



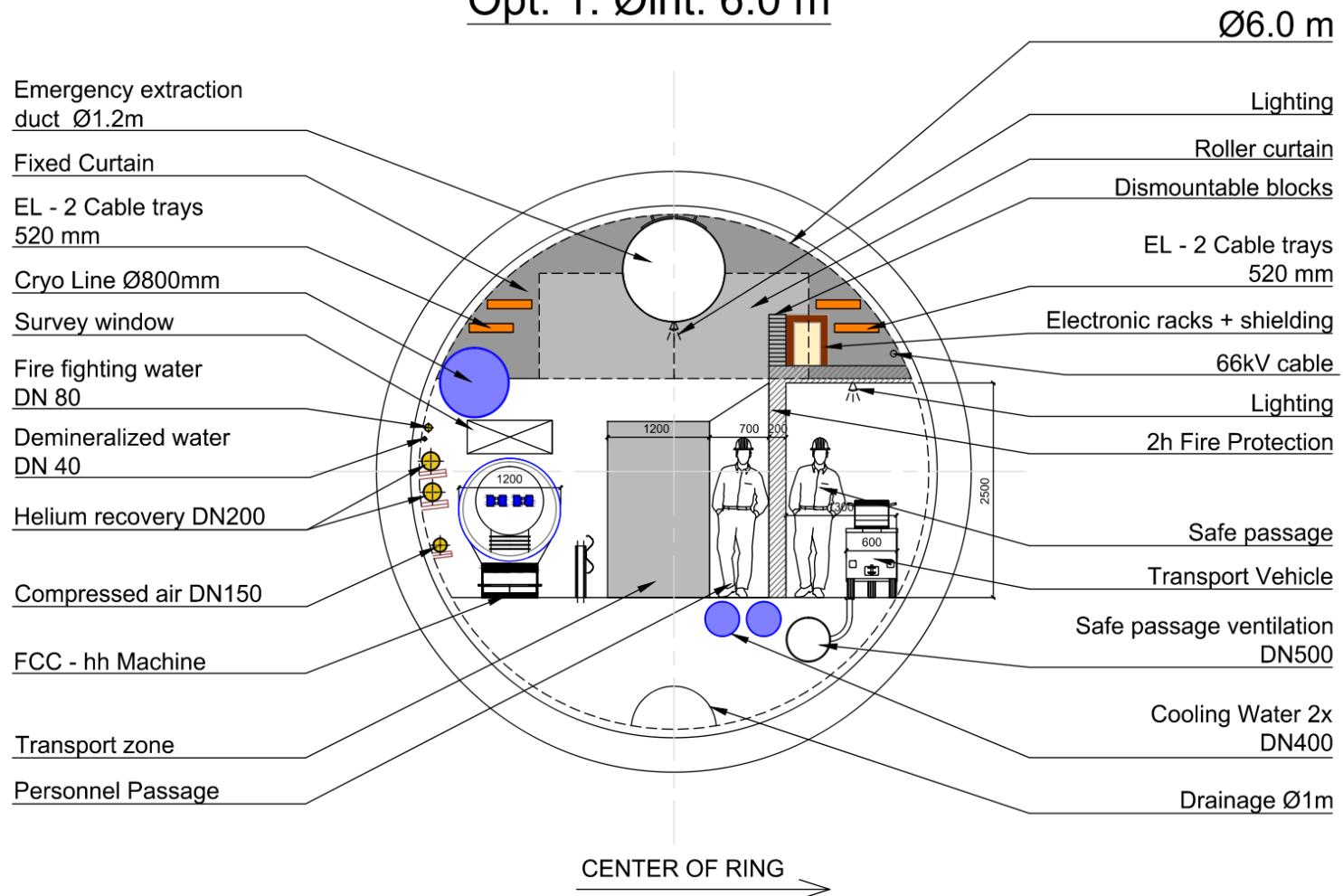
Additional calculations for the FCC (future circular collider) ventilation system

CFD-2016-03-FCC-2
EDMS 1704506

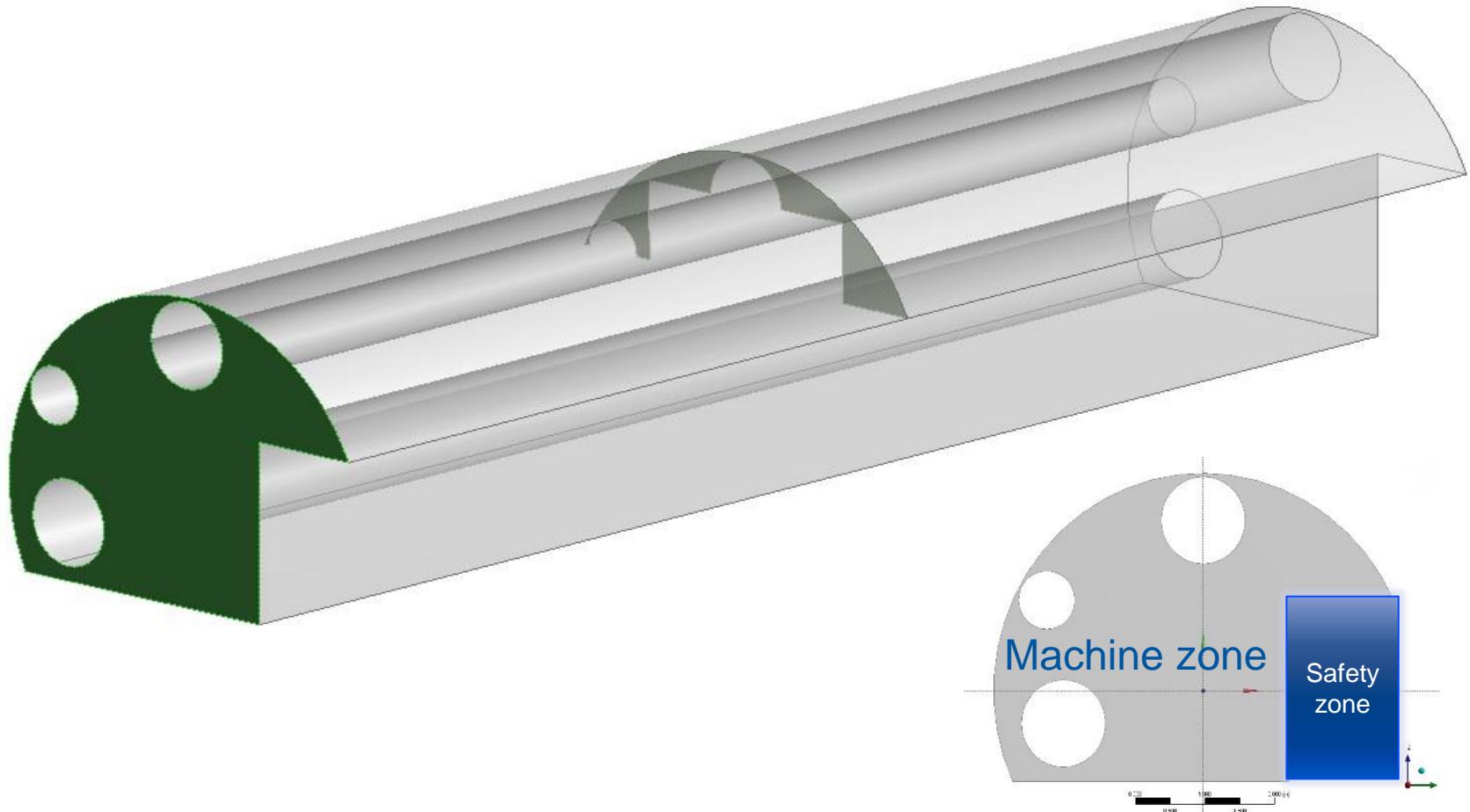


FCC tunnel design

Opt. 1: Øint: 6.0 m



FCC: machine+safety tunnel



Previous part

- CFD project 2015-05-FCC-tunnel
- Final report: EDMS 1523101
- Pressure drop calculations to evaluate the effect of fire curtain, both 1D hydraulic and 3D computational fluid dynamics (CFD) calculations.

Additional calculations

- MathCAD tool for fan choice
- MathCAD tool for thermal behaviour
- Demonstrative CFD case for an ODH situation
- Demonstrative CFD case for air curtain effects

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MatchCAD tool for fan choice

Mathcad - [FCC-machineTunnelCalculator]

Air properties:

$P_2 := 100000 \text{ Pa}$ $T_2 := 17^\circ\text{C}$ Elevation over sea level: $\text{elev}_F := 750 \text{ m}$ $\text{elev}_E := 550 \text{ m}$

$\rho_2 = 1.202 \frac{\text{kg}}{\text{m}^3}$ $\mu_2 = 1.795 \times 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{s}}$ $\nu_2 = 1.493 \times 10^{-5} \frac{\text{m}^2}{\text{s}}$

Flow functions:

System for machine tunnel:

Frictional loss:

$i := 0.5$ $Q_1 := (55000 + 20000 \cdot i) \frac{\text{m}^3}{\text{hr}}$ Evaluating points

Duct segment:

$D_d := 1.0 \text{ m}$ $H_d := 2500 \text{ m}$ $k_d := 0.00001 \text{ m}$

Tunnel segment:

$D_t := 2.16 \text{ m}$ $L_t := 9100 \text{ m}$ $k_t := 0.0001 \text{ m}$ $A_t := 14.44 \text{ m}^2$

Local losses:

$n_e := 2$ $k_e := 1$ Losses at elbows

$n_{BC} := 2$ $k_{BC} := 1$ Losses at sudden expansions

$n_c := 50$ $C_c := 0.78$ Losses at fire curtain

$D_{restriction} := 2 \text{ m}$

AHU losses:

Supply: $\Delta P_{AHU_supply} = 700 \text{ Pa}$

Extraction: $\Delta P_{AHU_extraction} = 350 \text{ Pa}$

Velocity and Reynolds numbers:

$\text{velTunnel}_1 := \text{vTunnel}(Q_1, A_t)$ $\text{ReTunnel}_1 := \text{Rey}(\rho_2, \text{velTunnel}_1, D_t, \mu_2)$

$fTunnel_1 := \text{friction}(k_t, D_t, \text{ReTunnel}_1)$ $\text{dpTunnel}_1 := \text{deltap}_F(\text{Tunnel}_1, L_t, D_t, \rho_2, \text{velTunnel}_1)$

$\text{velDuct}_1 := \text{vDuct}(Q_1, D_d)$ $\text{ReDuct}_1 := \text{Rey}(\rho_2, \text{velDuct}_1, D_d, \mu_2)$

$fDuct_1 := \text{friction}(k_d, D_d, \text{ReDuct}_1)$ $\text{dpDuct}_1 := \text{deltap}_F(\text{Duct}_1, H_d, D_d, \rho_2, \text{velDuct}_1)$

Q₁ =

| | | | | | | | | | |
|--------|--------------------------------|--------------------------|-----------------------------------|-------------------------|--------------------|------------------------|-------|-------------------------|---------------------|
| 55000 | $\frac{\text{m}^3}{\text{hr}}$ | velTunnel ₁ = | $1.058 \frac{\text{m}}{\text{s}}$ | ReTunnel ₁ = | $1.531 \cdot 10^5$ | fTunnel ₁ = | 0.016 | dpTunnel ₁ = | 46.518 Pa |
| 75000 | | | 1.443 | $2.087 \cdot 10^5$ | | 0.015 | | | 81.425 |
| 95000 | | | 1.827 | $2.644 \cdot 10^5$ | | 0.015 | | | 124.924 |
| 115000 | | | 2.212 | $3.201 \cdot 10^5$ | | 0.014 | | | 176.702 |
| 135000 | | | 2.597 | $3.757 \cdot 10^5$ | | 0.014 | | | 236.524 |
| 155000 | | | 2.982 | $4.314 \cdot 10^5$ | | 0.014 | | | 304.199 |

Two identical ducts assumed

n_{BC} -number of sudden expansion k_{BC} -loss coeff of sudden expansion

n_e -number of elbows k_e -loss coeff of one elbow

k_t -roughness of tunnel

k_d -roughness of duct

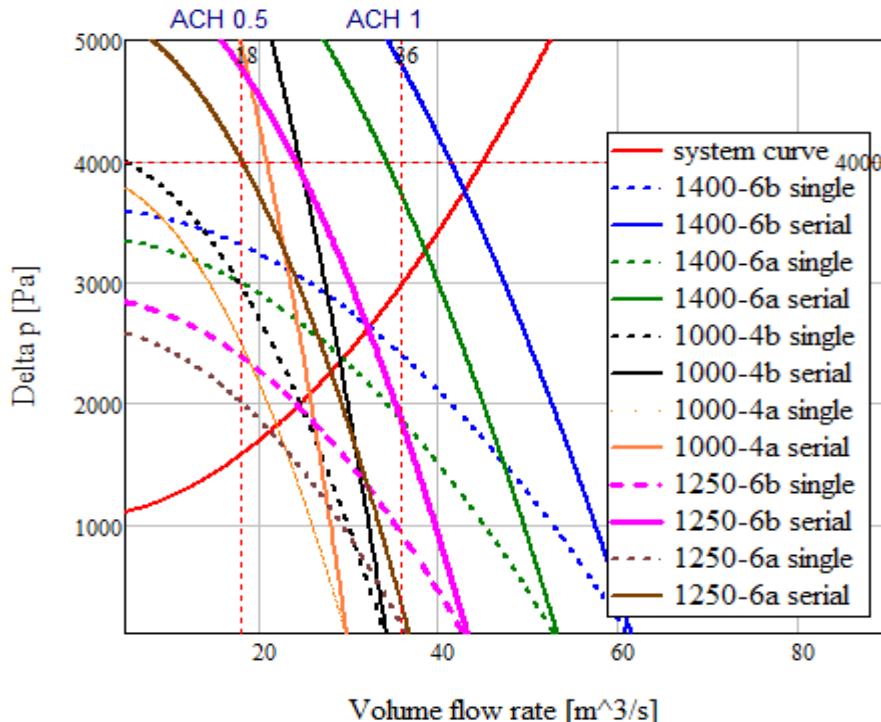
D_t -Hydraulic diameter of funnel cross section

A_t -tunnel cross section

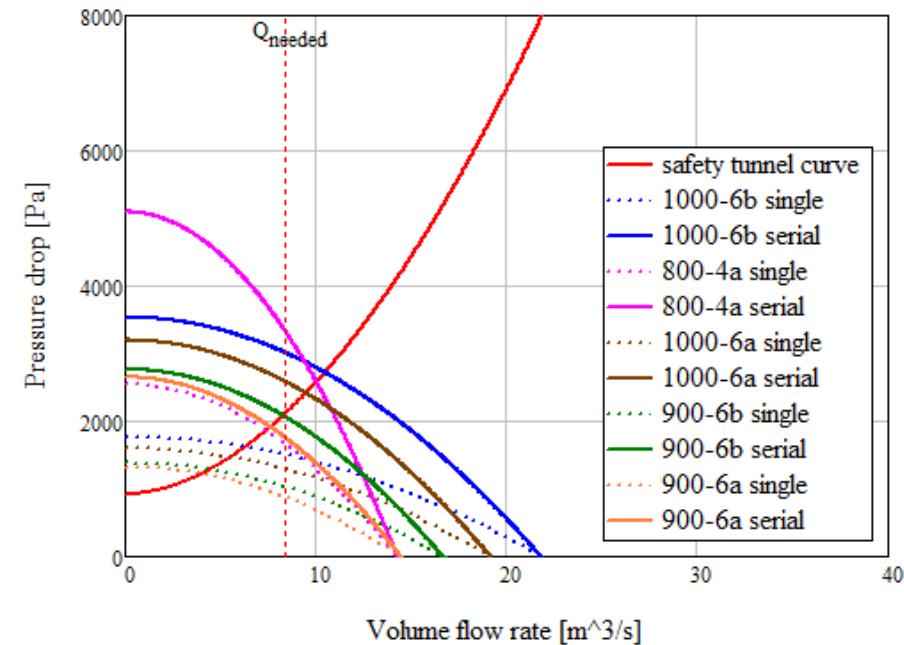
Attached to the EDMS document, scripts must be enabled, and evaluation of lists as well, works in MatchCAD 15.

FCC fan choices

Machine tunnel

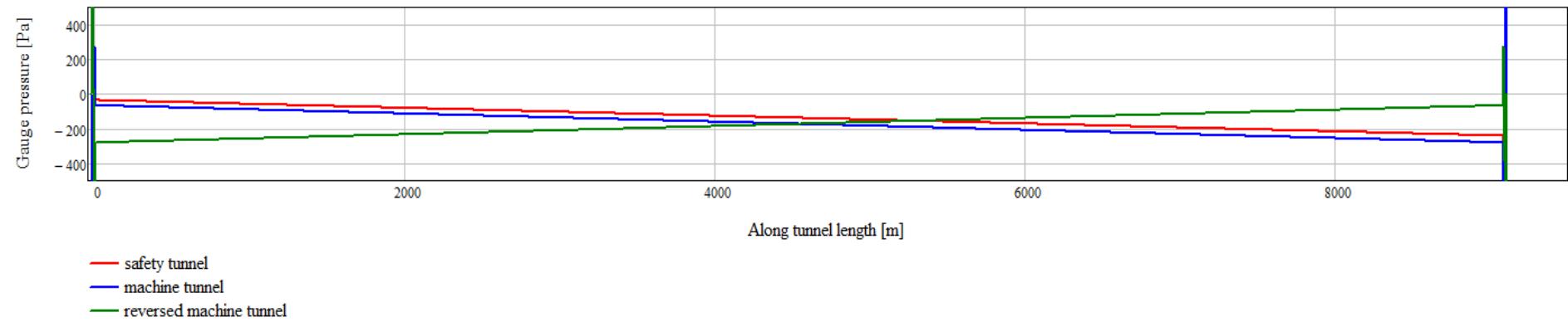


Safety tunnel



Fans taken from a CLICK workshop listing for non standard industrial fans.

FCC pressure in the two tunnel



Max pressure difference between machine and safety tunnel in operation: 40Pa for same direction. In case of reversed direction, the overpressure maintenance is more complicated.

Escape doors

Note that the pressure difference between the machine and safety tunnel has an important effect on the escape door operation, see

Michael Lierau, Marcus Römer, Luigi De Candido from Elkuch Group and Eisenring – Tunnel Escape Doors presented at Swiss Tunnel Conference 2016

| Tür Dimension/Door dimensions | | | Neue Tür/New door | | Gealterte Tür/Aged door | |
|---|-----------------|----------------|--|---|--|---|
| Höhe Height | Breite Width | Fläche Area | Zulässige Öffnungskraft Permissible opening force | Max. Druckdifferenz Max. pressure difference | Zulässige Öffnungskraft Permissible open- ing force | Max. Druckdifferenz Max. pressure difference |
| m | m | m ² | N | Pa | N | Pa |
| Türen nach DIN 18101/Doors according to DIN 18101 | | | | | | |
| 1,985 | 0,610 | 1,211 | 100 | 83 | 120 | 99 |
| 1,985 | 0,735 | 1,459 | 100 | 69 | 120 | 82 |
| 1,985 | 0,860 | 1,707 | 100 | 59 | 120 | 70 |
| 1,985 | 0,985 | 1,955 | 100 | 51 | 120 | 61 |
| 1,985 | 1,110 | 2,203 | 100 | 45 | 120 | 54 |
| Fluchttür nach TSI-SRT/Escape door according to TSI-SRT | | | | | | |
| 2,000 | 1,400 | 2,800 | 100 | 36 | 120 | 43 |

Quelle/credit: Elkuch Group

Paper attached to EDMS document



Additional calculations

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MathCAD tool for thermal behaviour

Mathcad - [FCC-heatTransferCalculatorIndependent]

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Supply air properties:

$P_2 = 100000\text{Pa}$ $T_2 = 17^\circ\text{C}$ $T_{\text{supply}} := T_2 - 273\text{K}$

Tunnel segment

hydraulic diameter length roughness cross section area wetted perimeter

$D_t := 2.16\text{m}$ $L_t := 9100\text{m}$ $k_t := 0.00001\text{m}$ $A_t := 14.44\text{m}^2$ $P_t := 26.74\text{m}$

concrete heat conductivity (from Virtual Maths) concrete thickness

$k_{\text{concrete}} = 1.63 \frac{\text{W}}{\text{m}\cdot\text{K}}$ $d_{\text{concrete}} := 0.5\text{m}$

Tunnel wall temperature: Ground temperature

$T_{\text{tunnelw}} := 20^\circ\text{C}$ $T_{\text{ground}} := 20^\circ\text{C}$ $T_{\text{wall}} := T_{\text{tunnelw}} - 273\text{K}$

Machines volume flow:

Volume flow rate: $Q_{\text{chosen}} := 55000 \frac{\text{m}^3}{\text{hr}}$

Heat load from machines in tunnel:

$Q_{\text{gradientFull,magnet}} := 460 \frac{\text{W}}{\text{m}}$ $\text{ratioToAir} = 0.05$

$Q_{\text{gradient,cables}} := 44 \frac{\text{W}}{\text{m}}$

$Q_{\text{gradient,machine}} := Q_{\text{gradientFull,magnet}} \text{ratioToAir} + Q_{\text{gradient,cables}}$

$Q_{\text{heat,machine}} := L_t Q_{\text{gradient,machine}}$ $Q_{\text{heat,machine}} = 6.097 \times 10^5 \text{W}$

Air properties for 20°C (values from REFPROP):

Machine tunnel results:

Mean velocity $v_{\text{elTunnel}} = 1.058 \frac{\text{m}}{\text{s}}$

Reynolds number: $Re_{\text{Tunnel,op}} = 1.531 \times 10^5$

Richardson number: $Re_{\text{Tunnel,op}} = 1.941 \times 10^{-1}$

Heat transfer functions:

Heat transfer coefficients

HTC at tunnel wall: HTC combined of tunnel wall and concrete layer:

$h_{\text{tunnel,wall}} = 2.9 \frac{\text{W}}{\text{m}^2\cdot\text{K}}$ $h_{\text{tunnel,concrete}} = 1.527 \frac{\text{W}}{\text{m}^2\cdot\text{K}}$

Attached to the EDMS document, works in MatchCAD 15.



FCC thermal behaviour

Thermal load: 5% of magnets (23 W/m) and cables (55 W/m or 27 W/m)

3 assumptions:

1. All heat load going to air, tunnel adiabatic (no heat exchange with wall)
2. Heat also leaves by tunnel wall which remains constant temperature (20°C)
3. Tunnel wall resistance included (concrete thermal conductivity: 1.28 W/(mK), thickness 0.5m), constant ground temperature (20°C)

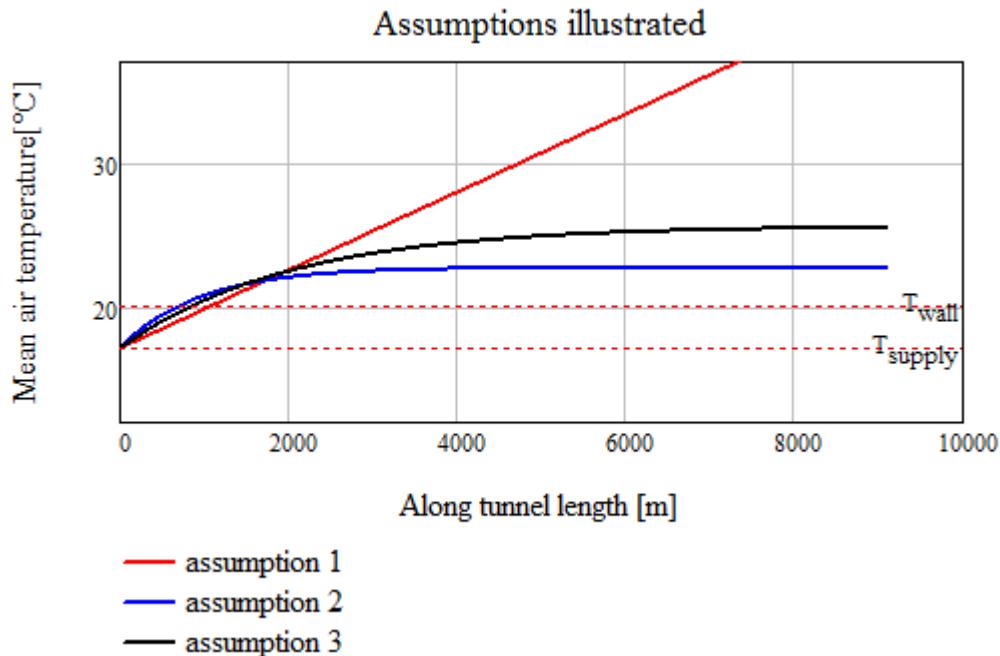


Illustration for 27 W/m
cables, 55000 m³/h flow

FCC thermal behaviour

| Tunnel volume flow rate m ³ /h | ACH "-" | cables 55 W/m | | Assumption 1 | | Assumption 2 | | Assumption 3 | |
|--|------------|------------------------------------|--------------------------------------|-----------------|----------|-----------------|----------|-----------------|----------|
| | | HTC-tunnel W/(m ² K) | HTC-combined W/(m ² K) | exhaust T °C | Δ T K | exhaust T °C | Δ T K | exhaust T °C | Δ T K |
| 55000 | 0.42 | 2.9 | 1.35 | 55.4 | 38.4 | 24 | 7 | 28.4 | 11.4 |
| 75000 | 0.57 | 3.7 | 1.51 | 45.2 | 28.2 | 23.1 | 6.1 | 27.3 | 10.3 |
| 95000 | 0.72 | 4.5 | 1.63 | 39.2 | 22.2 | 22.6 | 5.6 | 26.6 | 9.6 |
| 115000 | 0.88 | 5.2 | 1.72 | 35.4 | 18.4 | 22.2 | 5.2 | 26.1 | 9.1 |
| 135000 | 1.03 | 6 | 1.8 | 32.6 | 15.6 | 21.9 | 4.9 | 25.6 | 8.6 |

| Tunnel volume flow rate m ³ /h | ACH "-" | cables 27 W/m | | Assumption 1 | | Assumption 2 | | Assumption 3 | |
|--|------------|------------------------------------|--------------------------------------|-----------------|----------|-----------------|----------|-----------------|----------|
| | | HTC-tunnel W/(m ² K) | HTC-combined W/(m ² K) | exhaust T °C | Δ T K | exhaust T °C | Δ T K | exhaust T °C | Δ T K |
| 55000 | 0.42 | 2.9 | 1.35 | 41.6 | 24.6 | 22.6 | 5.6 | 25.4 | 8.4 |
| 75000 | 0.57 | 3.7 | 1.51 | 35.1 | 18.1 | 22 | 5 | 24.7 | 7.7 |
| 95000 | 0.72 | 4.5 | 1.63 | 31.3 | 14.3 | 21.6 | 4.6 | 24.2 | 7.2 |
| 115000 | 0.88 | 5.2 | 1.72 | 28.8 | 11.8 | 21.4 | 4.4 | 23.8 | 6.8 |
| 135000 | 1.03 | 6 | 1.8 | 27 | 10 | 21.2 | 4.2 | 23.5 | 6.5 |

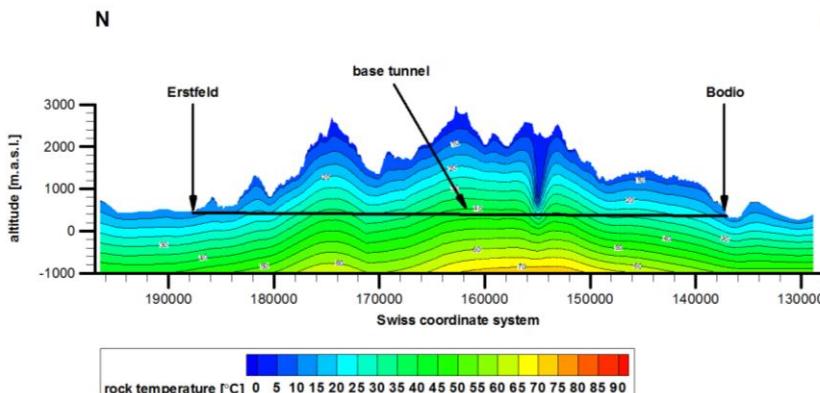
As the volume flow rate, and thus the velocity increases, HTC is increasing as well, so more heat can be removed.



Virgin rock temperature issue

- Adiabatic or constant 20°C is most probably not valid for tunnel depths considered
- More expertise is needed, see example:

From Ladislaus Rybach, Institute of Geophysics ETHZ, Zurich, Switzerland and Andreas Busslinger HBI Haerter Consulting Engineers, Bern, Switzerland - **Numerical modelling for rock temperature prediction in deep tunneling - methodology and verification at Eurock 15, 64th Geomechanics Colloquium**



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FCC double duct safety tunnel

Fresh air can arrive to the safety tunnel from an additional duct



**Additional duct on
top with fresh air**

**Opening on duct to
deliver fresh air to tunnel**

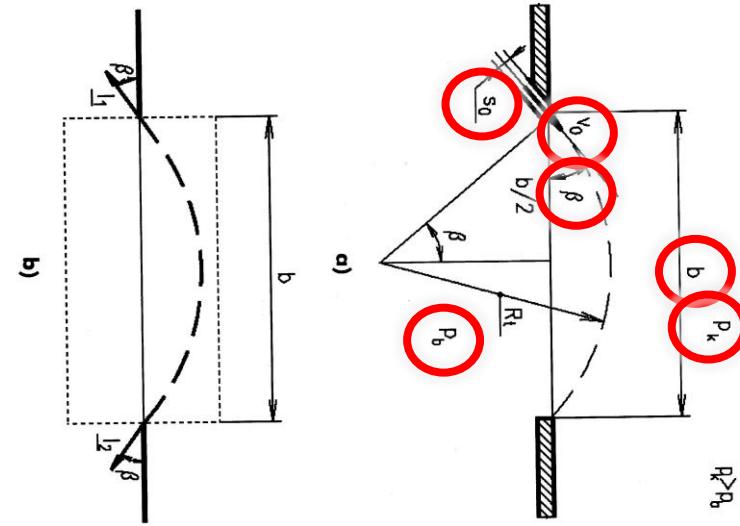
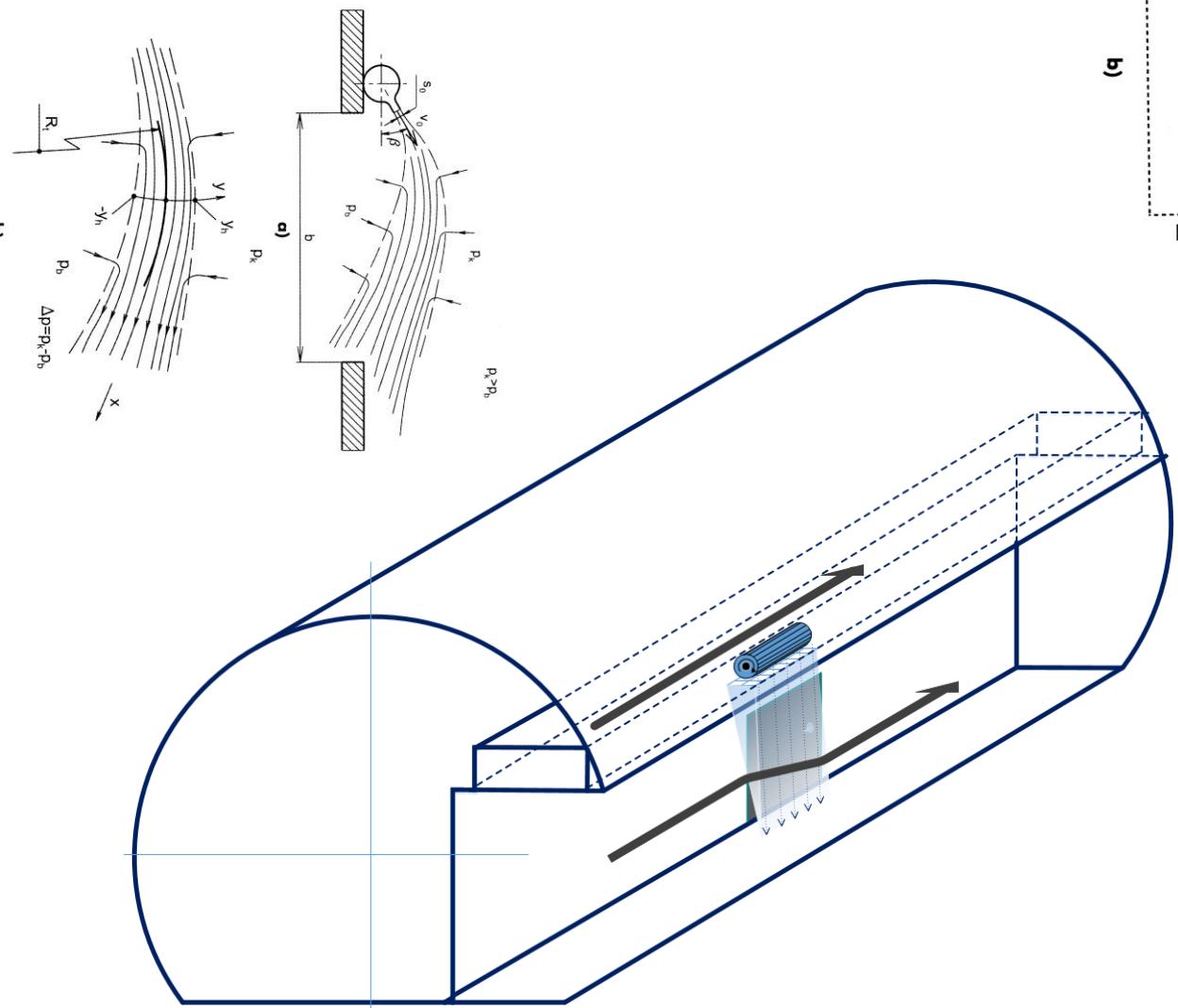
ODH source



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Air curtain basics:

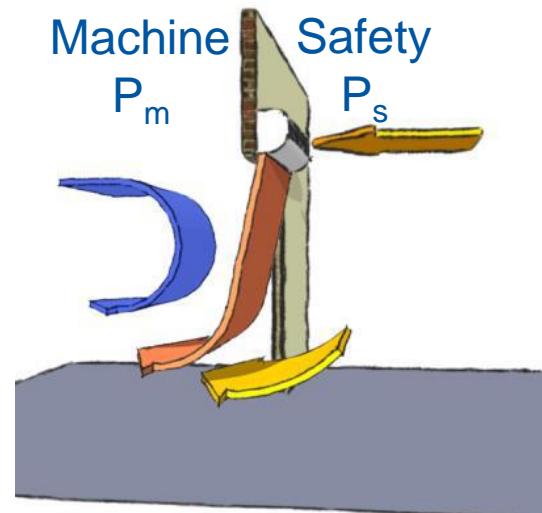
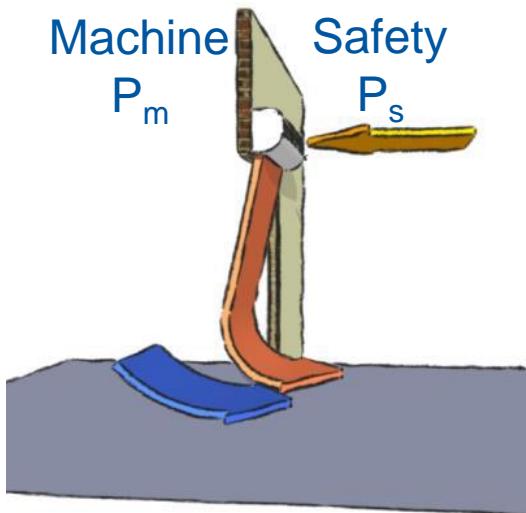
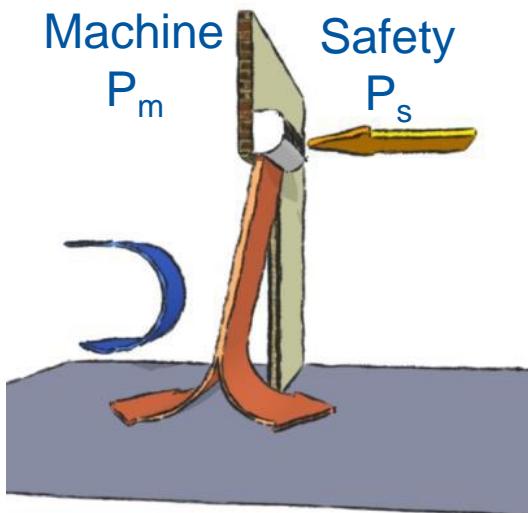
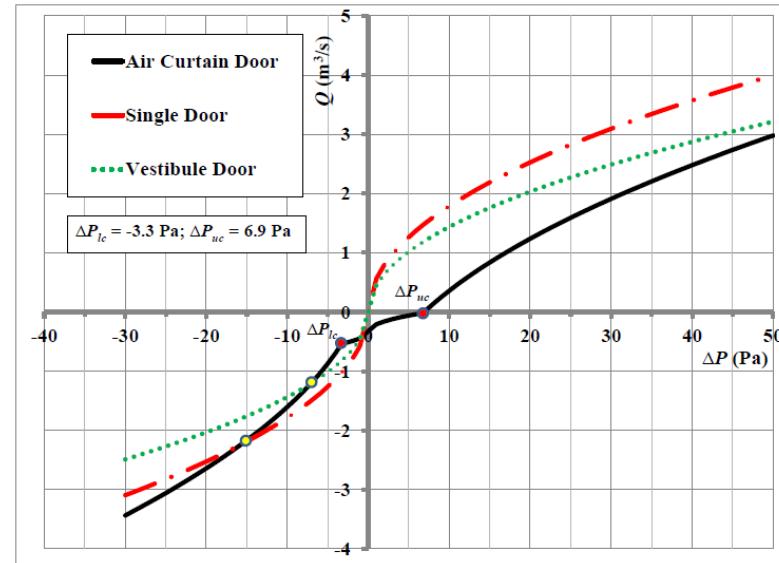


Necessary jet velocity
to keep pressure
difference:

$$v_0 = \sqrt{\frac{\Delta p \cdot b}{2 \rho \cdot s_0 \cdot \sin \beta}}$$

In literature:

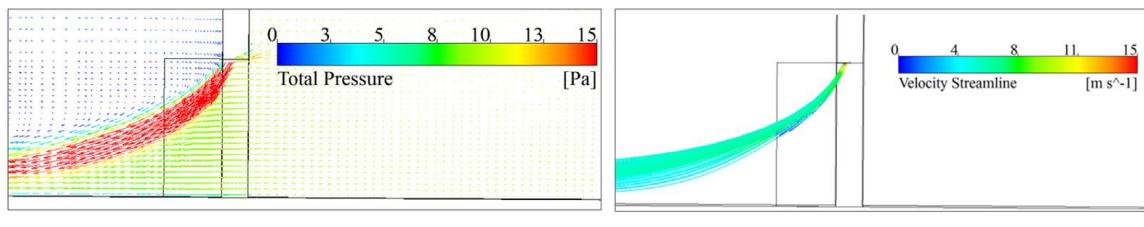
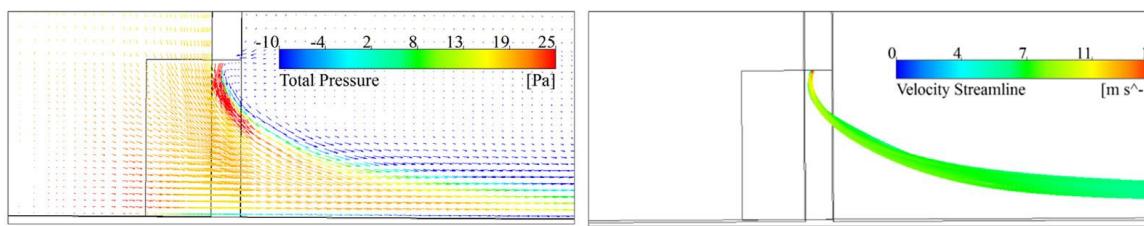
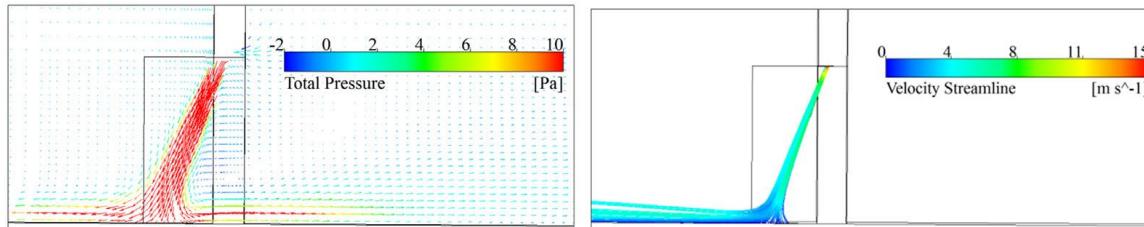
Air filtration depending on different pressure ratios from: **L. Wang** – Investigation of the Impact of Building Entrance Air Curtain on Whole Building Energy Use



Paper attached to EDMS document

In literature:

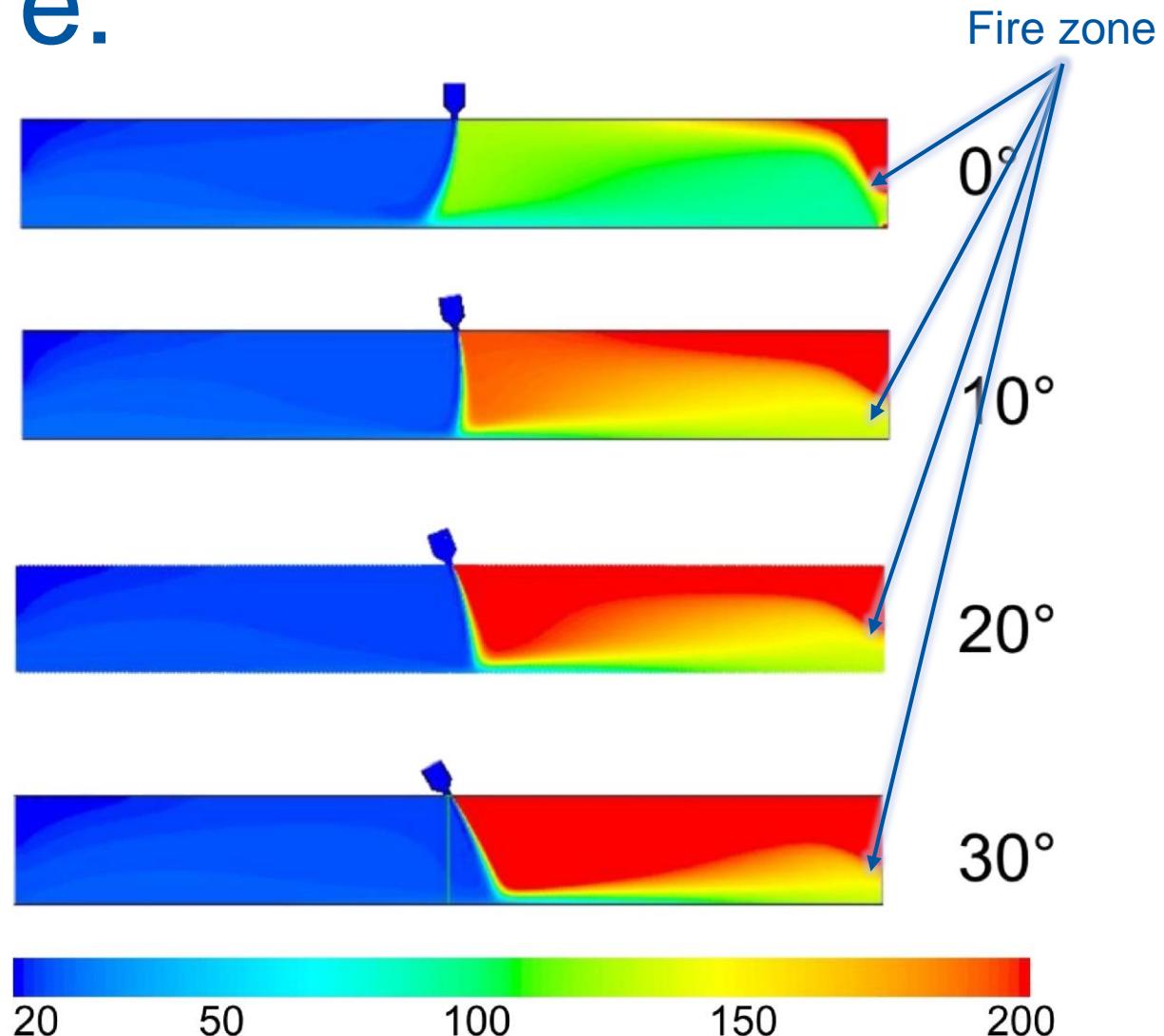
L. Wang –Investigation of the Impact of Building Entrance Air Curtain on Whole Building Energy Use



In literature:

KRAJEWSKI and WĘGRZYŃSKI – *Air curtain as a barrier for smoke in case of fire: Numerical modelling*

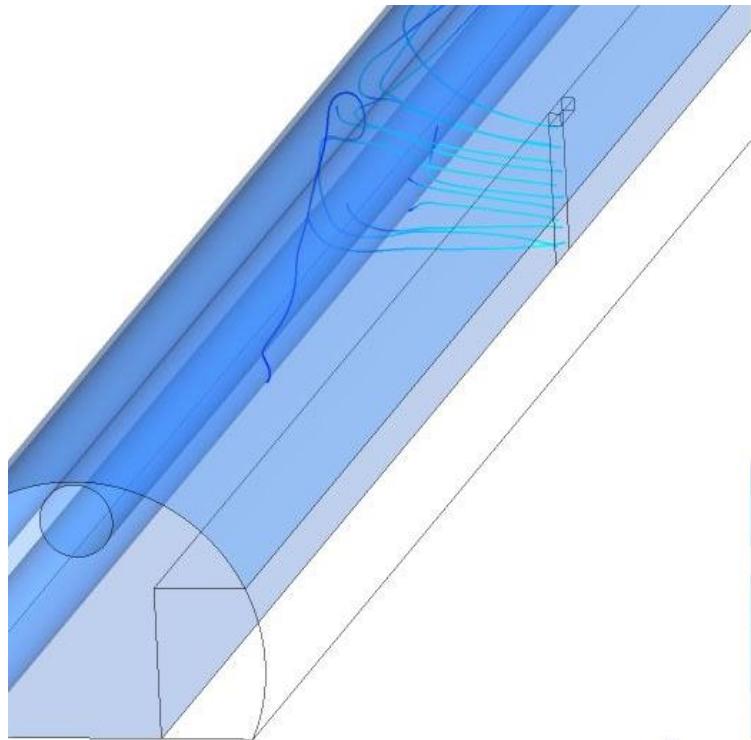
Paper attached to EDMS document



Air curtain FCC simulation:

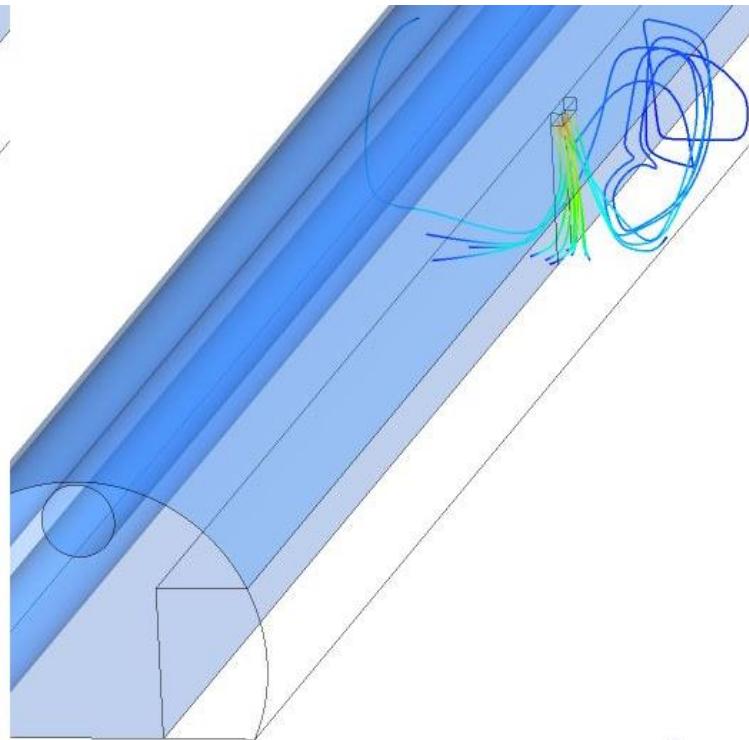
Without air curtain:

- Flow into machine tunnel due to pressure difference when door is open



With air curtain:

- Flow into machine tunnel can be reduced with a well positioned air curtain
- Δp better maintained



Air curtain:

Example:

- $\Delta p = 40$ Pa pressure difference
- Door between safety and machine tunnel: 2.3 m x 1 m
- With an air curtain (inlet width 0.2 m, inlet velocity 22 m/s, inlet angle 22.5°) the escape volume flow rate to machine tunnel can be reduced to 25%



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