3.000 mm ‚Hole' element (adjusted to the 500x500 mm grid), with a frame modelling the thickness of the floor slab and the footing to simulate friction

SUMMARY 2.

Further options for using the test method are as follows:

- carry out preliminary tests when developing new products and validate the actual test results;
- establish the actual C_v factor when installing roof smoke and heat vents of known C_v factor, strongly different from the test conditions (e.g. smoke and heat vent installed above a smoke-flue),
- test the effect that influences the efficiency for other active fire protection equipment (e.g. sprinkler heads installed below domes or their solar thermal collector dishes) added to roof smoke and heat ventilators of known C_v factor





Top and bottom view of a 2.500x3.000 mm smoke vent with sprinklers and heat collector plates in CFD/PyroSim environment; grid: 50x50 cm