WIND INFLUENCE IN NUMERICAL ANALYSIS OF NSHEVS PERFORMANCE

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M.Sc. Env. Eng. Grzegorz Krajewski

Scope of the presentation:

(i) Computational Wind Engineering

(ii) Traditional approach to wind influence in NSHEVS

(iii) Good practice in CWE

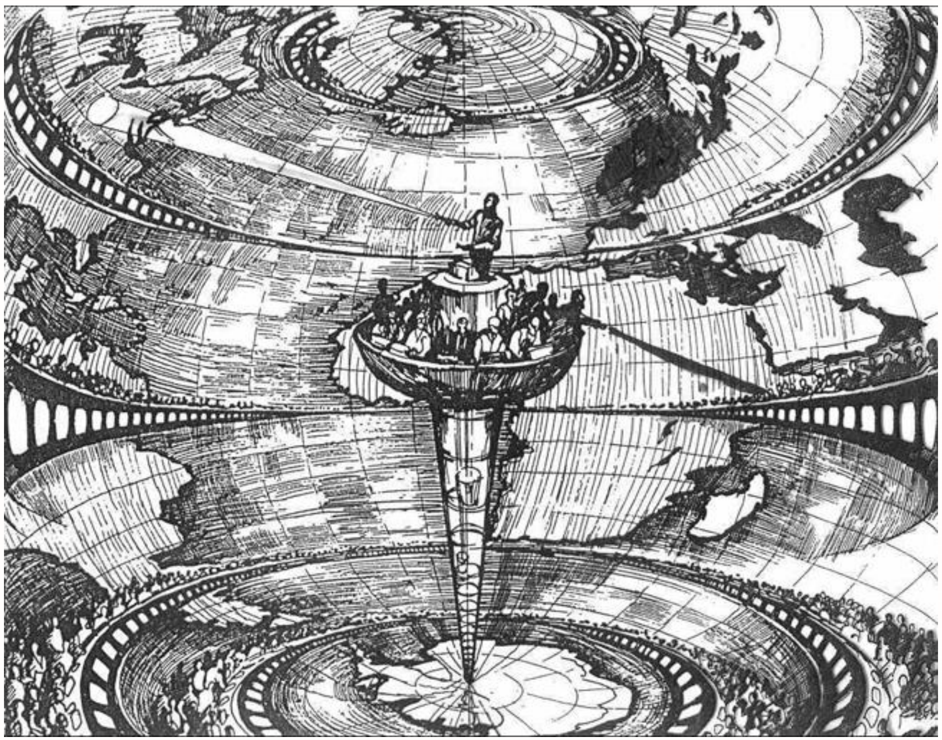
Computational Wind Engineering (CWE)

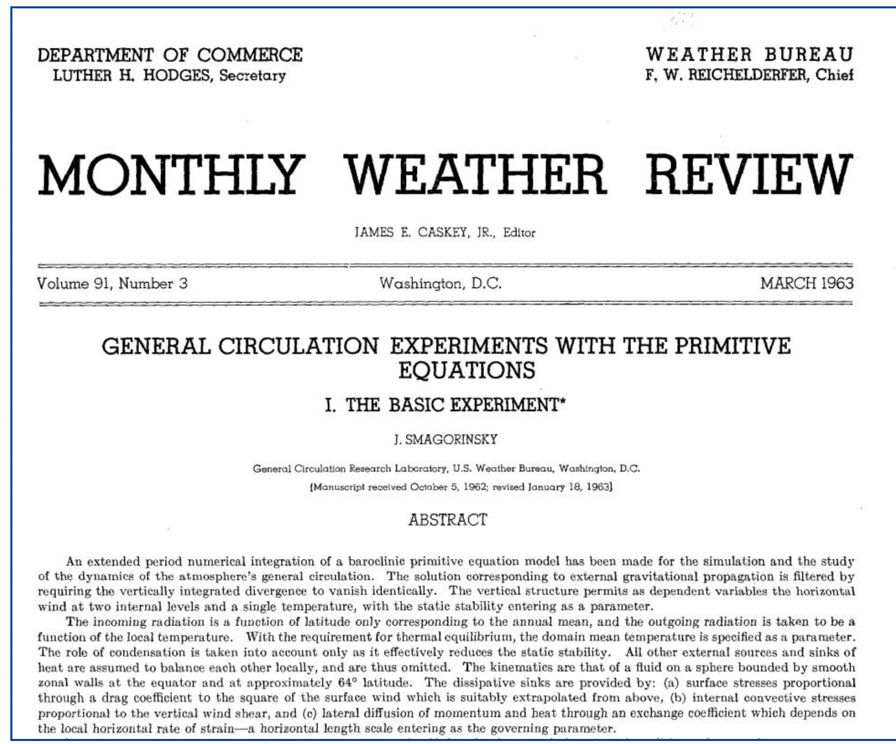
„(...) the use of Computational Fluid Dynamics (CFD) for wind engineering applications."

Main areas of interest

- Structural wind engineering
- Wind driven rain and snow
- Pedestrian level wind and urban flows
- Bluff-body aerodynamics

For more than 50 years the advances of CWE push forward Computational Fluid Dynamics, of which we, Fire Safety Engineers, benefit greatly.





DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary

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MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

Volume 91, Number 3 Washington, D.C. MARCH 1963

GENERAL CIRCULATION EXPERIMENTS WITH THE PRIMITIVE EQUATIONS

I. THE BASIC EXPERIMENT*

J. SMAGORINSKY

General Circulation Research Laboratory, U.S. Weather Bureau, Washington, D.C.

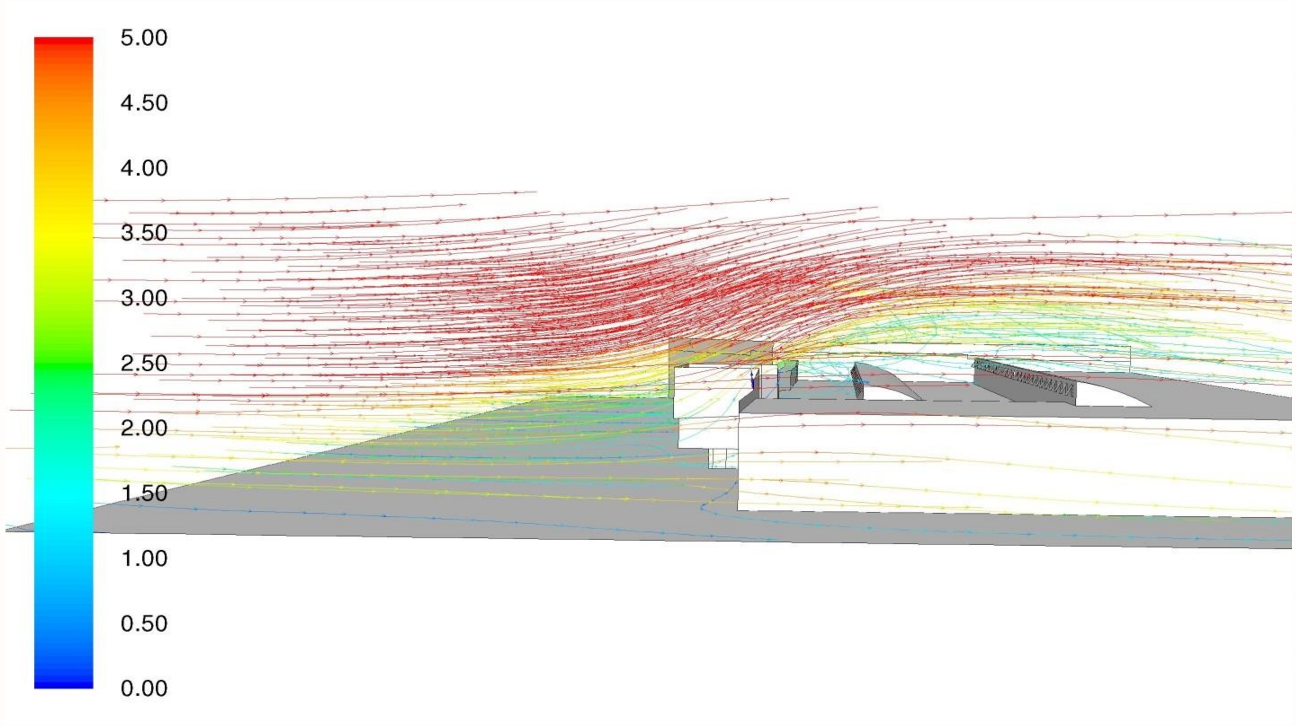
[Manuscript received October 5, 1962; revised January 18, 1963]

ABSTRACT

An extended period numerical integration of a baroclinic primitive equation model has been made for the simulation and the study of the dynamics of the atmosphere's general circulation. The solution corresponding to external gravitational propagation is filtered by requiring the vertically integrated divergence to vanish identically. The vertical structure permits as dependent variables the horizontal wind at two internal levels and a single temperature, with the static stability entering as a parameter.

The incoming radiation is a function of latitude only corresponding to the annual mean, and the outgoing radiation is taken to be a function of the local temperature. With the requirement for thermal equilibrium, the domain mean temperature is specified as a parameter. The role of condensation is taken into account only as it effectively reduces the static stability. All other external sources and sinks of heat are assumed to balance each other locally, and are thus omitted. The kinematics are that of a fluid on a sphere bounded by smooth zonal walls at the equator and at approximately 64° latitude. The dissipative sinks are provided by: (a) surface stresses proportional through a drag coefficient to the square of the surface wind which is suitably extrapolated from above, (b) internal convective stresses proportional to the vertical wind shear, and (c) lateral diffusion of momentum and heat through an exchange coefficient which depends on the local horizontal rate of strain—a horizontal length scale entering as the governing parameter.

What we want from CWE is to apply this:



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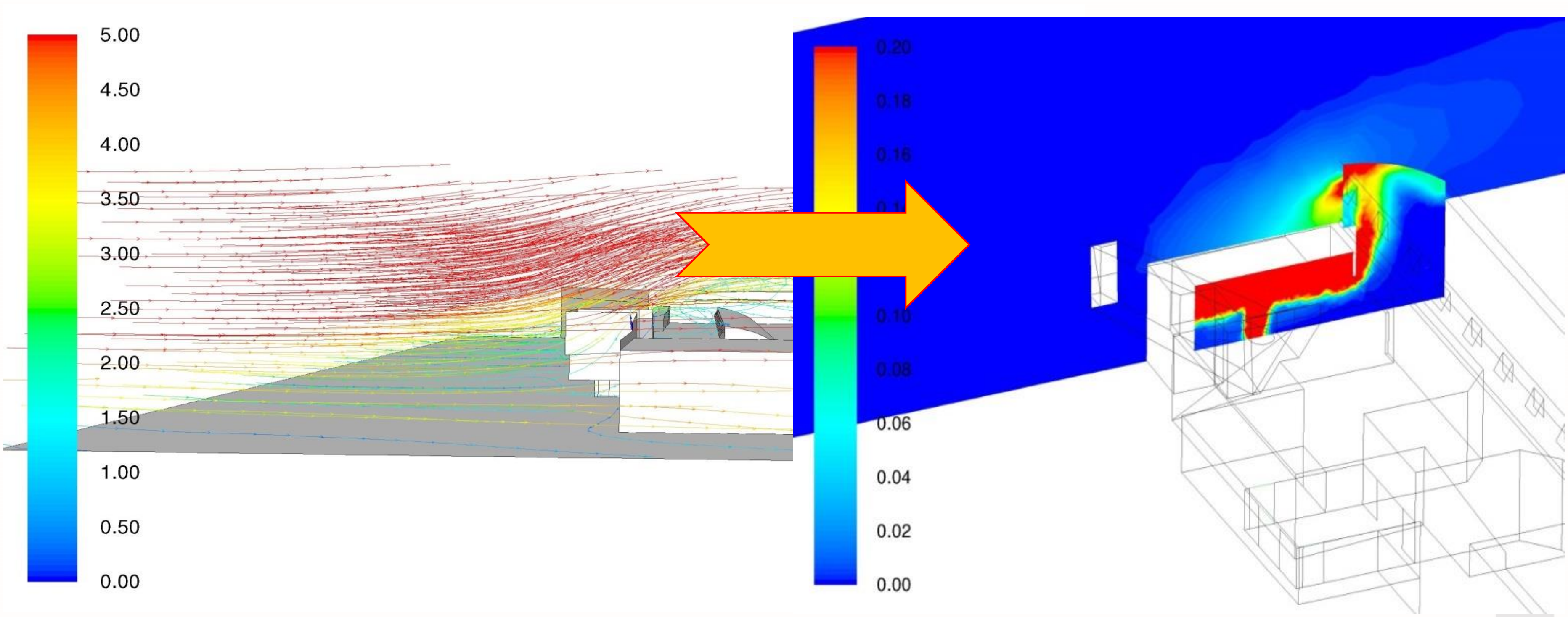
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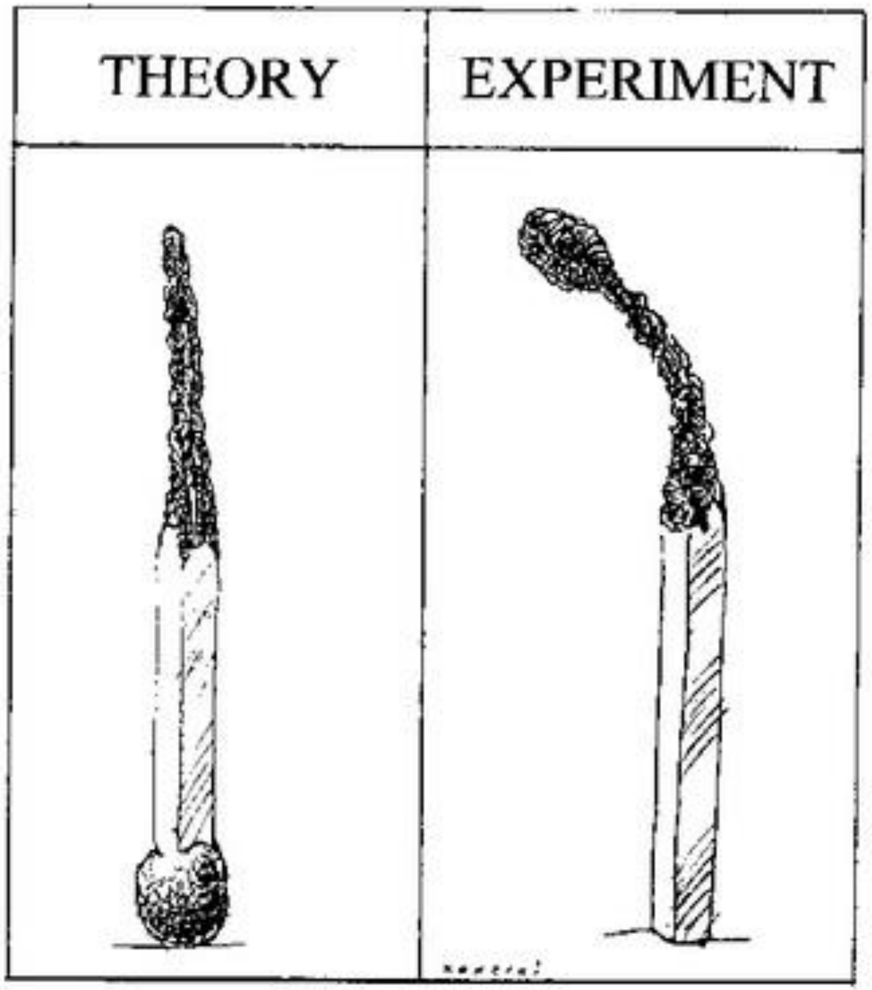
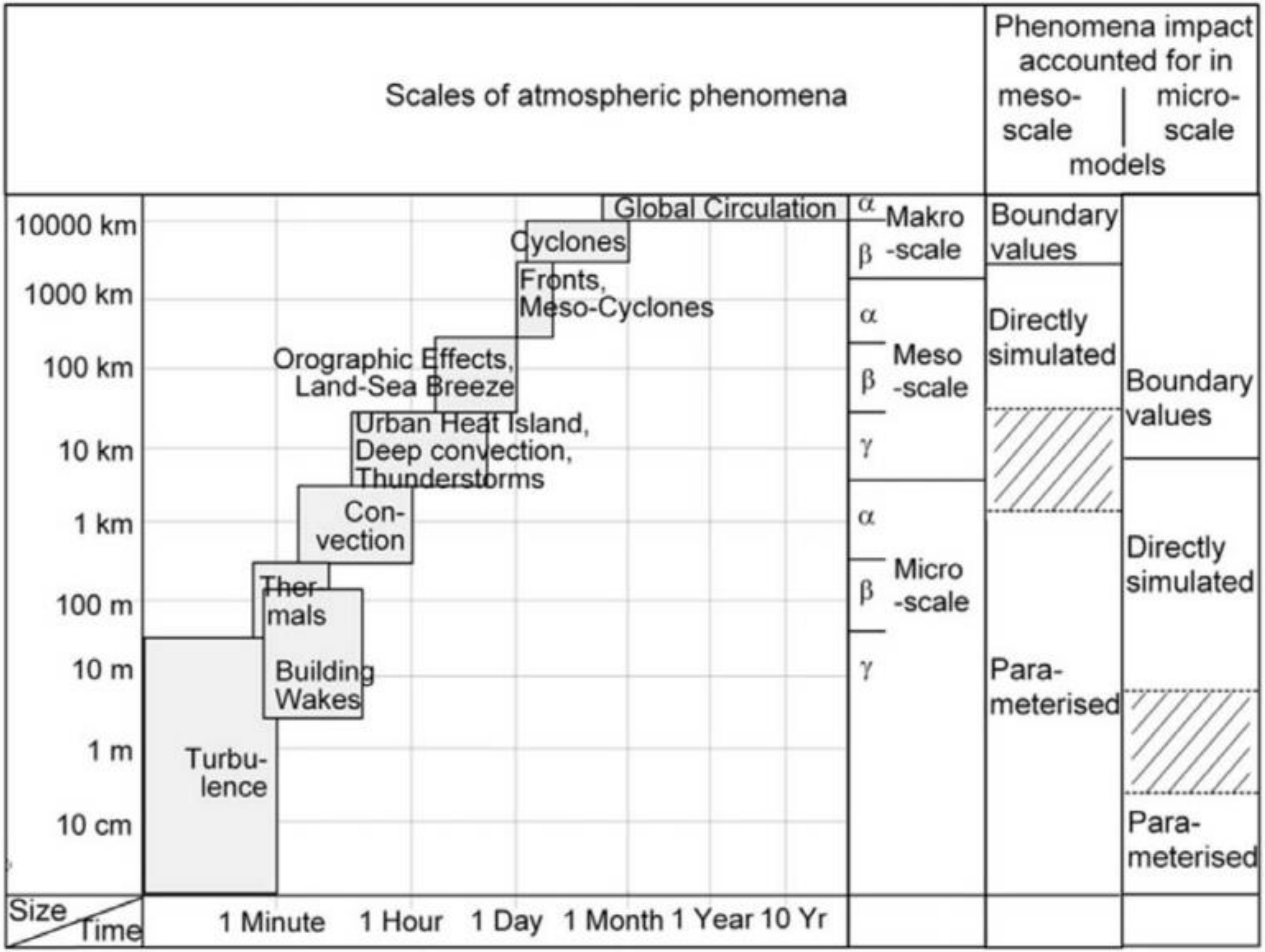
in a way that does not end like this

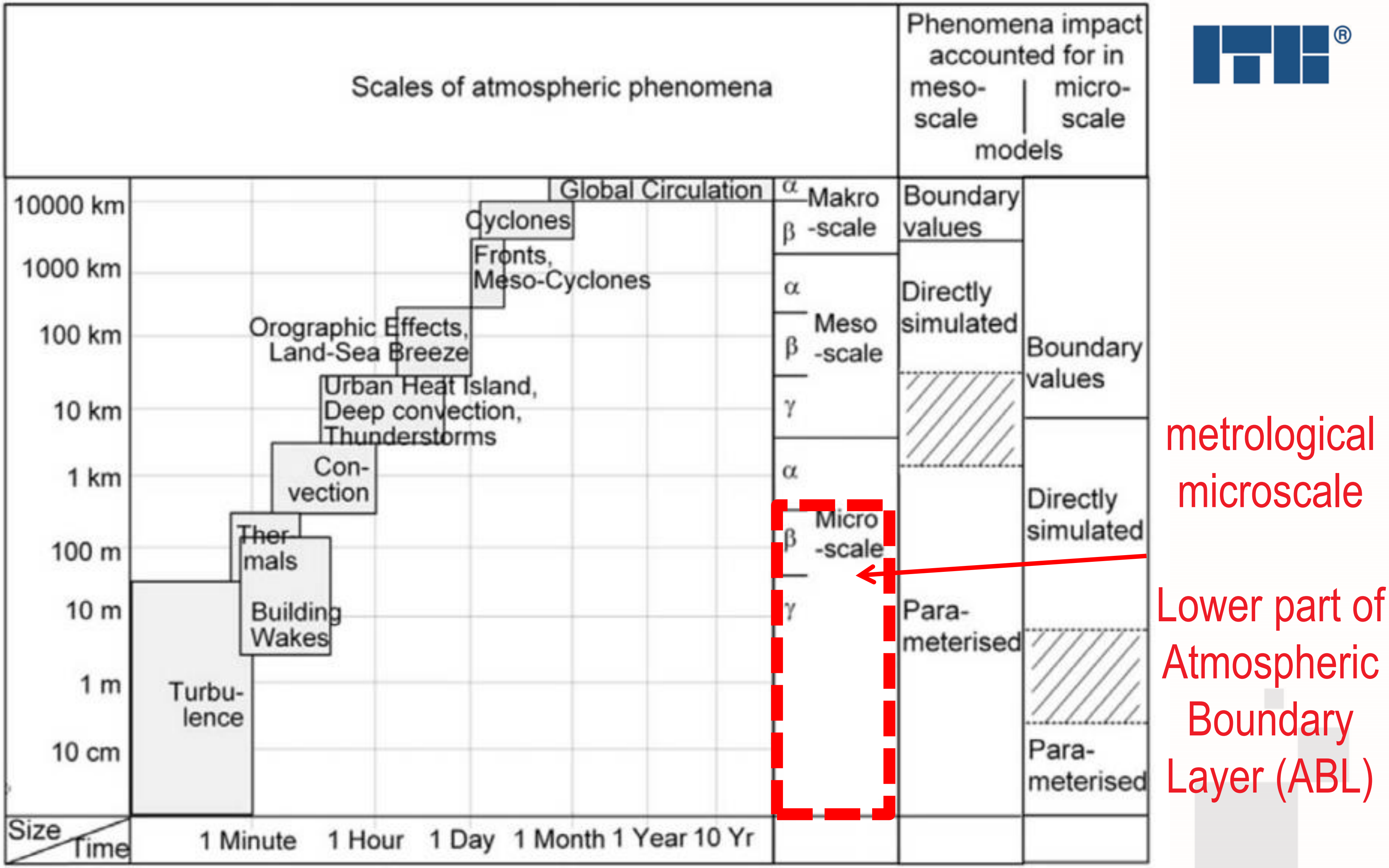


Courtesy of prof. Marek Konecki, SGSP



www.itb.pl

Schlünzen, K.H., Grawe, D., Bohnenstengel, S.I., Schlüter, I. and Koppmann, R. (2011) Joint modelling of obstacle induced and mesoscale changes-Current limits and challenges. *Journal of Wind Engineering and Industrial Aerodynamics*, **99**, 217–25



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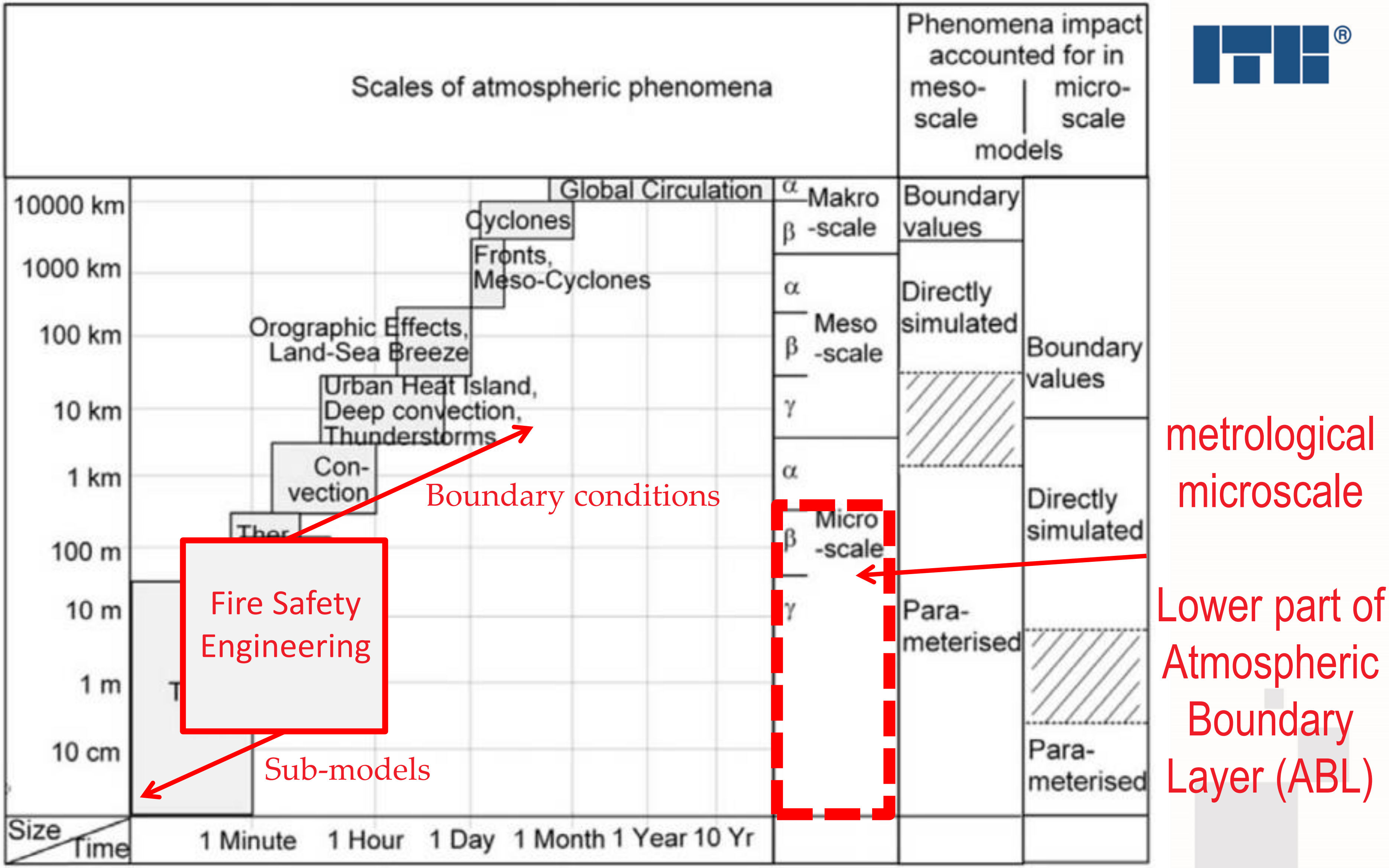

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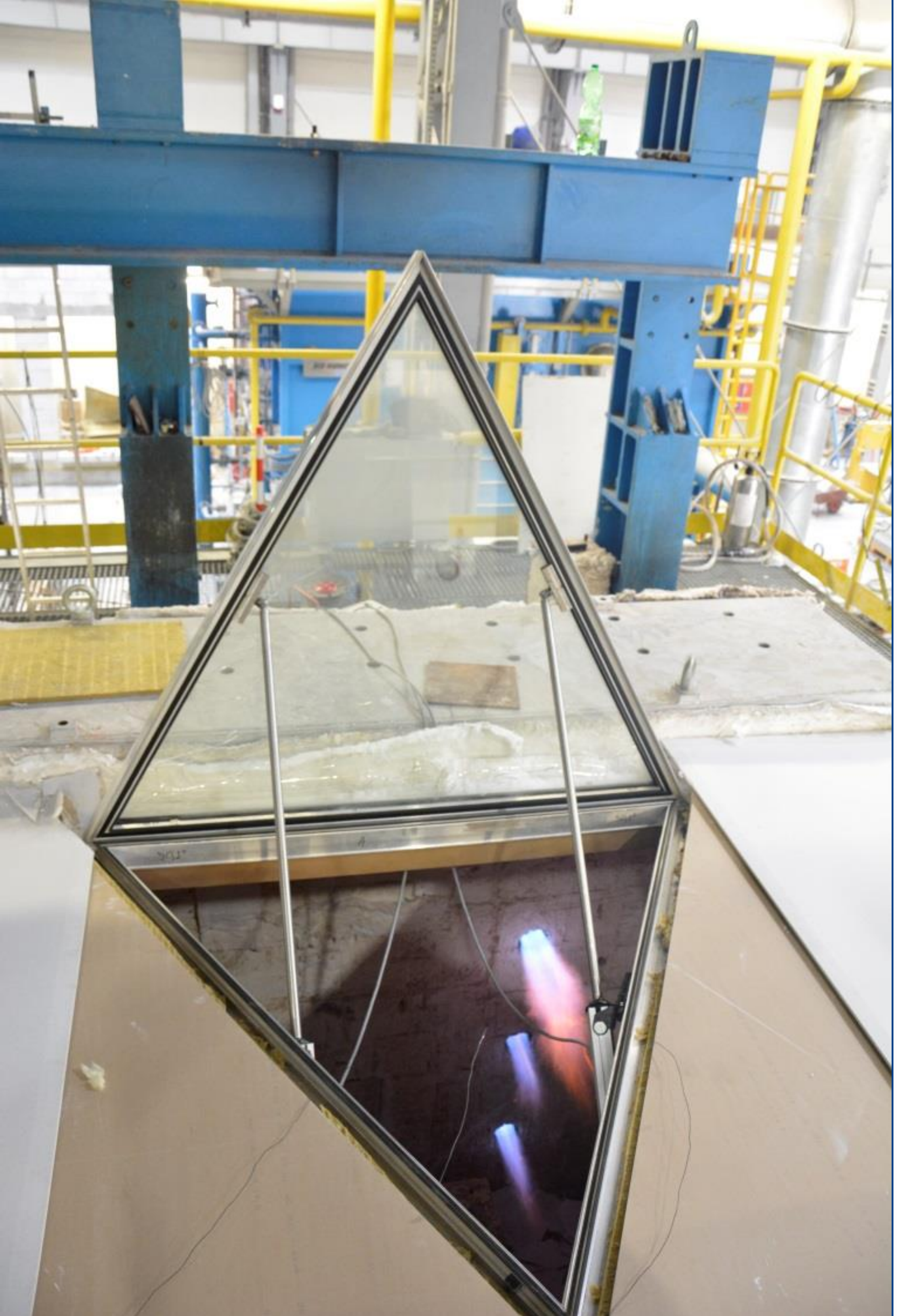


Natural Smoke and Heat Ventilation Systems

EN TR 12101-5

$$A_{vtot}C_v = \frac{M_l T_l}{[2\rho_{amb}^2 g d_l \theta_l T_{amb} - \frac{M_l^2 T_l T_{amb}}{(A_i C_i)^2}]^{\frac{1}{2}}}$$

VDI 6019-1

$$A_{vtot} = \frac{\dot{V}}{\bar{c}_{v0}} \sqrt{\frac{T_{amb}}{2g\Theta d - \frac{1}{\bar{c}_{v0,in}^2} w_i^2 T_l}}$$

NFPA 204

$$\dot{m}_v = \frac{C_{d,v} A_v}{\sqrt{1 + \frac{C_{d,v}^2 A_v^2}{C_{d,i}^2 A_i^2}\left(\frac{T_o}{T}\right)}} \sqrt{\left(2\rho_o^2 g d\right)} \sqrt{\frac{T_o\left(T - T_o\right)}{T^2}}$$

EN TR 12101-5

$$A_{vtot}C_v = \frac{M_l T_l}{\left[2\rho_{amb}^2 g d_l \theta_l T_{amb} - \frac{M_l^2 T_l T_{amb}}{(A_i C_i)^2}\right]^{\frac{1}{2}}}$$

VDI 6019-1

$$A_{vtot} = \frac{\dot{V}}{\bar{c}_{v0}} \sqrt{\frac{T_{amb}}{2g\Theta d - \frac{1}{\bar{c}_{v0,in}^2} w_i^2 T_l}}$$

NFPA 204

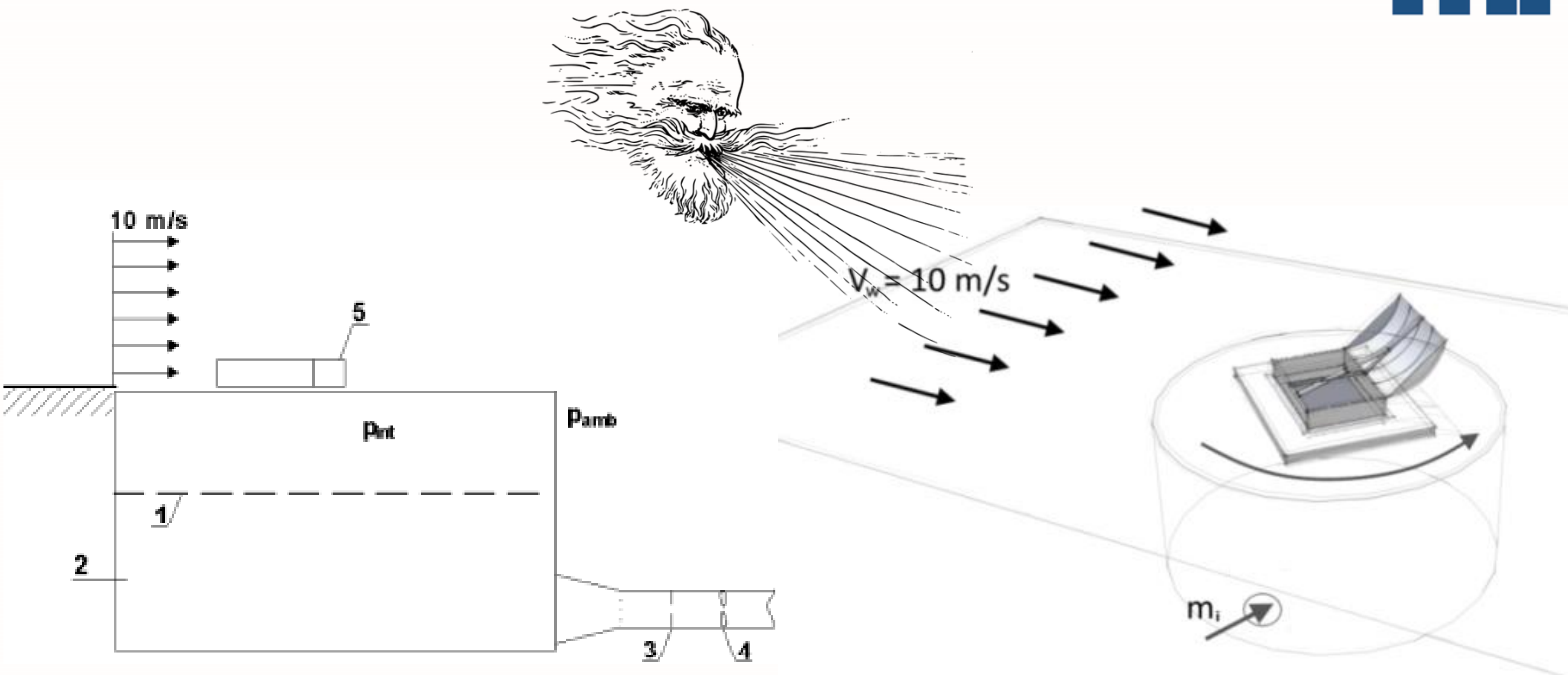
$$\dot{m}_v = \frac{C_{d,v} A_v}{\sqrt{1 + \frac{C_{d,v}^2 A_v^2}{C_{d,i}^2 A_i^2}\left(\frac{T_o}{T}\right)}} \sqrt{\left(2\rho_o^2 g d\right)} \sqrt{\frac{T_o\left(T - T_o\right)}{T^2}}$$

discharge coefficient

C_v

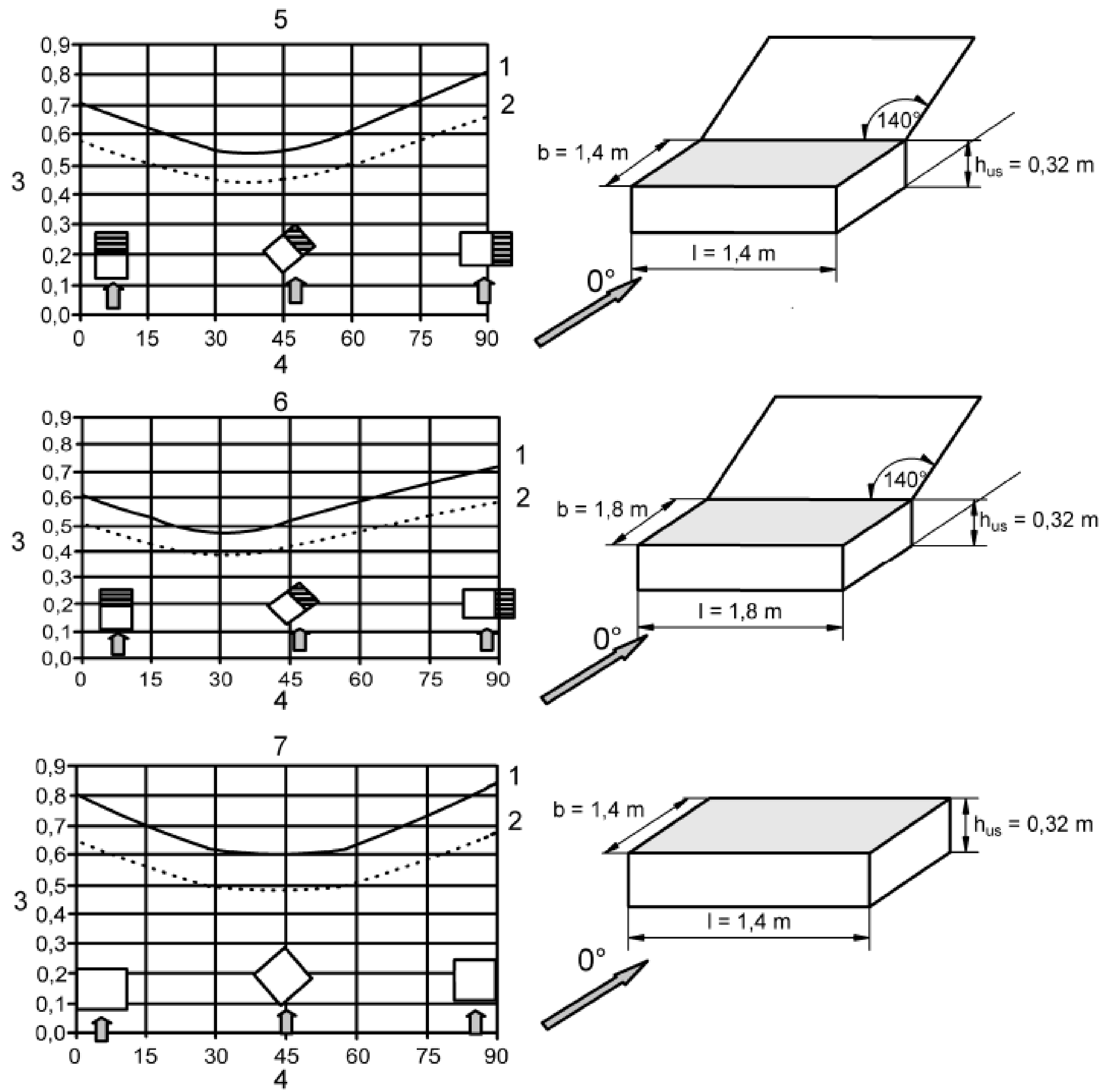
The discharge coefficient C_v provided by manufacturers is not exactly same thing, as opening coefficients described in pioneering work of Prahl & Emmons (1975) and further in FSE related literature

Prahl, J. and Emmons, H.W. (1975) Fire induced flow through an opening. Combustion and Flame, 25, 369–85. https://doi.org/10.1016/0010-2180(75)90109-1



$$C_V = \frac{\dot{m}_i}{A_{v,test}\sqrt{2\rho_{air}\Delta p_{\text{int}}}}$$

EN 12101-2 Smoke and heat control systems. Specification for natural smoke and heat exhaust ventilators.



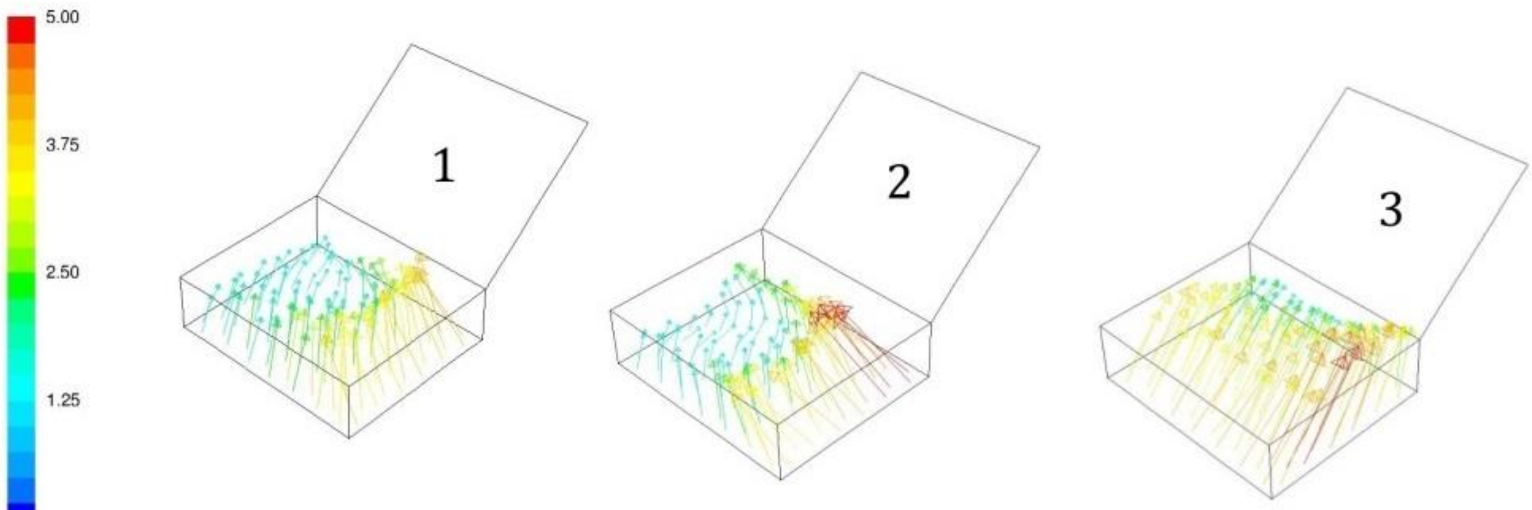
FprEN 12101-2 (2015) Smoke and heat control systems. Specification for natural smoke and heat exhaust ventilators.

Problems with this approach:

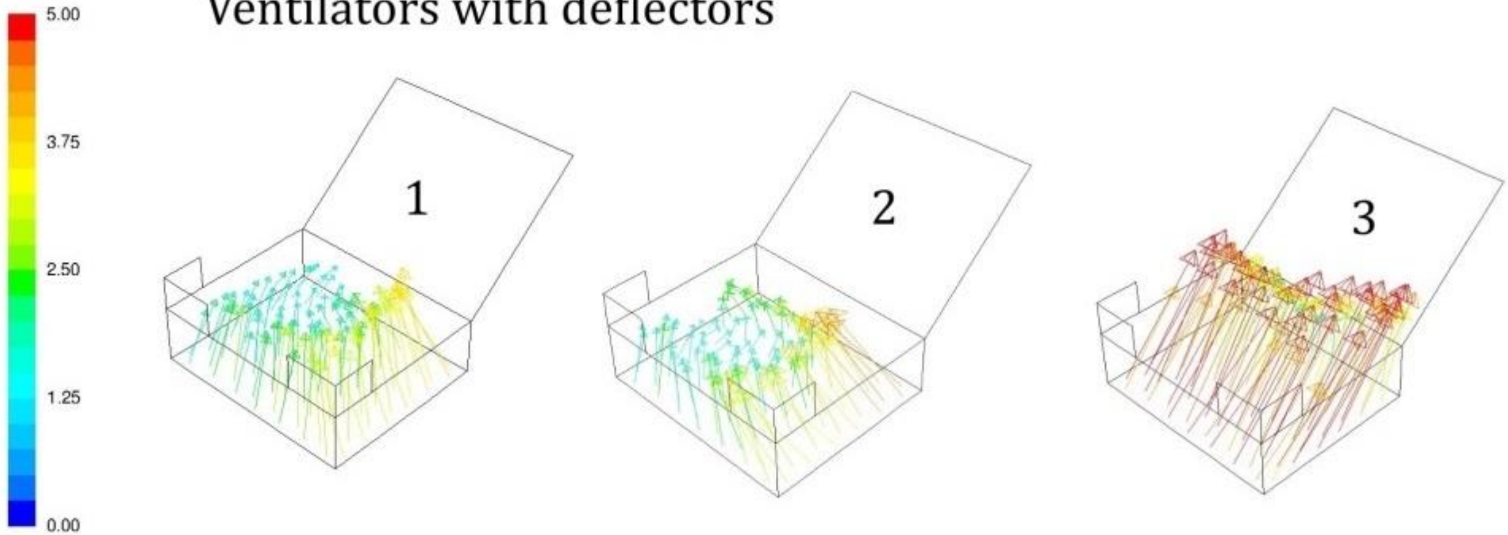
- manufacturers are generally very good at maximizing the C_v for the purpose of test…
- one, arbitrarily chosen wind velocity (10 m/s)
- small range of pressure difference values assessed
- it is a parameter of a single device and not a system

EN 12101-2 Smoke and heat control systems. Specification for natural smoke and heat exhaust ventilators.

Ventilators without deflectors



Ventilators with deflectors



Węgrzyński, W. and Krajewski, G. Influence of wind on natural smoke and heat exhaust system performance in fire conditions (in press). *Journal of Wind Engineering and Industrial Aerodynamics*

How to make a ~~good~~ not completely terrible coupled CWE/FSE analysis?

Blocken, B. (2014) 50 years of Computational Wind Engineering: Past, present and future. *Journal of Wind Engineering and Industrial Aerodynamics*, 129, 69–102.

Blocken, B. (2015) Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. *Building and Environment*, Elsevier Ltd. 91, 219–45

Blocken, B., Stathopoulos, T. and van Beeck, J.P.A.J. (2016) Pedestrian-level wind conditions around buildings: Review of wind-tunnel and CFD techniques and their accuracy for wind comfort assessment. *Building and Environment*, Elsevier Ltd. 100, 50–81.

Franke, J. Introduction to the Prediction of Wind Loads on Buildings by Computational Wind Engineering (CWE). Wind Effects on Buildings and Design of Wind-Sensitive Structures, Springer Vienna, Vienna. p. 67–103.

Franke, J., Hellsten, A., Schlünzen, H. and Carissimo, B. (2007) *Best practice guideline for the CFD simulation of flows in the urban environment*. COST Office Brussels

Murakami, S. (1998) Overview of turbulence models applied in CWE–1997. *Journal of Wind Engineering and Industrial Aerodynamics*, 74–76, 1–24.

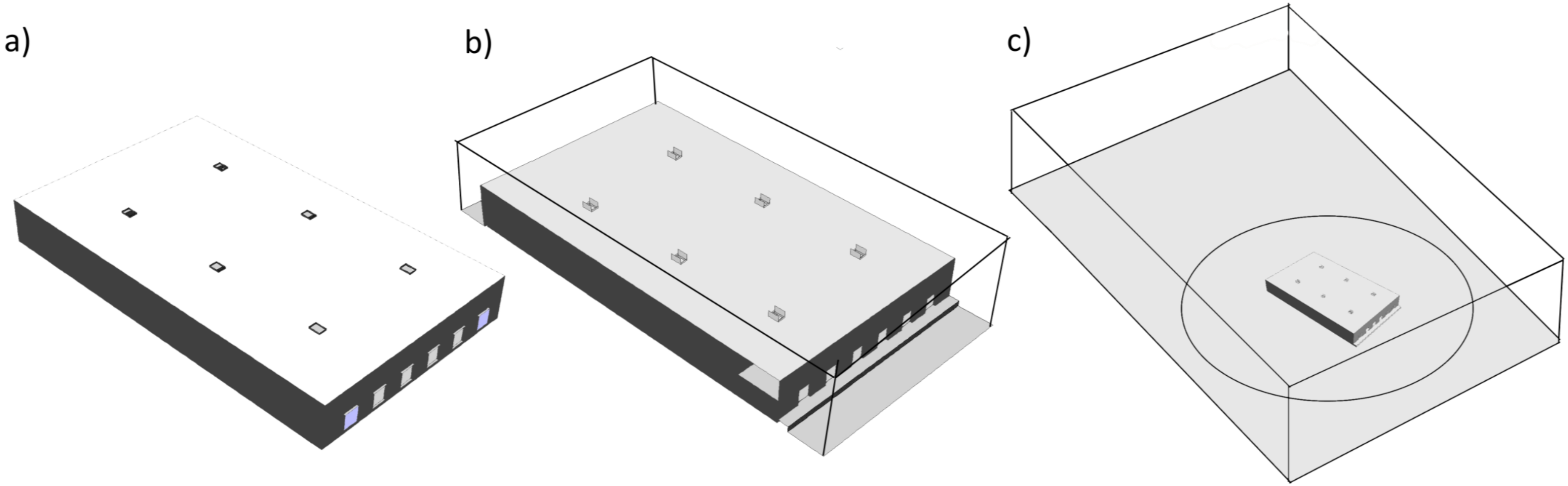
Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M. et al. (2008) AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. *Journal of Wind Engineering and Industrial Aerodynamics*, 96, 1749–61.

Among the key elements for a CWE study, are:

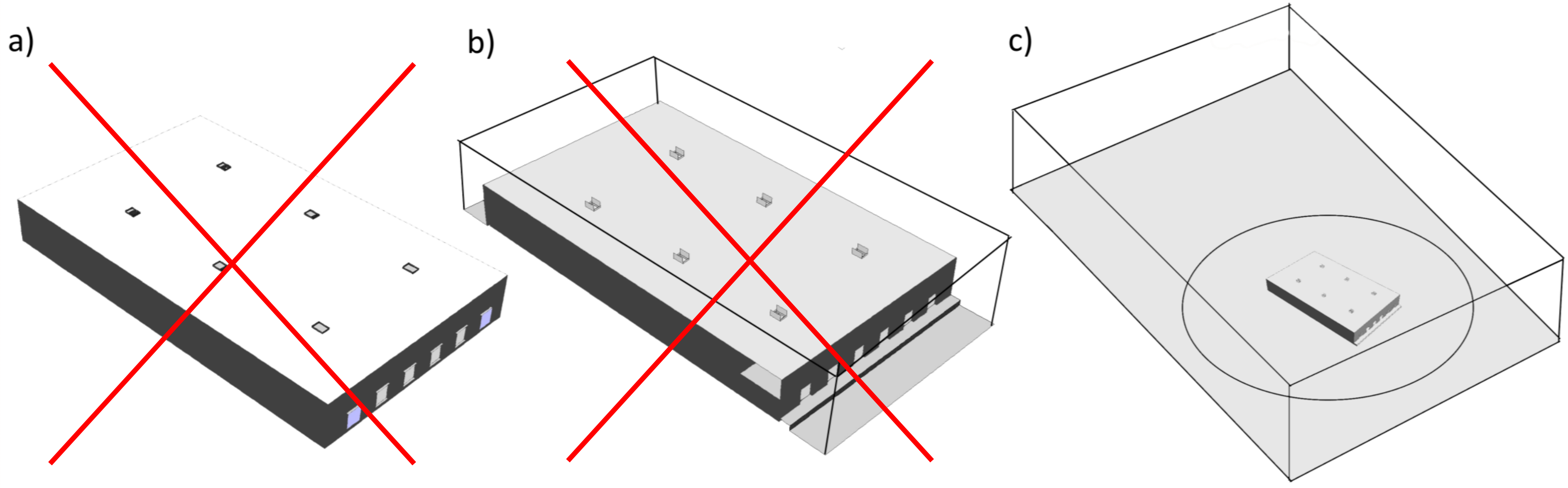
- ✓ Size of the domain, level of details of the model
- ✓ Blockage ratio, boundary conditions
- ✓ Wind profile, terrain roughness
- ✓ Time discretization method, numerical schemes, convergence criteria
- ✓ Tubulence modelling

and many others covered in detail in mentioned guidelines...

Three approaches to a numerical domain



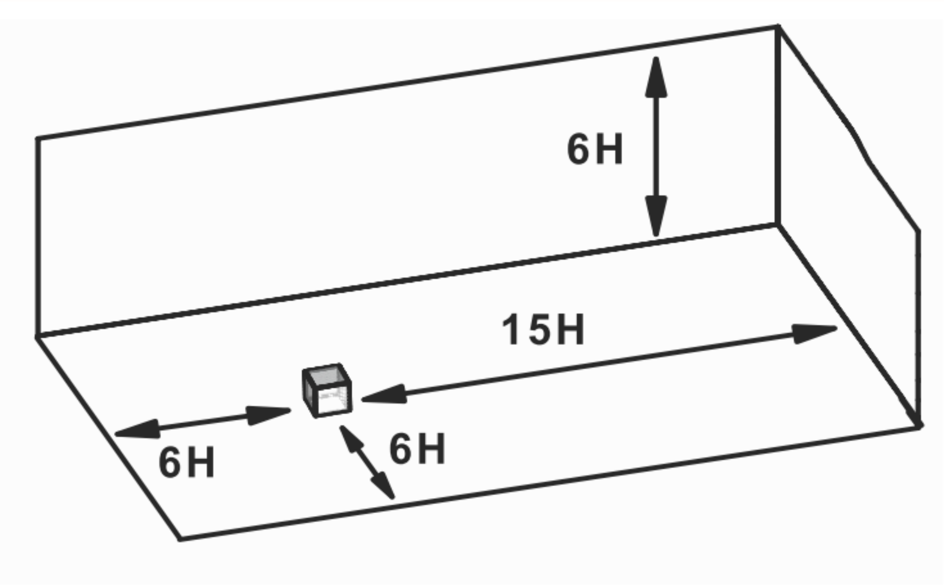
Three approaches to a numerical domain

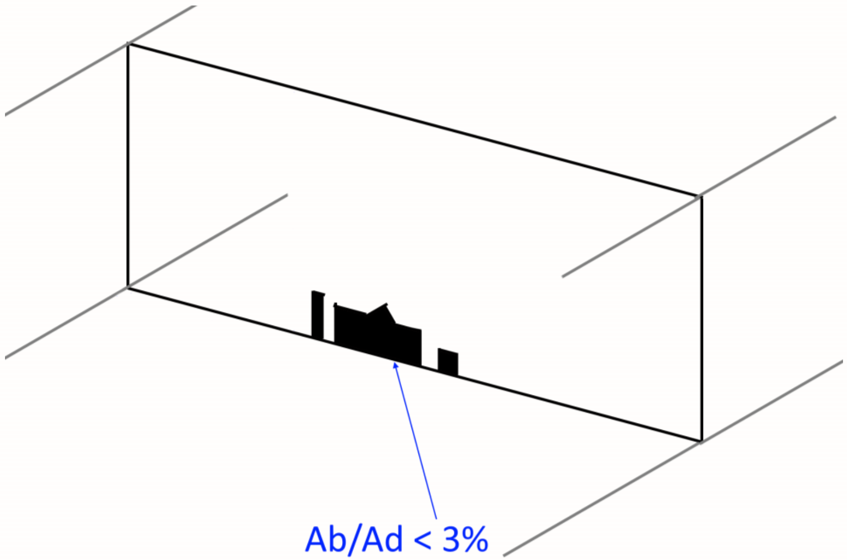


crime

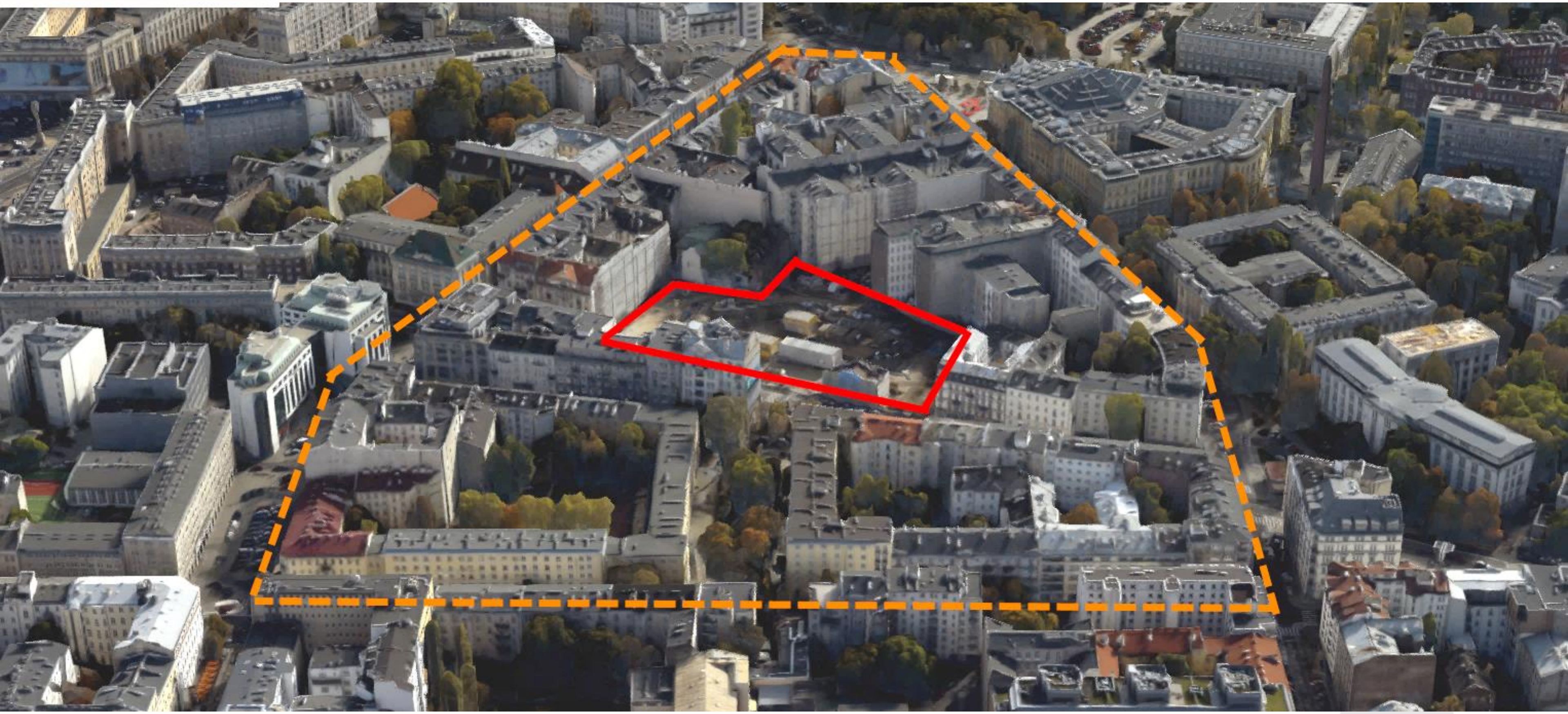
wrong

✓ not completely terrible


6H
15H
6H
6H

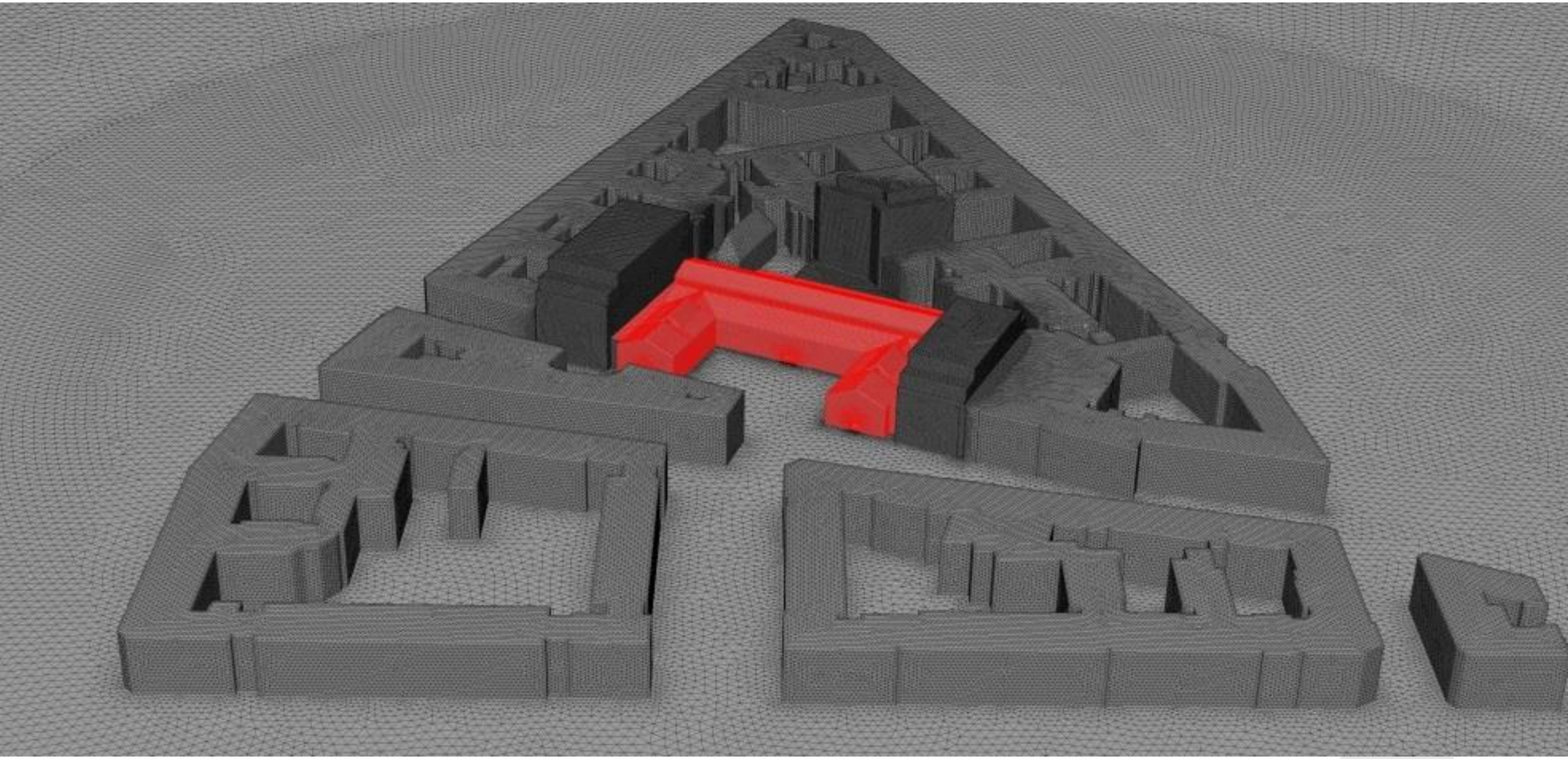

Ab/Ad < 3%

GoBIG...

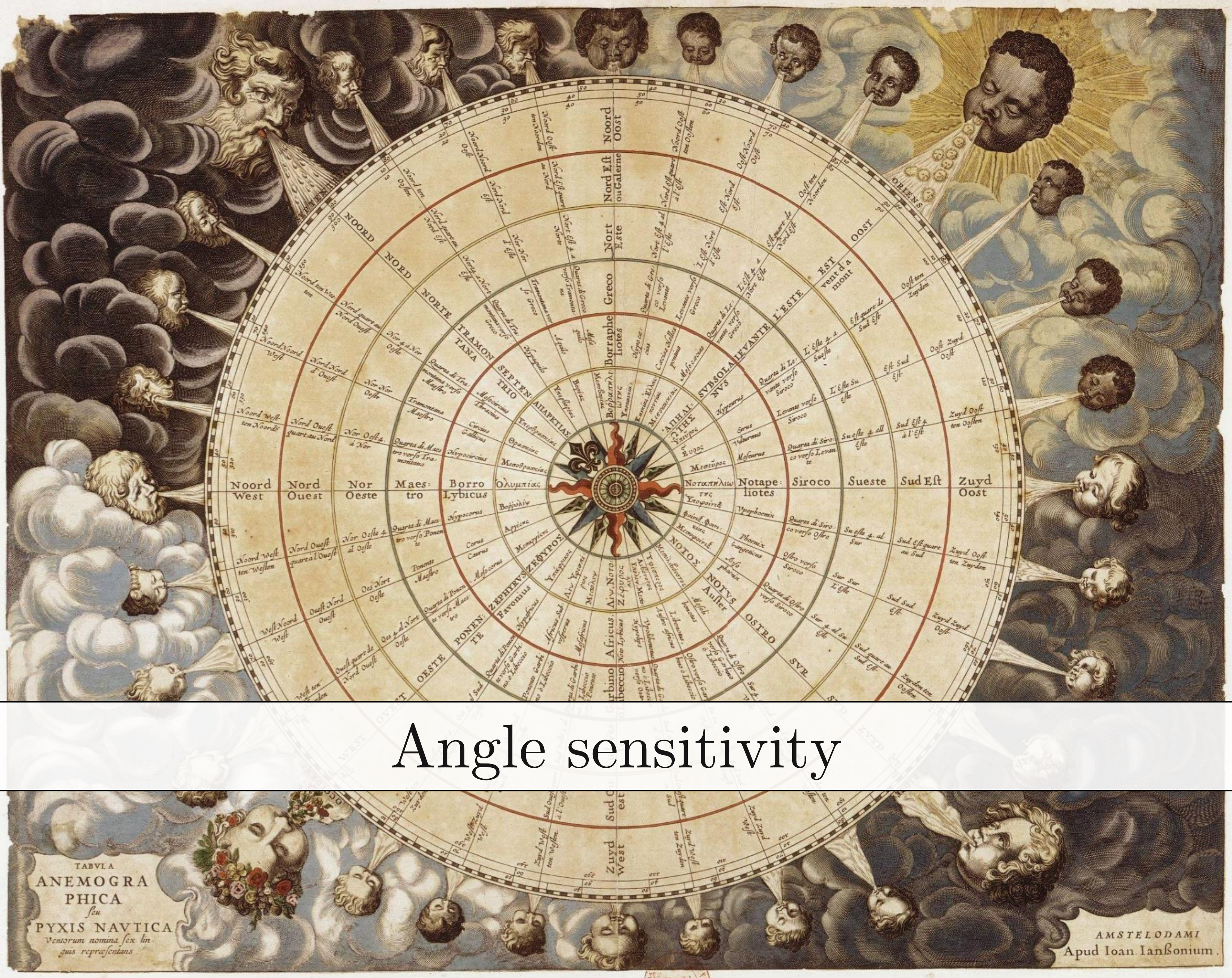


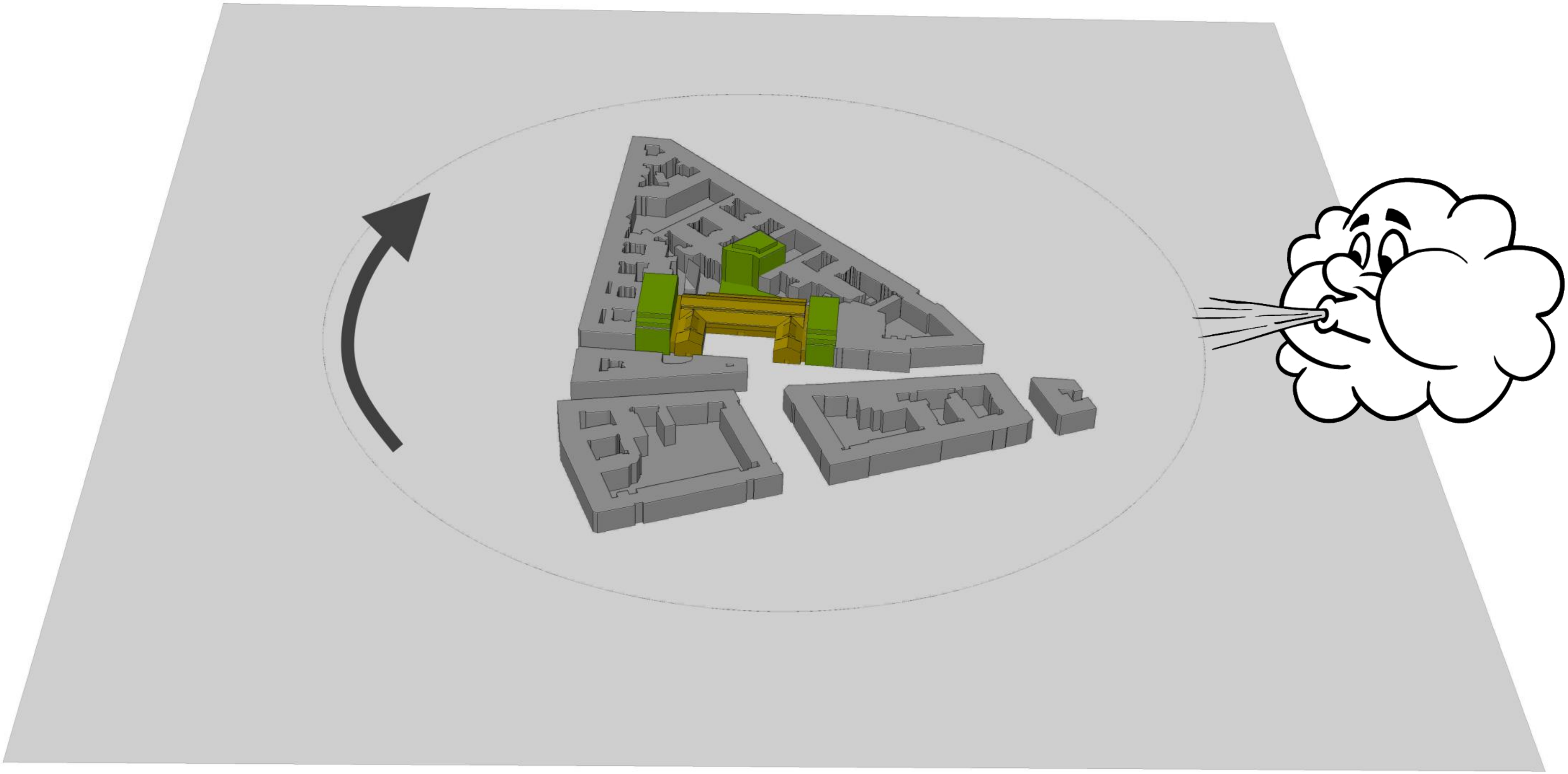
Warsaw, area at Koszykowa St. / Google Maps

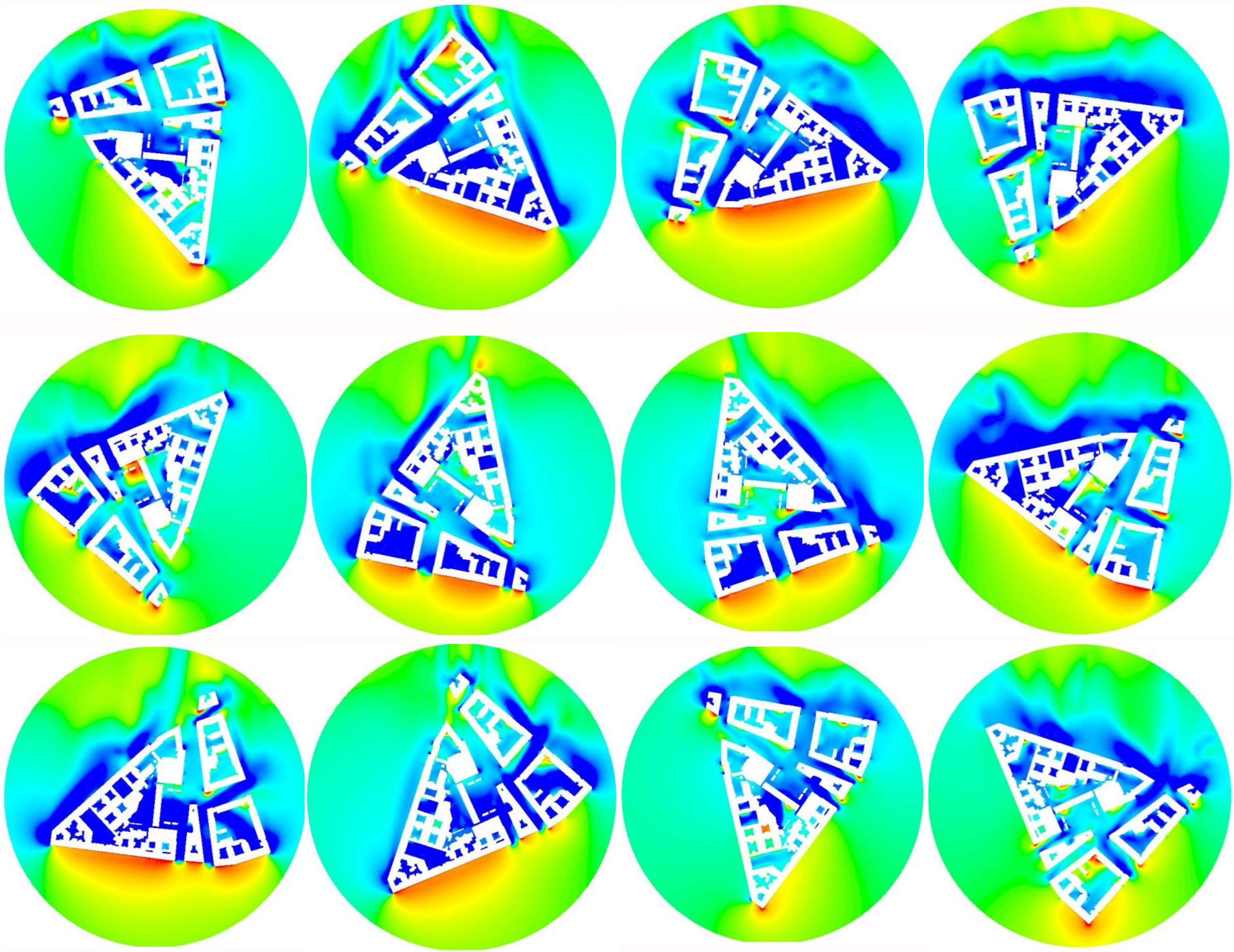
GoBIG...

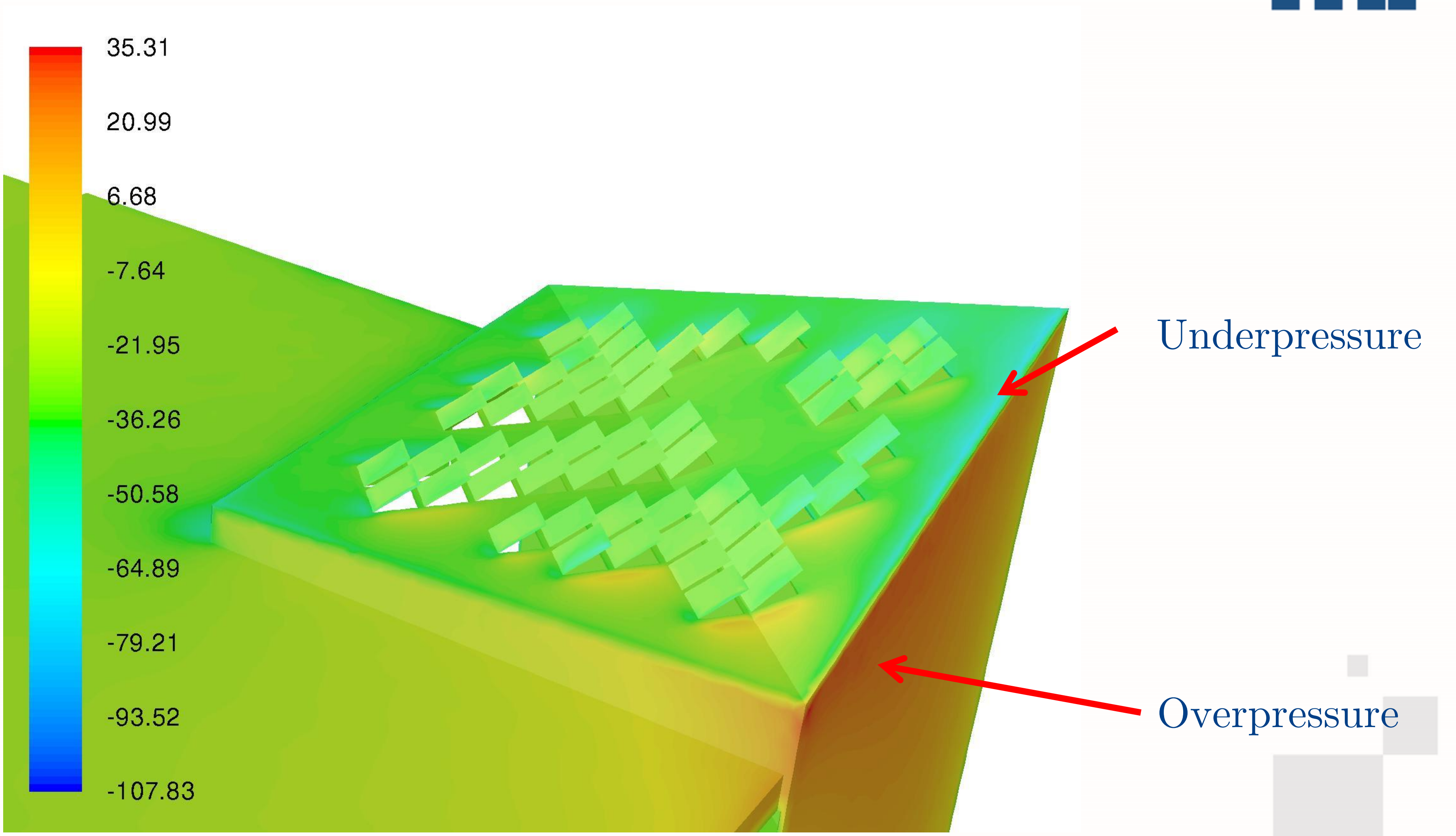


Angle sensitivity



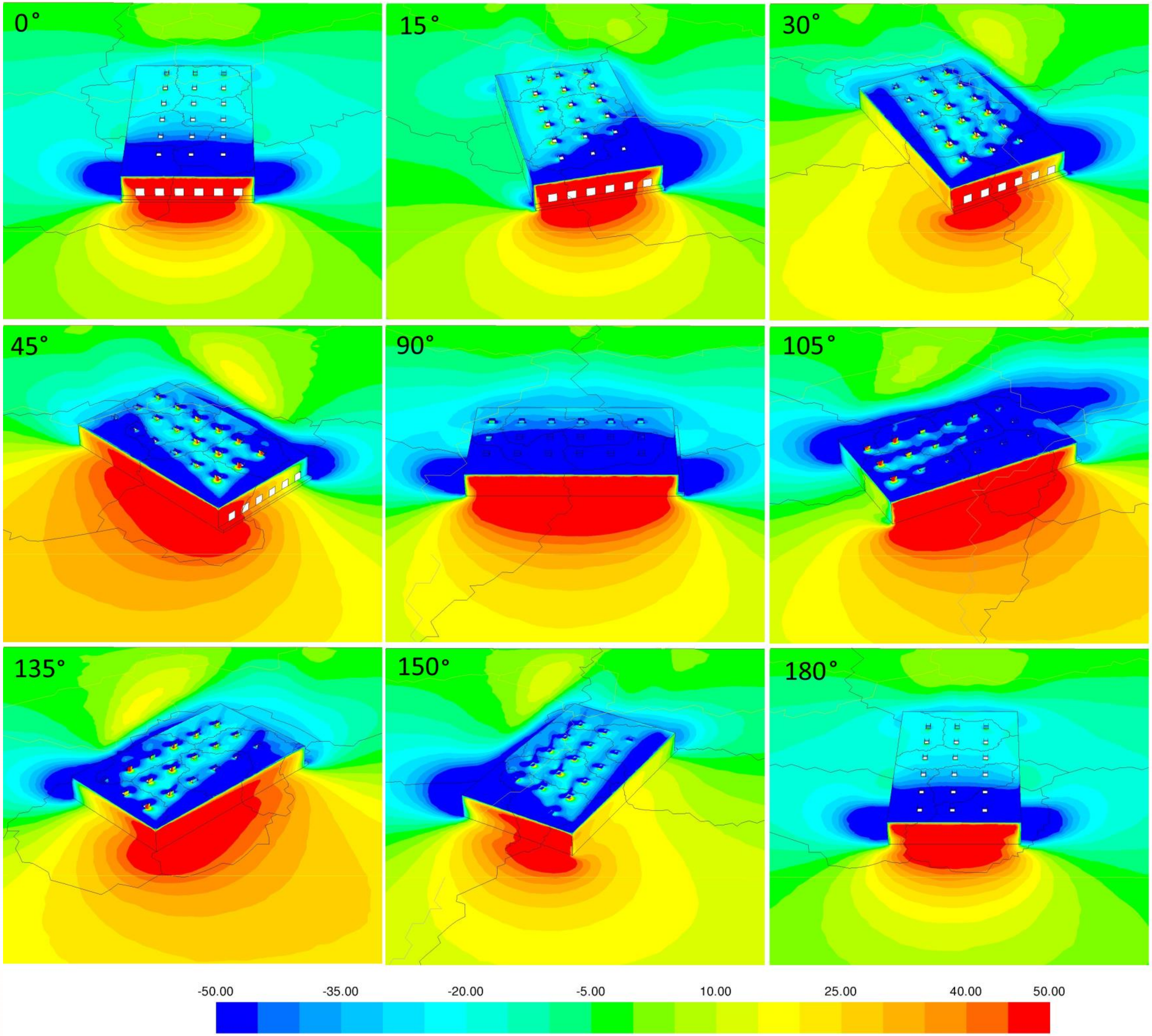





35.31
20.99
6.68
-7.64
-21.95
-36.26
-50.58
-64.89
-79.21
-93.52
-107.83
Underpressure
Overpressure

How to save time and money?
Decouple analsyis into steps:

1. Steady state wind pressure coefficient analysis for at least 12 angles
2. Transient fire analysis only for the worst case scenario(s)
3.
4. Profit


0°
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30°
45°
90°
105°
135°
150°
180°
-50.00
-35.00
-20.00
-5.00
10.00
25.00
40.00
50.00

Angle	Wind velocity u_{ref} [m/s/]	roof mounted smoke ventilators	roof mounted ventilators with deflectors	wall mounted ventilators on back façade	wall mounted ventilators on front façade
-	0 (reference)	33,25	34,6	23,8	-
0	4	30,4	31,8	22,9	8,75
45°	4	27,6	29,1	23,5	11,8
60°	4	25,4	27,1	22,2	13,7
90°	4	29,7	29,7	19,0	18,5
60°	8	18,3	20,8	23,7	

Węgrzyński, W. and Krajewski, G. Influence of wind on natural smoke and heat exhaust system performance in fire conditions (in press). *Journal of Wind Engineering and Industrial Aerodynamics*

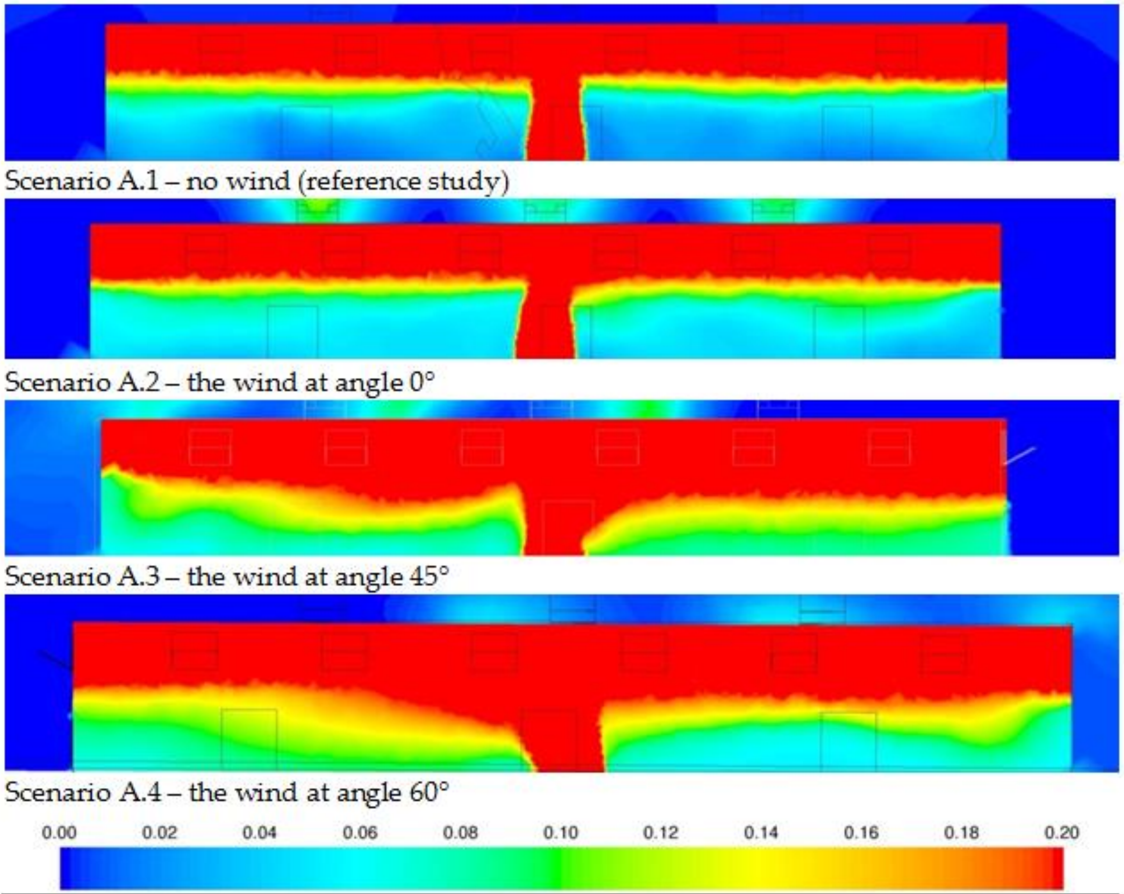
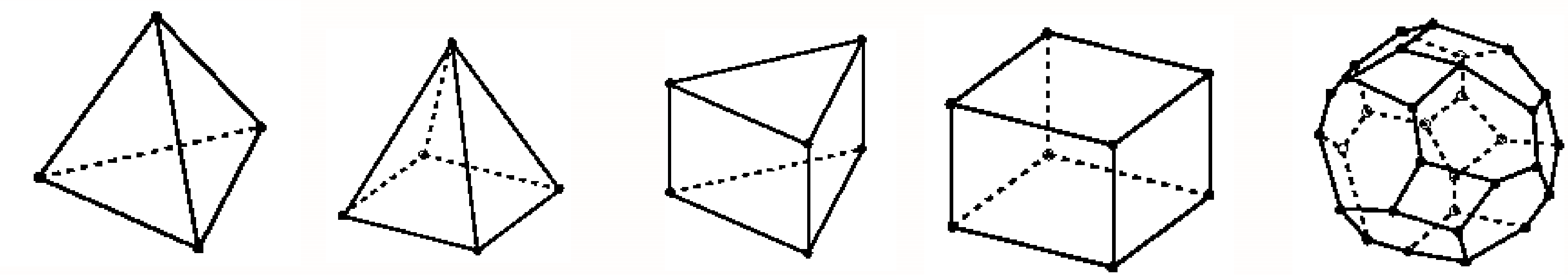


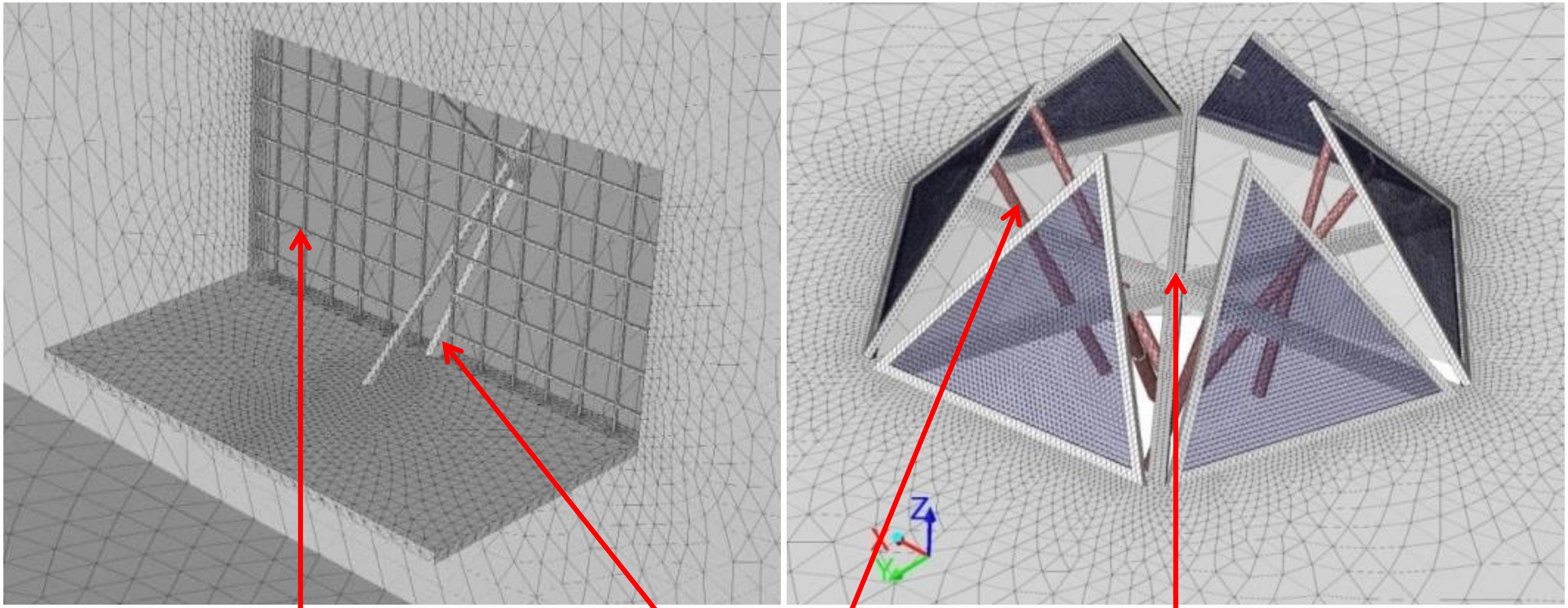
Figure 3. Comparison of local mass concentration of smoke (0,00 – 0,20 g/m³ and more) in section through the building for various wind angles [34]

Węgrzyński, W. and Krajewski, G. Influence of wind on natural smoke and heat exhaust system performance in fire conditions (in press). *Journal of Wind Engineering and Industrial Aerodynamics*

Space discretization



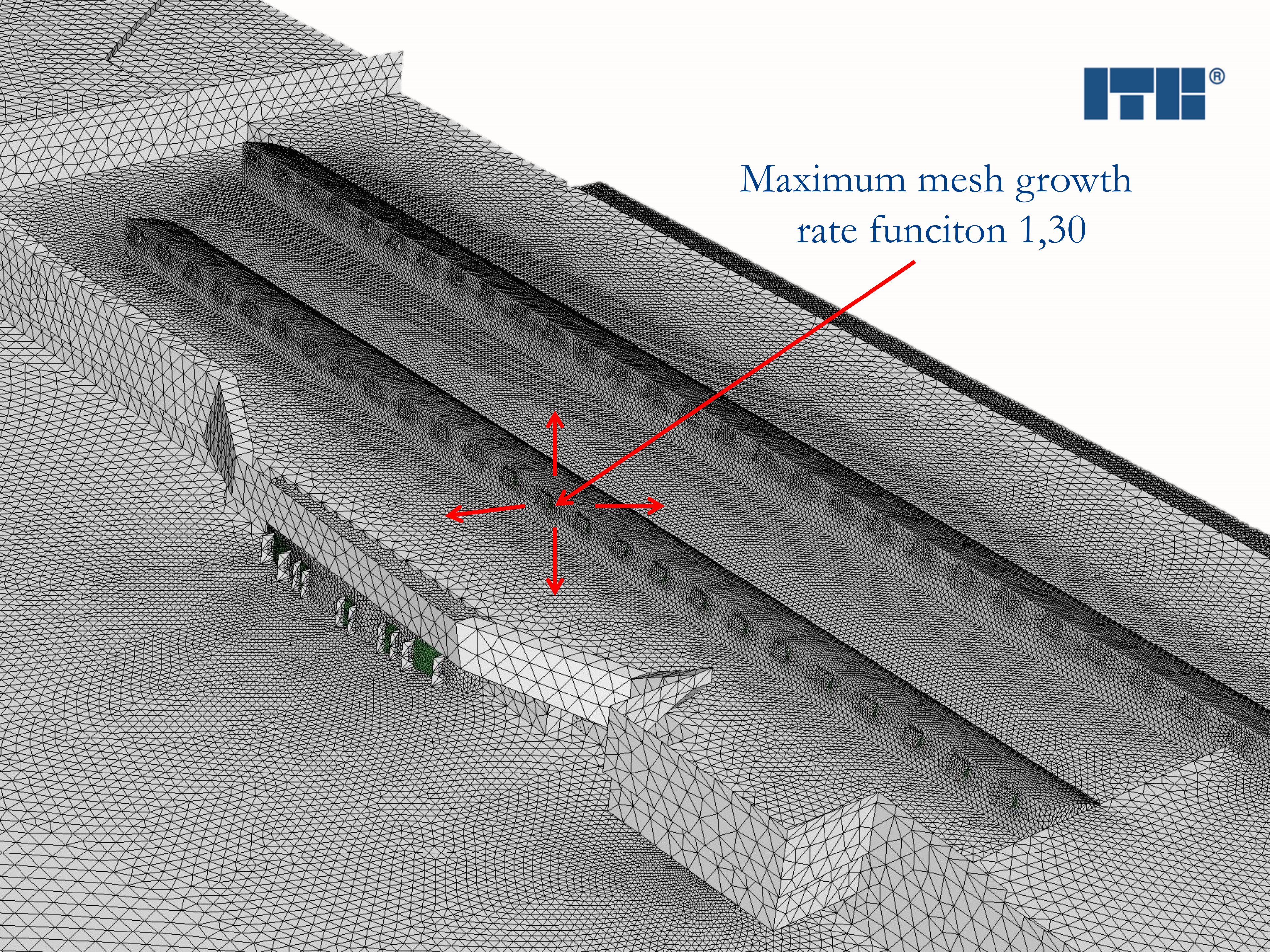
Required level of details



This changed Cv about - 0,02

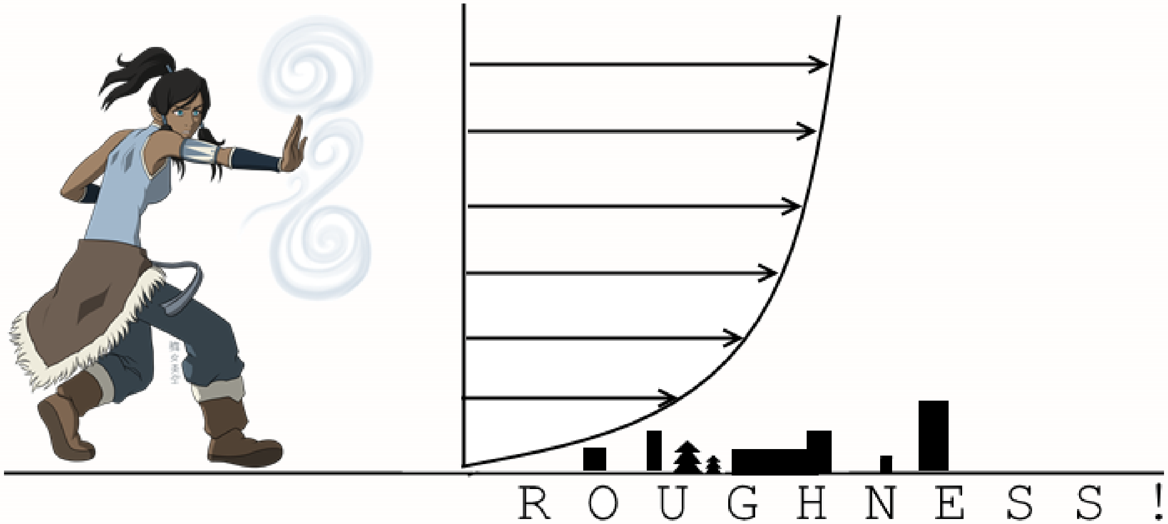
This changed Cv about - 0,02 to – 0,03

This changed Cv more than - 0,03


Maximum mesh growth
rate funciton 1,30

Introducing wind as a boundary condition

Logarithmic wind profile



$$\langle u \rangle(z) = \frac{u_\tau}{\kappa} ln\left(\frac{z + z_0}{z_0}\right)$$

$$k(z) = u_\tau^2 / \sqrt{C_\mu}$$

$$\varepsilon(z) = u_\tau^3 / [\kappa(z + z_0)]$$

Wieringa, J. (1992) Updating the Davenport roughness classification. *Journal of Wind Engineering and Industrial Aerodynamics*, **41**, 357–68

RICHARDS, P.J. and HOXEY, R.P. (1993) Appropriate boundary conditions for computational wind engineering models using the k-ε turbulence model. *Computational Wind Engineering 1*, Elsevier. p. 145–53.

Turbulence modelling

Image by the USGS EROS Data Center Satellite Systems Branch.

http://earthobservatory.nasa.gov/

LES

- better for wind engineering
- captures wake formations, flame pulsation etc.
- allows estimation of peak values

- difficult to prepare a good boundary conditions
- order of magnitude more expensive than RANS

RANS

- fast and robust
- quite well validated (sufficient accuracy for most applications)
- smaller requirements for meshes

- difficult to capture transient phenomena and large separation of flows
- more reliant on sub-models

Detached Eddy Simulation (DES)

- Interesting approach for massively separated flows
- LES for large vortices, RANS for regions close to walls and smaller vortices
- **Lesser computational requirements than LES, high quality results**

Spalart, P.R. (2009) Detached-Eddy Simulation. *Annual Review of Fluid Mechanics*, **41**, 181–202

Conclusions

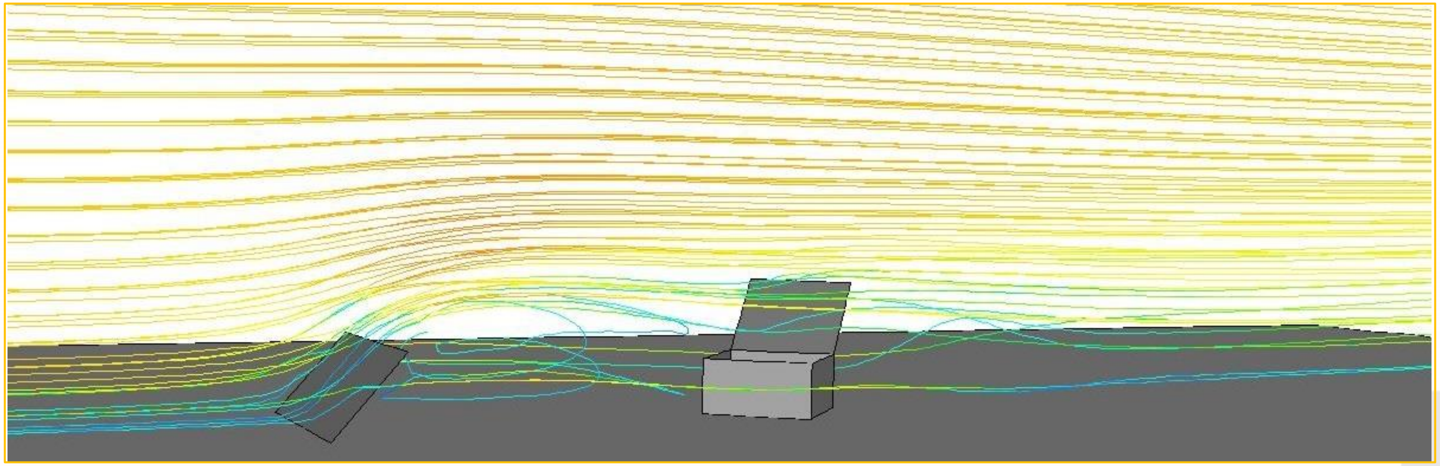
Conclusions

- Whole field of science exists (Computational Wind Engineering) devoted to numerical modeling of wind related phenomena, with more than 50 years of practical experience

- Wind can be introduced into a FSE oriented CFD analysis as an important boundary-condtion

Conclusions

- It is very difficult and computationally consuming to do this right, but it can be done and give a lot of benefit!



External aerodynamic elements to improve NSHEVS performance – research planned for 2017-18

Conclusions

- We are going to work further in this field, hopefully with some full scale results from our own wind tunnel facility!

ITB Variable Turbulence Wind Tunnel (as on 9.11.2016)
To be built in 2017!!!

Thank you!

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