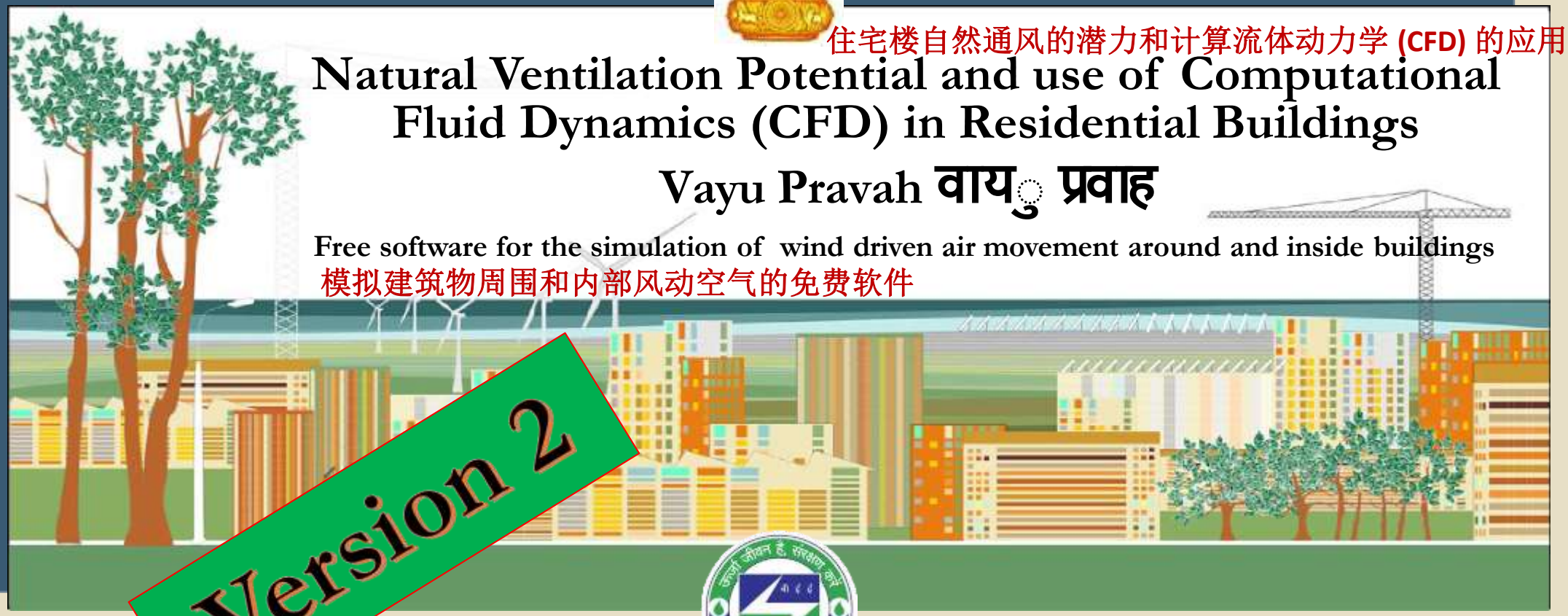
住宅楼自然通风的潜力和计算流体动力学 (CFD) 的应用

Natural Ventilation Potential and use of Computational Fluid Dynamics (CFD) in Residential Buildings

Vayu Pravah वायु प्रवाह

Free software for the simulation of wind driven air movement around and inside buildings

模拟建筑物周围和内部风动空气的免费软件



Version 2

Energy is Life, Conserve it.

Schweizerische Eidgenossenschaft
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Introduction to Vayu Pravah 2.0

Updated version of the freeware CFD developed by BEEP project under Indo-Swiss collaboration between Bureau of Energy Efficiency (BEE), Ministry of Power and the Swiss Agency for Development and Cooperation

Pierre Jaboyedoff, Effinart, Associate

13th of April

Vayu Pravah 2.0 介绍

模拟建筑物周围和内部风动空气的免费软件，由电力部能效局 (BEE) 和瑞士发展与合作机构合作开展，印度-瑞士 BEEP 项目开发的免费 CFD 软件的更新版本

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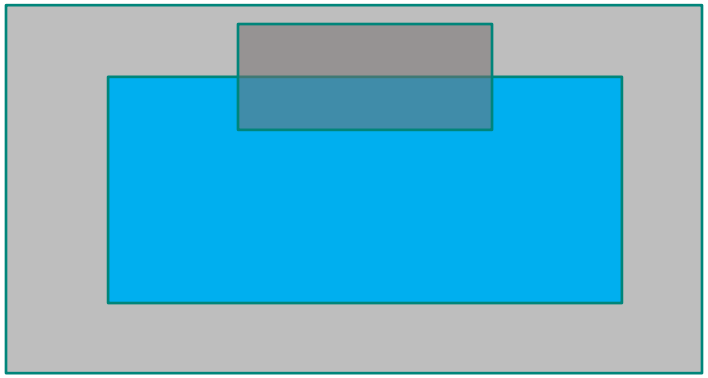
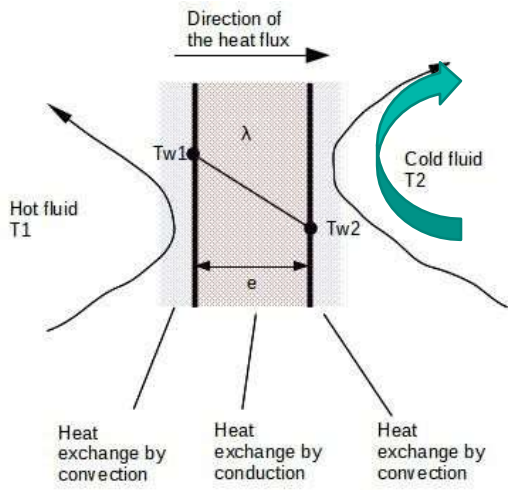
Basic passive design rules for non-AC buildings
非空调建筑的基本被动式设计规则



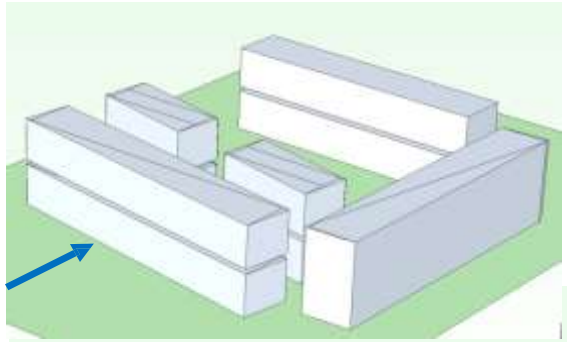
- Reduce heat gains 减少热增益
  - Lower window to wall ratio降低窗墙比
  - External dynamic shading ➔ less solar gains 外部动态遮阳 ➔减少太阳辐射
  - Low conductivity walling低传导性墙体
  - ➔ possible to change the orientation of the building …..可以改变建筑物的朝向
- Improve thermal inertia access改善热惯性通道
  - Generally, in dwellings, the thermal mass is directly exposed to the air flow (Earthquake …) 在住宅中，热质直接暴露在气流中（地震.....）
  - Also mostly heavy like concrete, bricks, etc 混凝土、砖块等重质材料
- Night ventilation cooling夜间通风降温
  - Removes the heat accumulated during the day, (should be more than 10 Air change per hour (ACH)) 清除白天积聚的热量（每小时换气次数应超过 10 次）

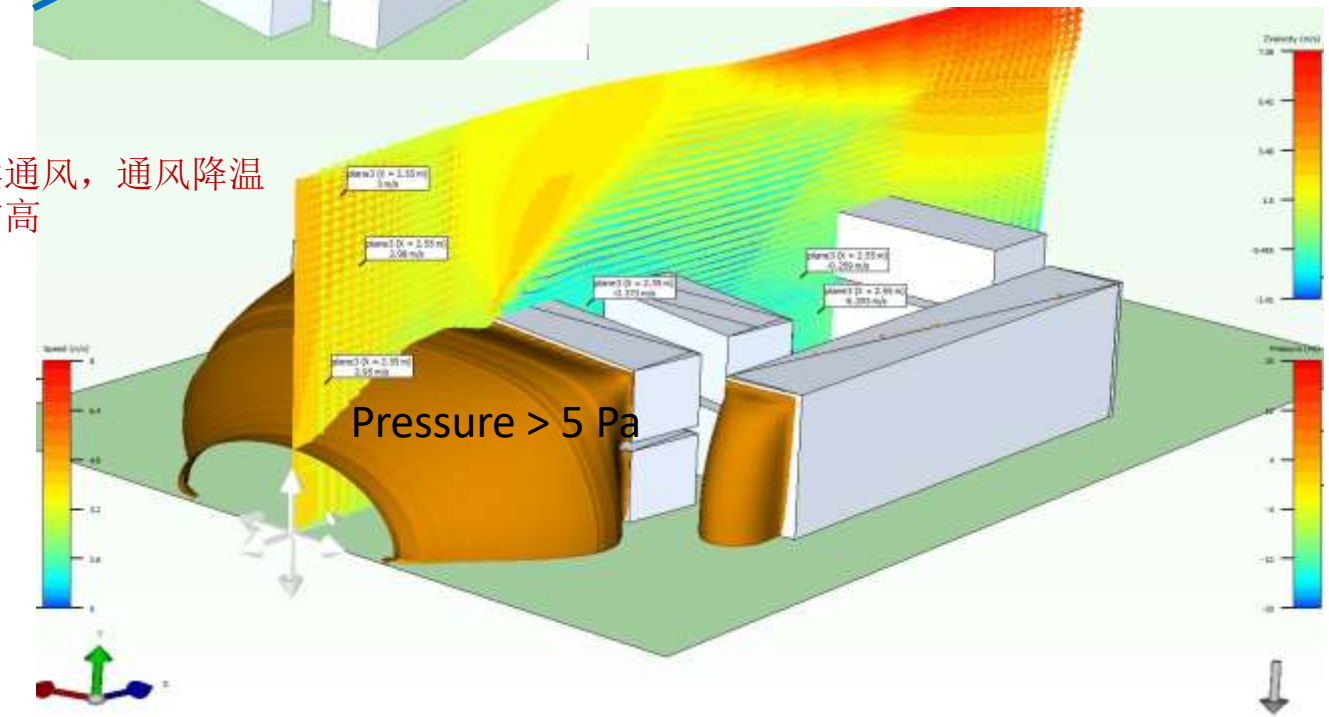


The background behind Vayu Pravah (1)

Vayu Pravah (1) 的背景

- BEEP has been involved in some residential building projects
  BEEP 参与了一些住宅建筑项目
- In India and in other hot climate countries the residential buildings are not equipped with central air conditioning except few high ends cases
  在印度和其他气候炎热的国家，除少数高端住宅外，住宅楼都没有安装中央空调
- Large part off residential dwelling's are not yet equipped or only partly with active cooling systems
  大部分住宅尚未配备或仅部分配备主动冷却系统
- The importance of access to wind for natural night cooling ventilation is very high for all these situations
  进行夜间自然通风，通风降温的重要性非常高
- The wind pattern around buildings in some of the projects we could see that the air velocity was very different in some part of the project
  在项目的某些部分，风速有很大的不同
- Building which had their facade windward were getting good condition for night cross ventilation but they were shielding the building behind with very little wind velocity remaining
  迎风面的建筑物夜间交叉通风条件良好，但它们遮挡了后面的建筑物，剩余风速很小
- It was very difficult to to assist in studying and giving advice without the use of CFD tools
  如果不使用 CFD 工具，就很难协助研究和提供建议





Why the night cross ventilation is important

夜间交叉通风为何重要

- Influence of the Air Change Rate on the convective heat flux from inside surfaces

换气率对来自内表面的对流热通量的影响

- With a Delta_T 0f 4 K ➔ factor 5-6 of heat flux increase from 2 ACH to 13 ACH

Delta_T 0f 4 K → 系数 5-6 的热通量从 2 ACH 增加到 13 ACH

- True for mixing and displacement ventilation pattern

适用于混合通风和置换通风模式

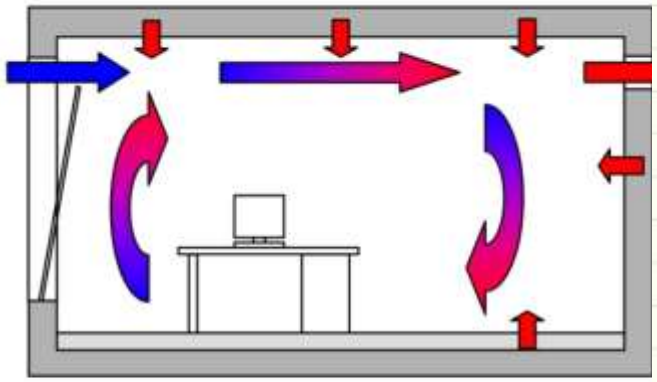


Figure 2. *Basic principle of cooling by night-time ventilation.*

Passive Cooling of buildings by night-time ventilation

Artmann, Nikolai; Manz, Heinrich; Heiselberg, Per

Artmann, N., Manz, H., & Heiselberg, P. (2008). *Passive Cooling of buildings by night-time ventilation*. Schlussbericht. Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation, UVEK.

Bundesamt für Energie BFE.

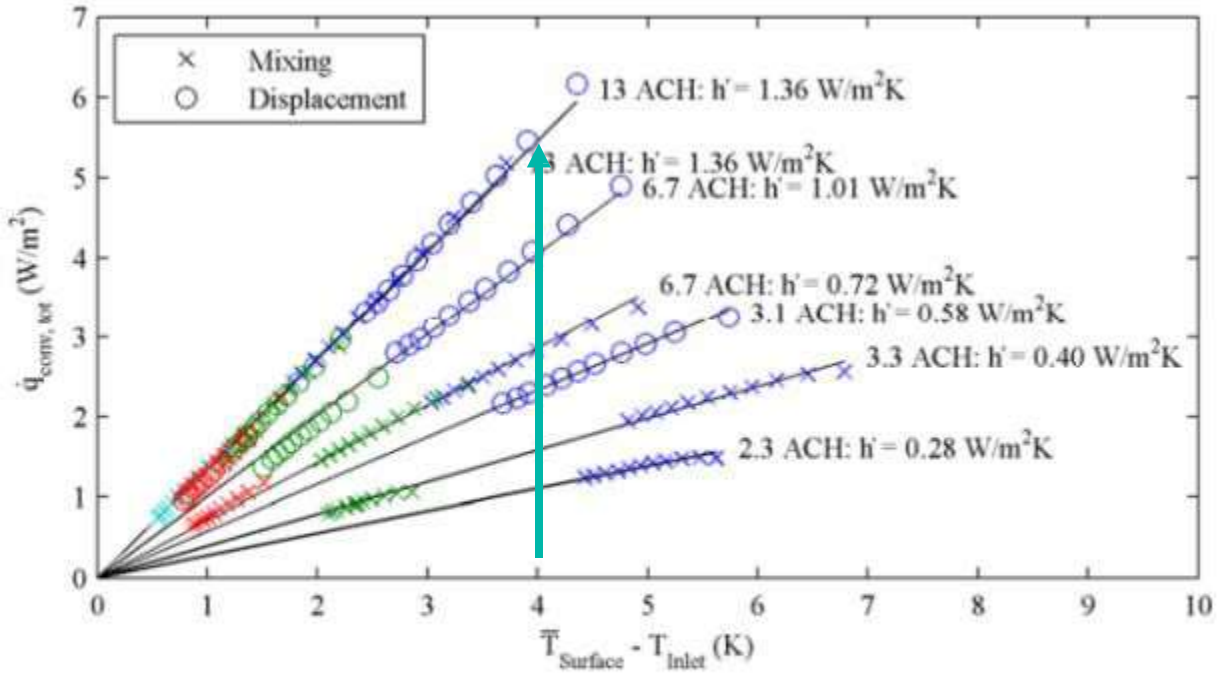


Figure 23. *Mean convective heat flux from all surfaces depending on the difference between the mean surface temperature and the inlet air temperature; hourly values, first hour excluded; different colours relate to different experiments. Uncertainty estimate for* $\dot{Q}_{conv,\,tot}$ *: ± 16 % [73].*

Other more recent study with a mix of experiment and simulations 其他最新的实验与模拟相结合的研究

- Measured influence of controlled ACH on indoor temperature

受控ACH对室内温度影响的测量结果

Energy Reports
Volume 8, November 2022, Pages 8426-8436

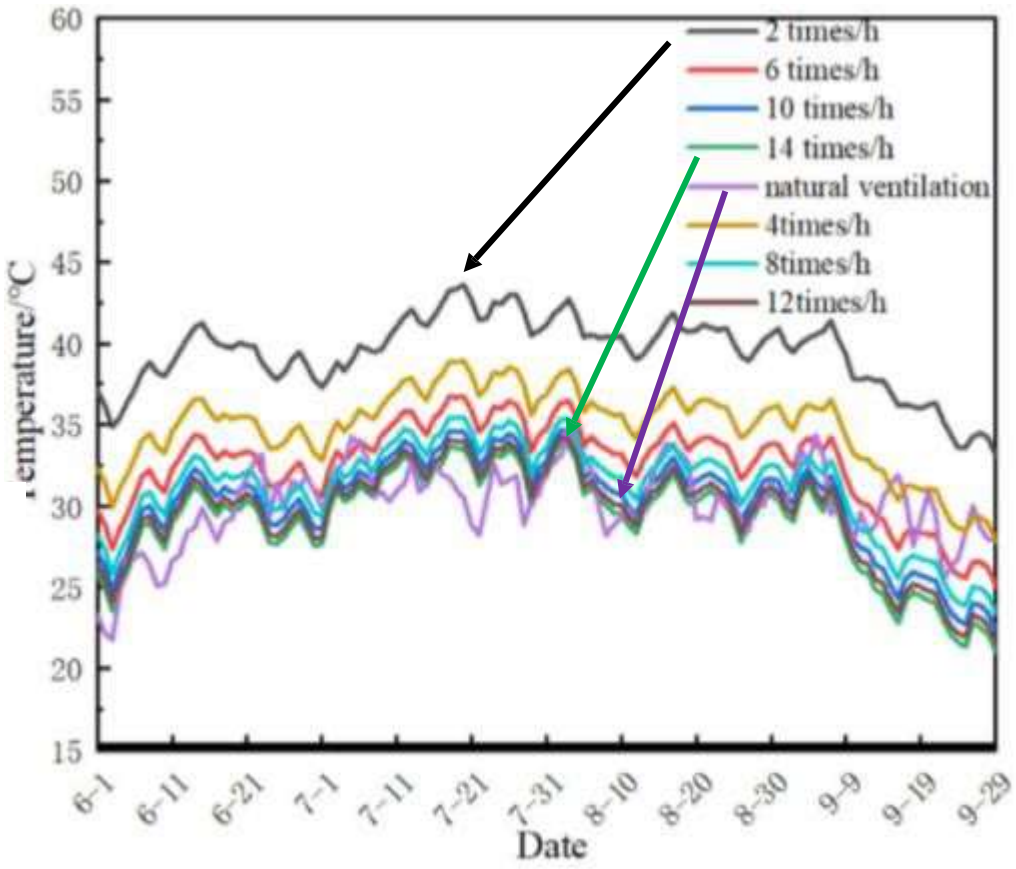
Night ventilation scheme optimization for an Ultra-low energy consumption building in Shenyang, China

Xiao-Xu Li [a,b], Kai-Liang Huang [a,*], Guo-Hui Feng [a], Wan-Yu Li [a], Jia-Xing Wei [a]

[a] School of Municipal and Environmental Engineering, Shenyang Jianzhu University, Shenyang 110168, China
[b] College of Petroleum and Natural Gas Engineering, Liaoning Shihua University, Fushun 113001, China

Table 1
The ventilation simulation scheme.

Ventilation time	Ventilation frequency (times/h)						
21:00–7:00 the next day	2	4	6	8	10	12	14
23:00–7:00 the next day	2	4	6	8	10	12	14
1:00–7:00	2	4	6	8	10	12	14



(a) ventilation time 21:00—next day 7:00

Smart Ghar III example

Smart Ghar III 示例

- BEEP Smart Ghar III charrette results

BEEP Smart Ghar III 结果

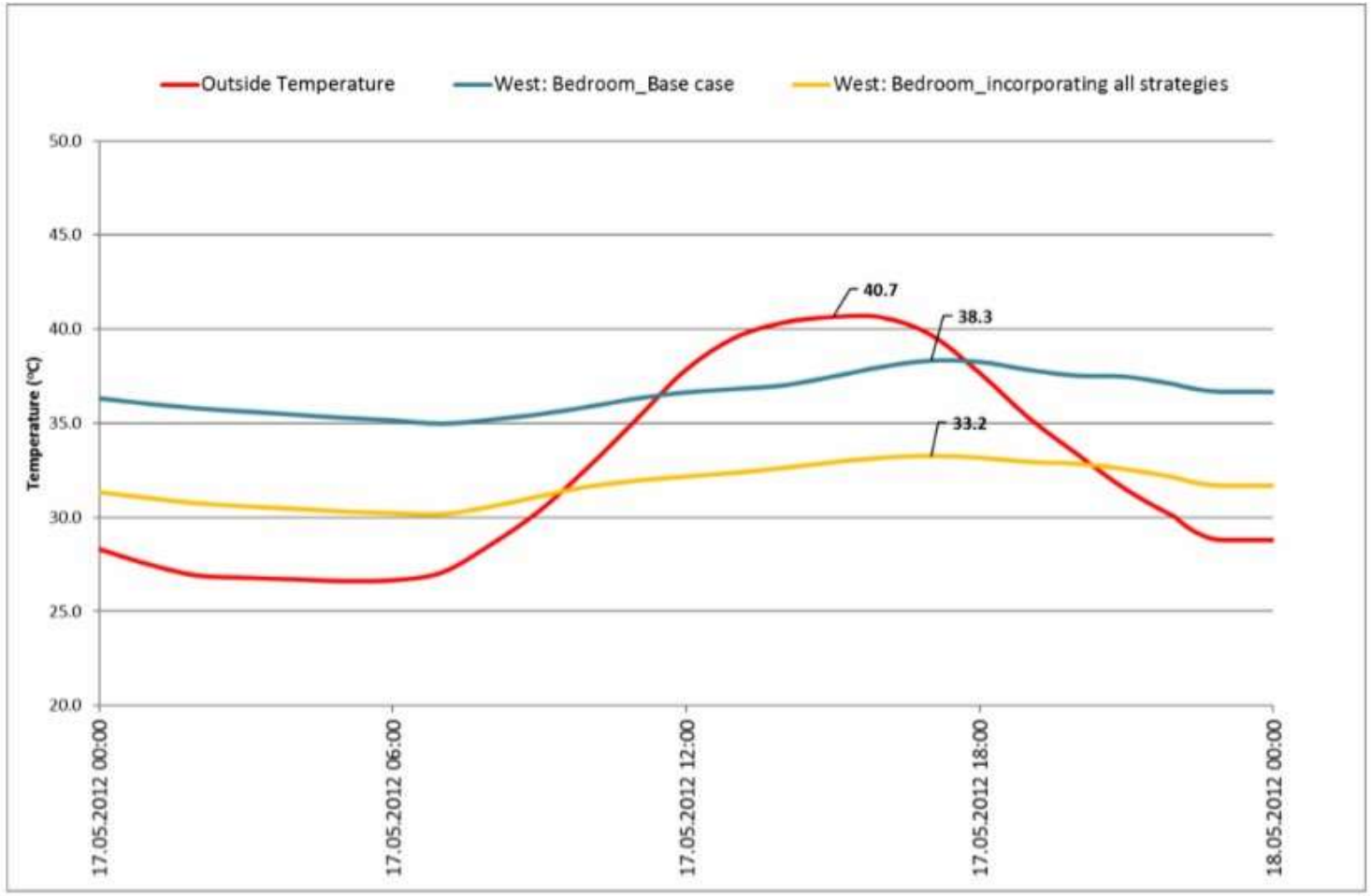


Figure 10: Peak operative temperature of a west-facing bedroom on an intermediate floor in a typical summer day- in the base case and with all strategies (Project 3, Rajkot)

Actual measurements in Smart Ghar III (Rajkot)

Smart Ghar III (Rajkot) 的实际测量结果

- Very high natural air change measured 测得极高的自然换气率
  - CO2 injection 注入二氧化碳
  - Calculation of the Air Change par hour 计算每小时换气量
  - At night ~23 ACH
  - ➔ very good night cooling 夜间 ~ 23 ACH →夜间制冷效果非常好

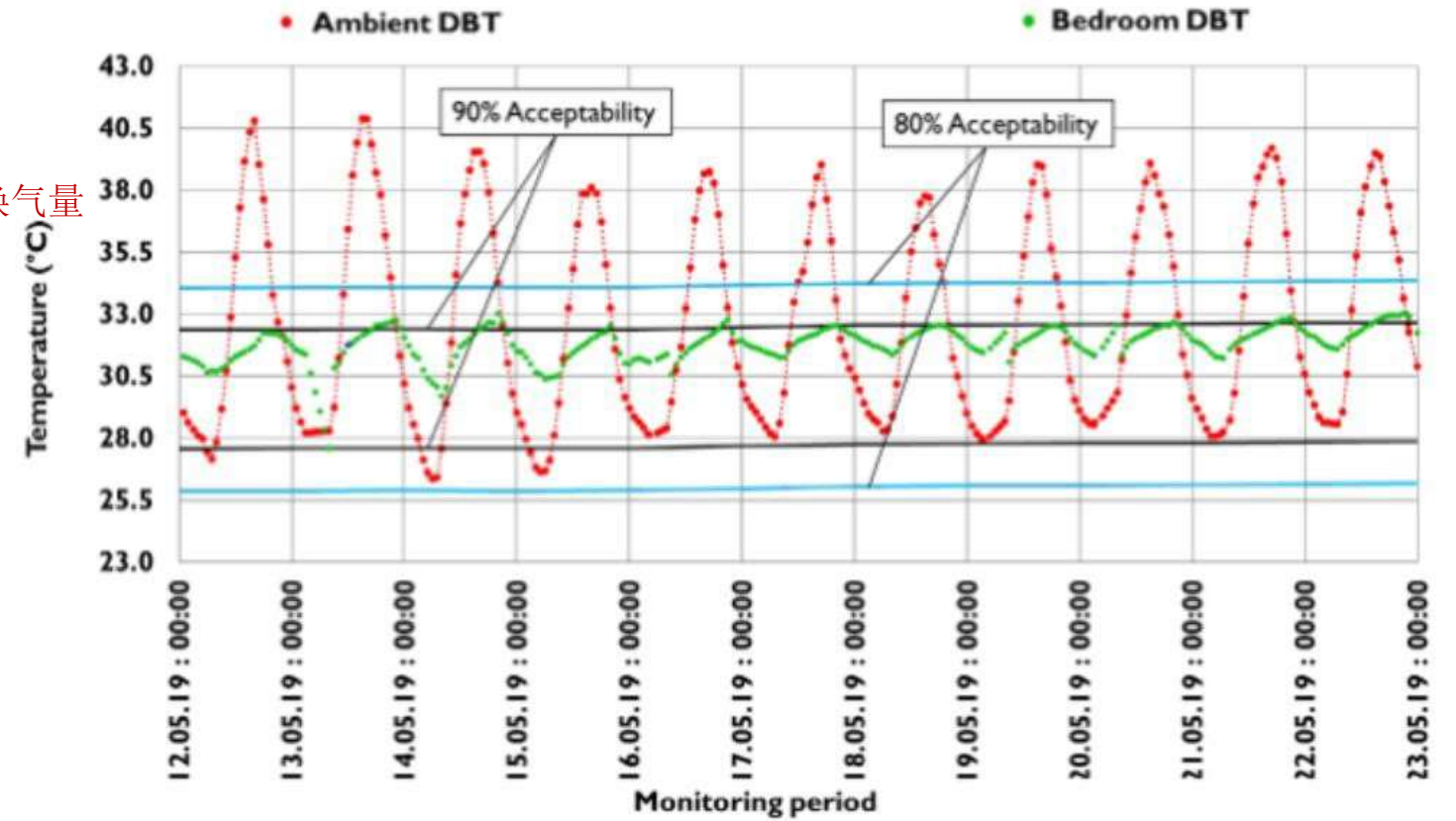


Figure 4: Graph showing monitored ambient temperature and temperatures inside the test flat (bedroom)

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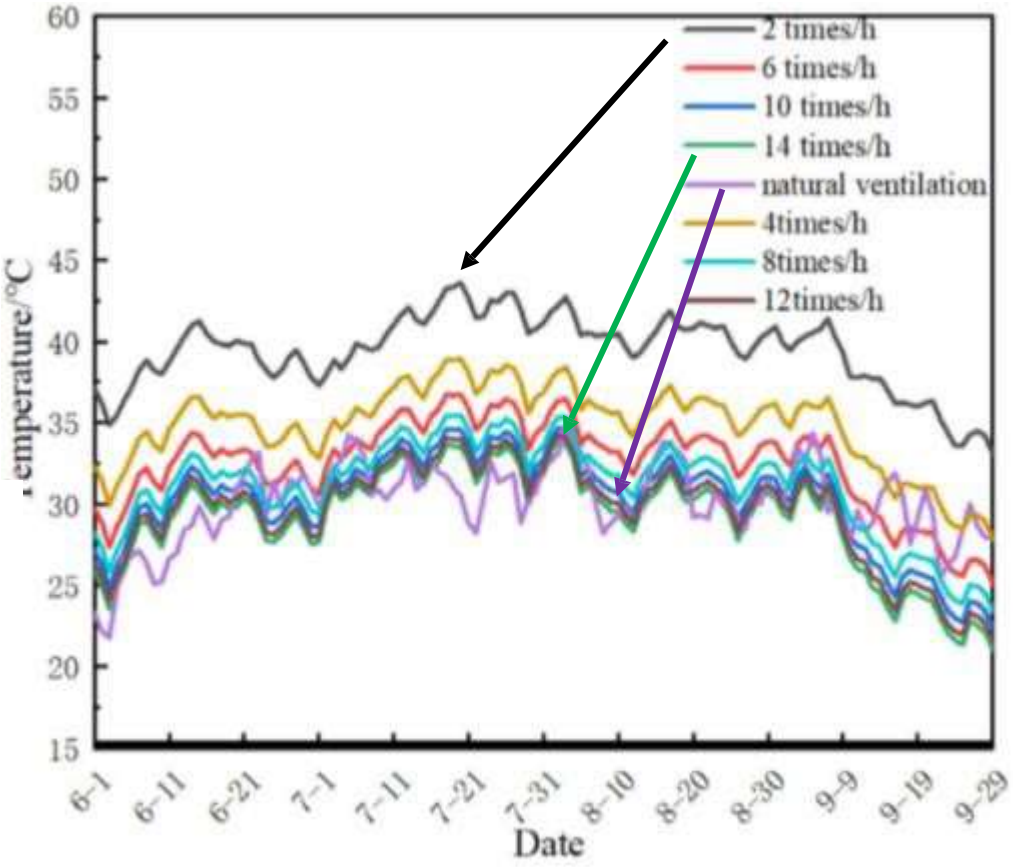
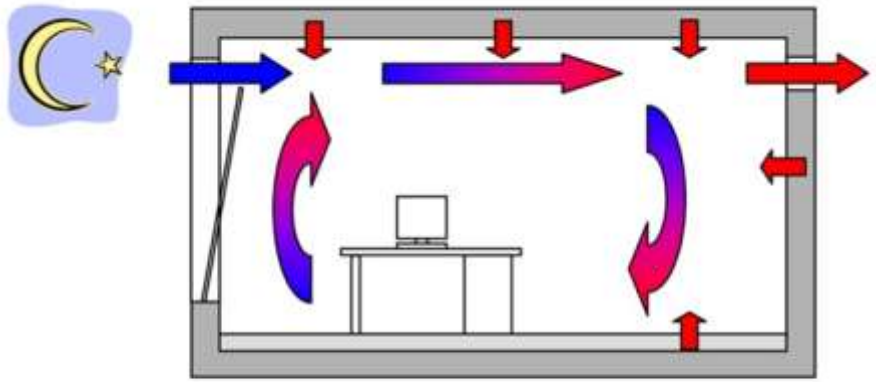


(a) ventilation time 21:00—next day 7:00

• Importance of bringing high ventilation rate 高通风率的重要性



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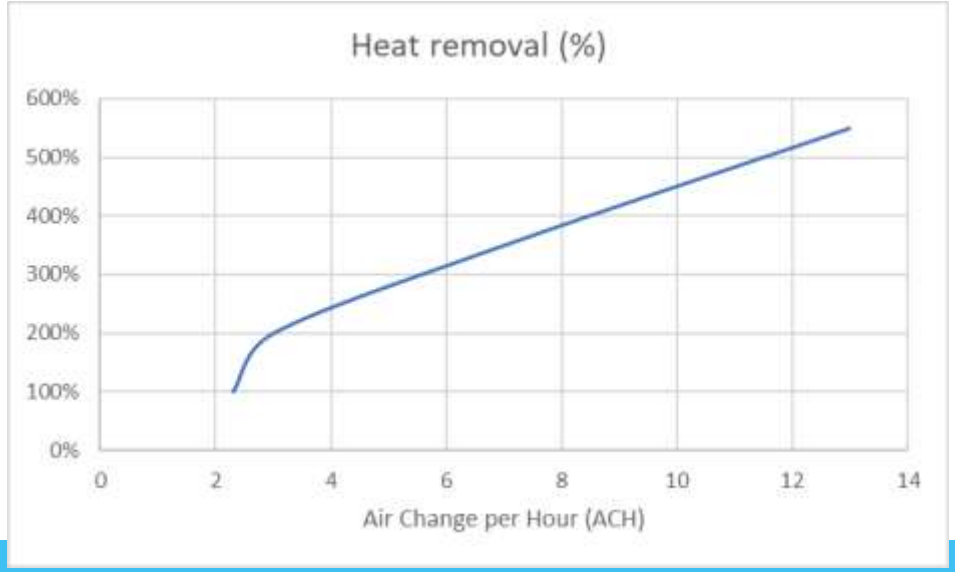
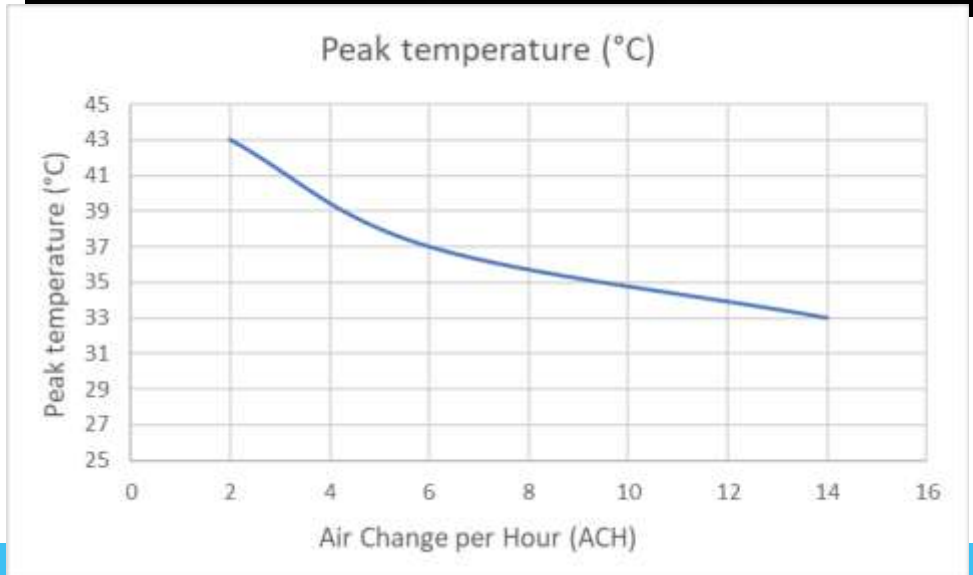




Vayu Pravah as an additional tool for the energy efficiency specially for non AC buildings

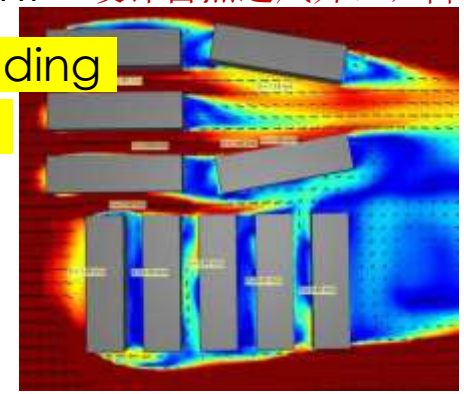
Vayu Pravah 是提高能效的一工具，特别适用于非空调建筑

- Eco Niwas Samhita
  - Guidance/Compliance for energy efficient building envelope 建筑围护结构节能指南/合规性
  - Major improvement in the protection against overheating against solar heat gains
  - Reduction of heat gains across the envelope, design for natural ventilation openings ➔ lower rate of AC equipment
  - But does not deal with building massing and its impact on natural ventilation

在防止过热和太阳辐射热获得方面取得重大改进

减少热增量，
设计自然通风开口，降低空调设备的使用率

不涉及建筑体量及其对自然通风的影响

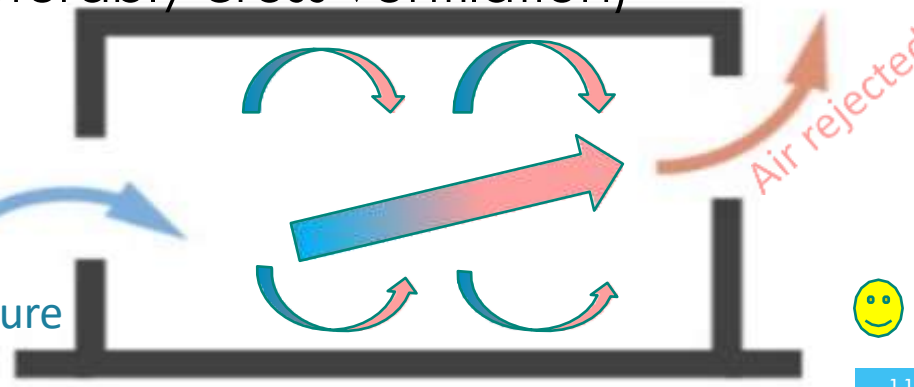


- Why वायु प्रवाह (Air Flow) ?
  - Natural (or ventilative cooling) night ventilation very important for the majority of residential buildings in India and other hot countries **not actively coole** (no Air conditioning)
  - Need to remove maximum heat during the night (preferably cross ventilation)

夜间自然通风（或通风降温）对印度和其他炎热国家的大多数非主动降温（无空调）住宅建筑非常重要

需要在夜间最大限度地排出热量（最好是交叉通风）

Night cool air removes heat from the structure
Reduce peak and average temperature



Main new features of Vayu Pravah 2.0 in a nutshell

Vayu Pravah 2.0 的主要新功能简述

Schweizerische Eidgenossenschaft
Confédération suisse
Swiss Agency for Development and Cooperation SDC
BEEP BUILDING ENERGY EFFICIENCY PROJECT

BEEP's freeware CFD tool Vayu Pravah 2.0 for designing building projects with better ventilation
用于设计通风效果更好的建筑项目

- Vayu Pravah 2.0 is developed to provide (isothermal model ➔ pressure and velocity)
  为提供（等温模型➔压力和速度）而开发的
  - Early simulation of wind patterns around buildings based on 2D dxf drawings in a very short simulation time (few minutes for most cases) 基于二维 dxf 图纸，在极短的模拟时间内对建筑物周围的风型进行早期模拟
  - It can read building outlines, set heights, select wind velocity profile and direction at night for a given location, and generate a base case simulation. 可以读取建筑物轮廓、设置高度、选择给定地点的夜间风速剖面和风向，并生成基本情况模拟
  - It allows easy comparison of different building orientations and locations in a project at an early stage
  - It is seen as an early design decision tool 便于在项目早期阶段对不同的建筑朝向和位置进行比较被视为早期设计决策工具
  - The meshing generation is automatic 自动生成网格
- Additionally, Vayu Pravah can simulate
  - Internal air flows
  - and calculate air flow across openings
  - accounting for resistances like mosquito nets

  还能模拟内部气流，计算开口处的气流，阻力计算
- Vayu Pravah 2.0 is based on a robust simulation engine (OpenFOAM) and has a very user-friendly graphical user interface. It has been designed to help the local town and country planning teams, architects, building designers, and HVAC consultants calculate the natural/assisted ventilation potential of buildings
  用户友好的图形用户界面，其设计目的是帮助地方城乡规划团队、建筑师、建筑设计师和暖通空调顾问计算建筑物的自然/辅助通风潜力

Accompanying the design process with Vayu Pravah वायु प्रवाह

Vayu Pravah 设计过程

Project from architect/client

1

Plan view buildings (dxf file)

2

create a project with a base case

Environment, wind velocity, direction, profile

Prepare for simulation

3

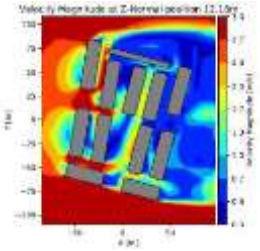
4

Perform approximate model (fast) simulations

Automatically saves each alternative design

Modify the building layout

5



6

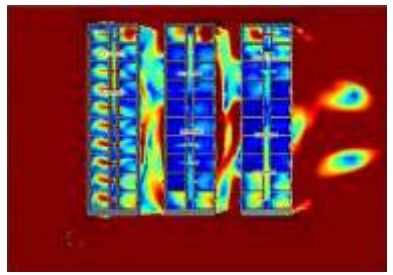
Qualitative assessment of the different alternatives

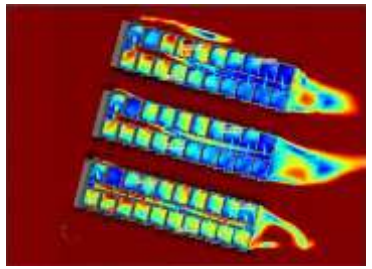
Velocity and pressure at different heights, distances generate pdf file

7

Select alternative design to be simulated in detail

8





Further Detailing of the facade element strategy

9

Develop cases with internal flow on a typical floor

10

Visualisation of the air flow inside the building (s)

11

The background behind Vayu Pravah (2)

Vayu Pravah (2) 的背景

- Commercial CFD tools are very expensive and therefore mostly out of reach for many consulting firms or architectural offices 商业 CFD 工具非常昂贵，因此对于许多咨询公司或建筑事务所来说，大多是可望而不可及的
- Public domain CFD are available since the 2000's but their interface and their use has kept them mostly out of reach for practitioners 公共领域的 CFD 早在 2000 年代就已问世，但其界面和使用方法较困难
- At the same time the importation possibilities may not correspond to the regular architectural drawings
  导入的可能与常规建筑图纸不一致
- Looking at the complementary role for Vayu Pravah with Eco Niwas Samhita it was developed with a version 1
  考虑到 Vayu Pravah 与 Eco Niwas Samhita 的互补作用，开发了第一版 Vayu Pravah
- After looking at the questions and using it it was decided to develop the version 2 with many more features
- During this session we are going to present the new version 2 to illustrate what's possible to do with this software and how to do it, then we will welcome question remarks comments in order to get first feedback

  在本次会议上，我们将介绍新的第 2 版，以说明该软件可以做什么以及如何做，然后我们将欢迎提问和评论，以获得第一手反馈意见

Freely distributable Computational Fluid Dynamics (CFD) tool for simulations of the flow around and inside a complex of buildings

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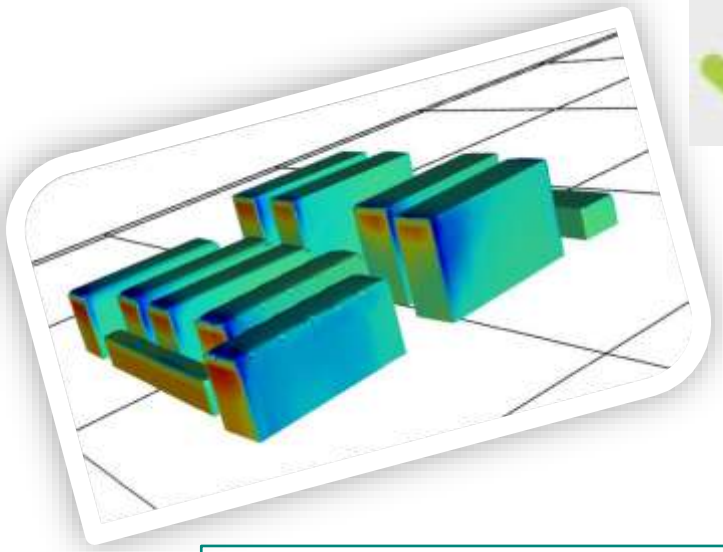
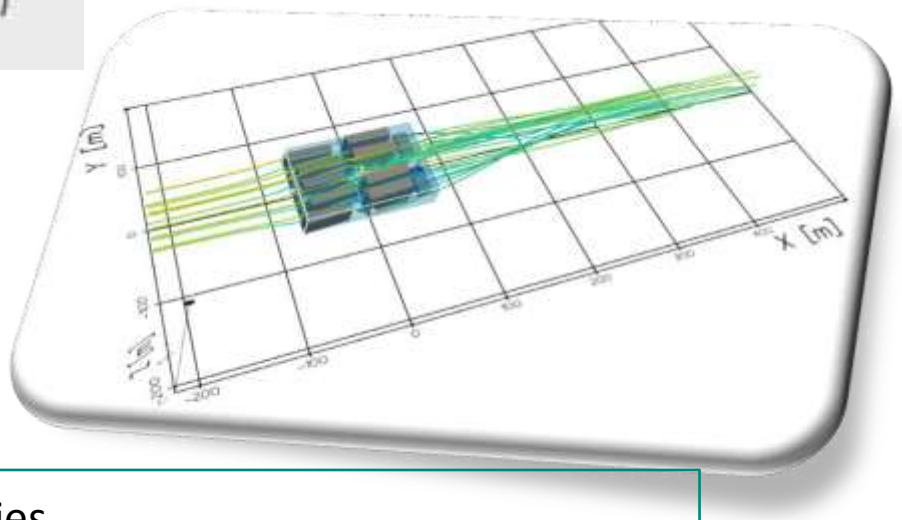
BEEP BUILDING ENERGY EFFICIENCY PROJECT

计算流体动力学（CFD）工具，用于模拟建筑群周围和内部的流动情况



INDO-SWISS BUILDING ENERGY EFFICIENCY PROJECT (BEEP)

Software based on the OpenFOAM simulation engine
Running on Windows 10/11 PC's
(tested also on Windows 7, 8.1)
16 Gb RAM
User manual explaining how to use it



IOPscience Journal of Physics: Conference Series

Development of a freely distributable CFD tool for approximate and detailed simulations of the flow around a complex of buildingsDevelopment of a freely distributable CFD tool for approximate and detailed simulations of the flow around a complex of buildings

J. Decaix* (HES-SO), P. Jaboyedoff (Effinart), G. Duthé (ETHZ), E. El Sergany (EPFL Master Student), L. Aiulfi (ESRI) , CISBAT 2021 – Lausanne, Switzerland Carbon Neutral Cities - Energy Efficiency & Renewables in the Digital Era EPFL, 8-10 September 2021

*jean.decaix@hevs.ch

https://iopscience.iop.org/article/10.1088/1742-6596/2042/1/012069

Vayu Pravah वायु प्रवाह
Scientific Development and comparisons

科学发展与比较

- The pictures ➔ present the comparison between 图片显示了以下对比
- The wind tunnel measurement 风洞测量
- A commercial CFD (Flovent from Mentor Graphics part of Siemens Simcenter softwares) and 商用 CFD （西门子旗下）
- The free software 免费 CFD (OpenFOAM, used as the simulation engine of वायु प्रवाह).

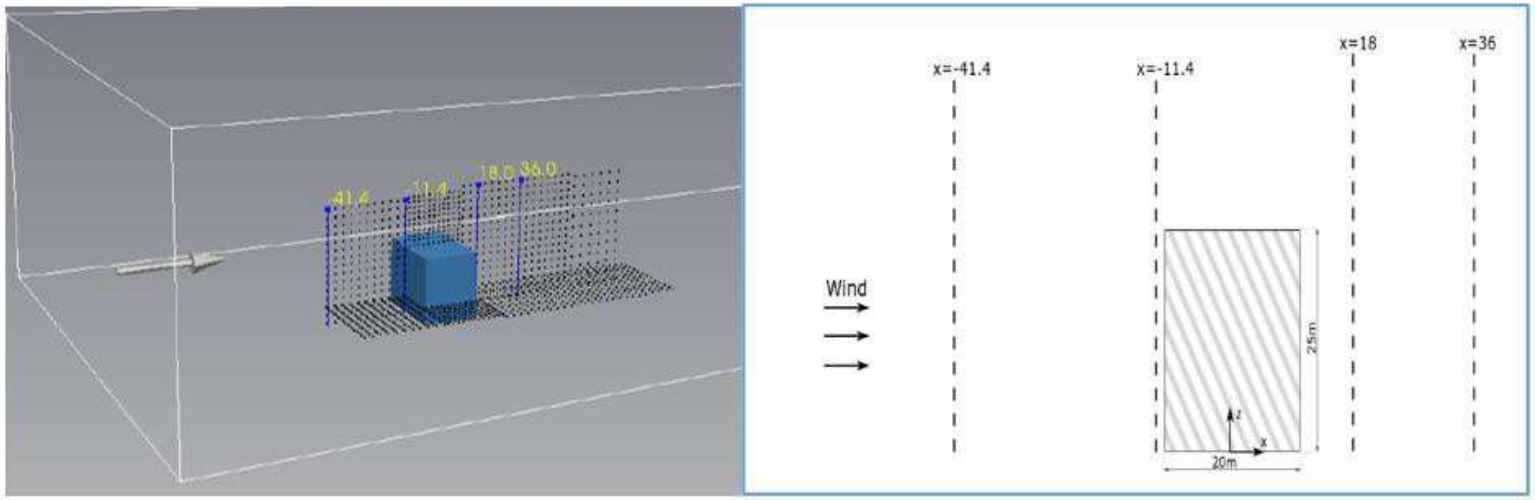


Figure 1: view of the single building in the wind tunnel with 1000 sensors in perspective and elevation

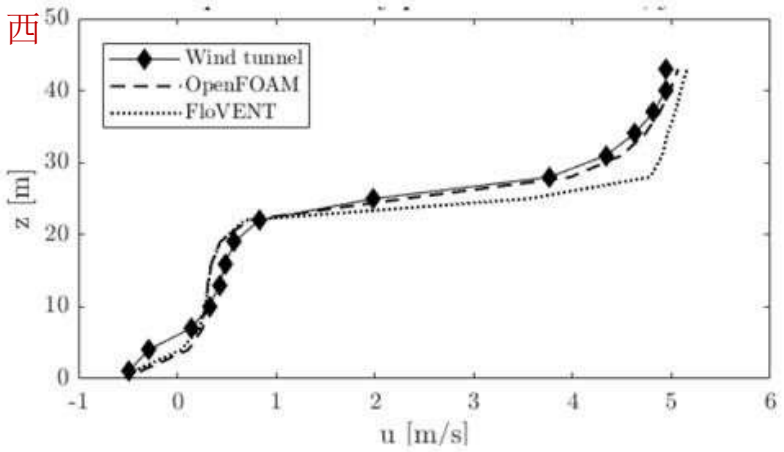


Figure 2: wind velocity (u) just before the winward façade as a function of the height (z), the building is 25 m high at x=-11.4 m

Vayu Pravah वायु प्रवाह Scientific Development CFD model cross-comparison Flovent ☒➔ OpenFOAM using wind tunnel test cases

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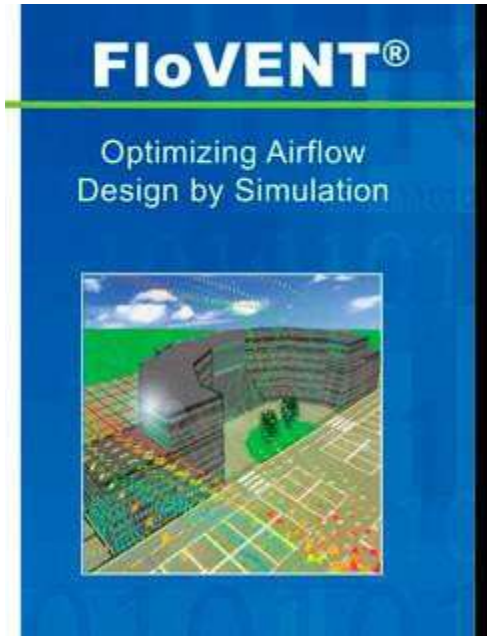
BEEP BUILDING ENERGY EFFICIENCY PROJECT

科学发展 CFD 模型交叉比较 → OpenFOAM 使用风洞试验案例

Comparison of air flow around nine buildings (Wind tunnel case of the Architectural Institute of Japan (AIJ Case C)) 九座建筑物周围的气流比较
With colour matching (special development by Effinart)

Mentor, a Siemens Business FloVENT® 3D Computational Fluid Dynamics Software



E Flow around buildings: AIJ case C

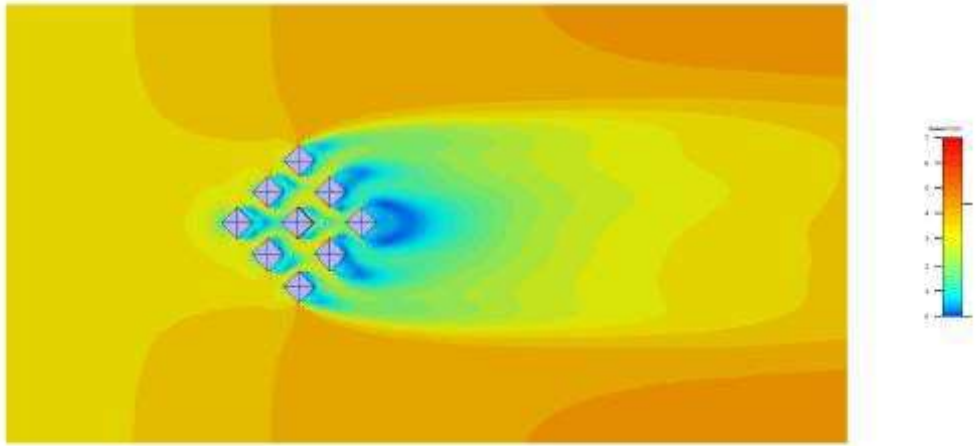


Figure 16 – Velocity magnitude contours of the solution generated using FloVENT, for plane z = 10.

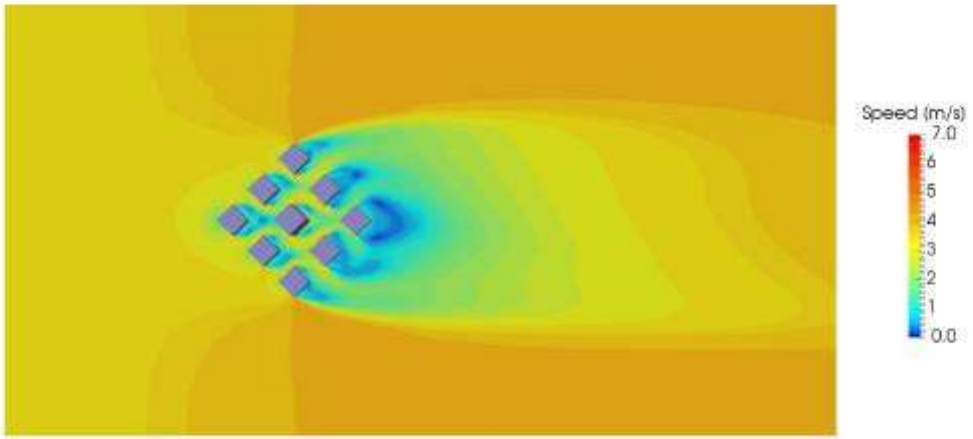


Figure 17 – Velocity magnitude contours of the solution generated using OpenFOAM, for plane z = 10.

Air flow inside buildings (Internal air flows)

建筑物内的气流（内部气流）

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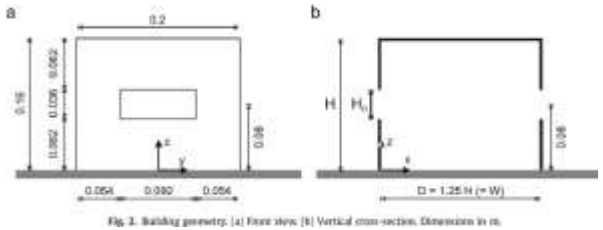
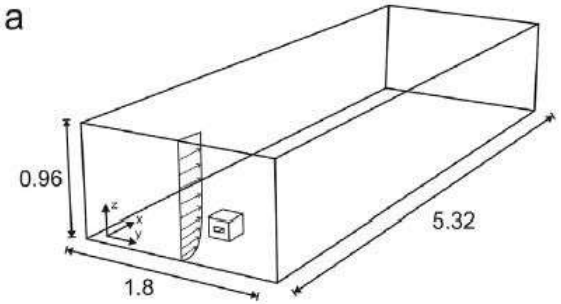
BEEP BUILDING ENERGY EFFICIENCY PROJECT

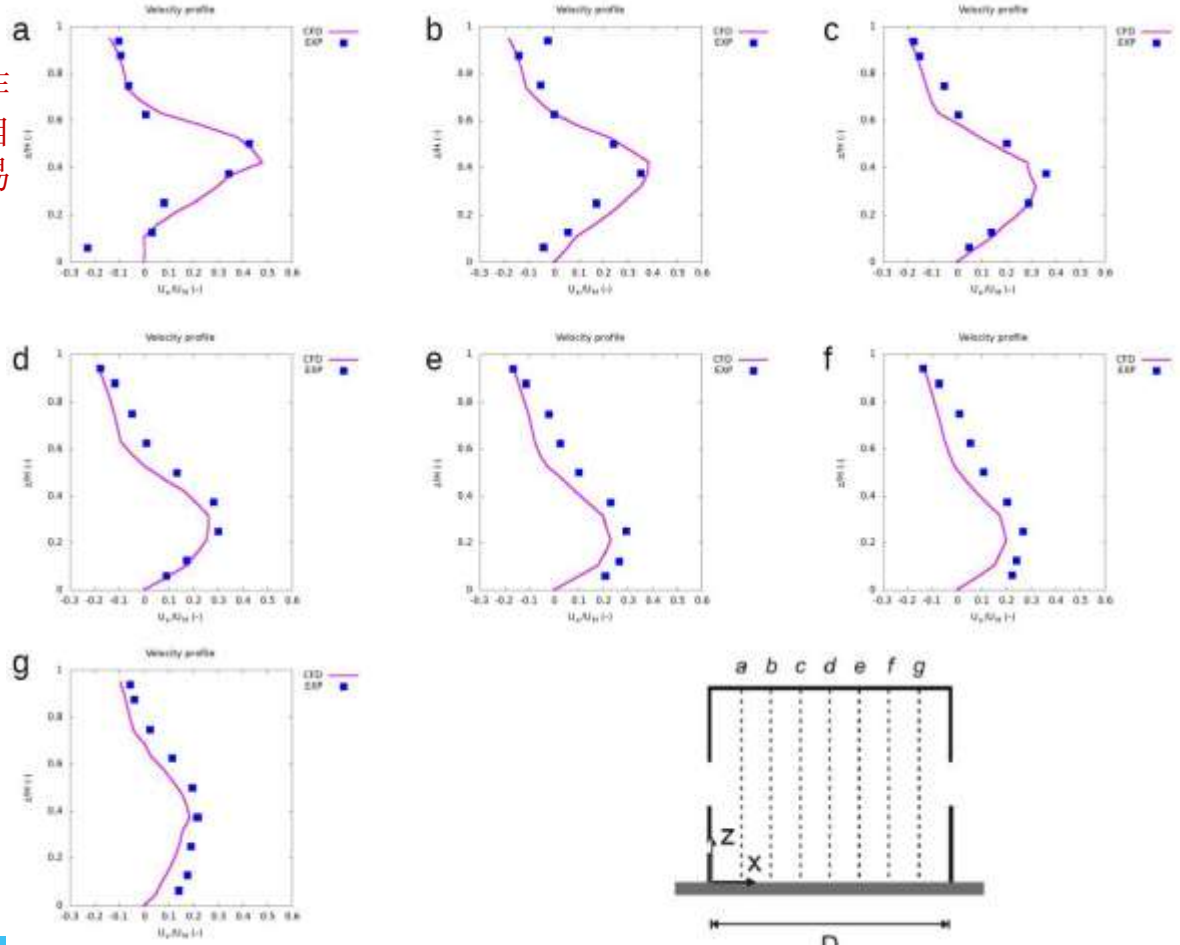
- CFD comparison between wind tunnel experimental data and वायु प्रवाह
- (Jean Decaix, HES-SO वायु प्रवाह development

Comparison of the velocity profile inside the simple building between the wind tunnel experimental data and Vayu Pravah (environment using OpenFOAM as simulation engine with an automatic meshing algorithm, user does not have to care about it)

风洞实验数据与 Vayu Pravah（使用 OpenFOAM 作为仿真引擎的环境，具有自动网格划分算法）之间简易建筑内部速度曲线的比较







On the accuracy of CFD simulations of cross-ventilation flows for a generic isolated building: Comparison of RANS, LES and experiments, T. van Hooff a, b, *, B. Blocken a, b, Y. Tominaga c
a Department of Civil Engineering, KU Leuven, Kasteelpark Arenberg 40 e bus 2447, 3001 Leuven, Belgium
b Department of the Built Environment, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
c Department of Architecture and Building Engineering, Niigata Institute of Technology, 1719, Fujihashi, Kashiwazaki, Japan
Building and Environment 114 (2017) 148-165

Some other validation/comparison modelling with OpenFOAM in the academic domain (illustration)

在学术领域使用 OpenFOAM 进行的其他一些验证/比较建模（示例）

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BEEP BUILDING ENERGY EFFICIENCY PROJECT

- For illustration
- Few other studies with OpenFOAM

Applied Mechanics and Materials Vol 554 (2014) pp 696-700 Online: 2014-06-02

doi:10.4028/www.scientific.net/AMM.554.696

A Verification and Validation Study of CFD Simulation of Wind-induced Ventilation on Building with Single-sided Opening

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Mohamed Sukri Mat Ali1, c, Ahmad Faiz Mohammad1, d and Azli Abd Razak2, e
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eazlirazak@salam.uitm.edu.my

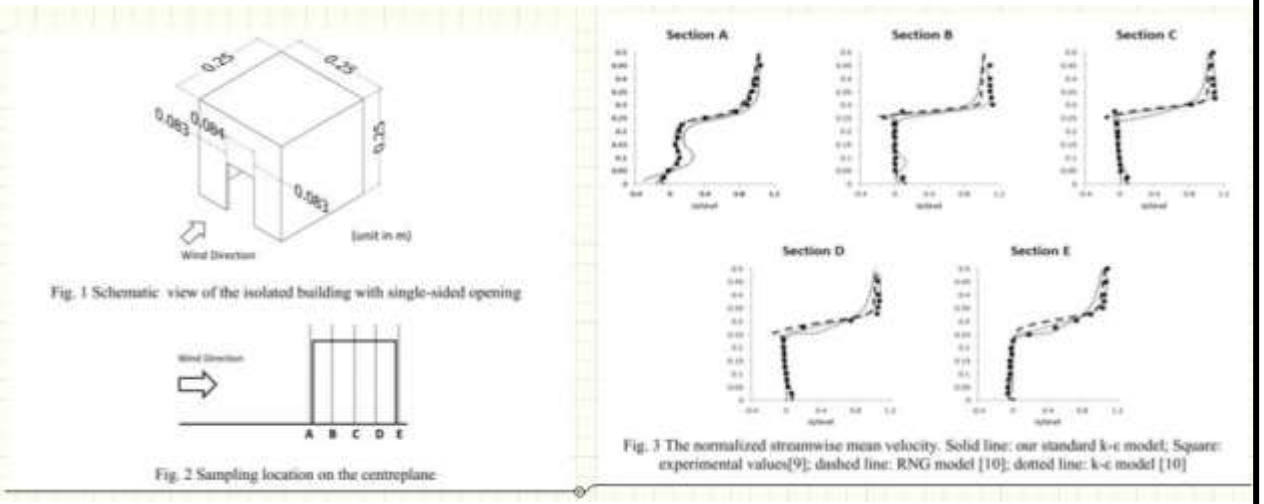

Fig. 1 Schematic view of the isolated building with single-sided opening

Fig. 2 Sampling location on the centreplane

Fig. 3 The normalized streamwise mean velocity. Solid line: our standard k-ε model; Square: experimental values[9]; dashed line: RNG model [10]; dotted line: k-ε model [10]

X. Zhang, A.U. Weerasuriya, K.T. Tse, CFD Simulation of Natural Ventilation of a Generic Building in Various Incident Wind Directions: Comparison of Turbulence Modelling, Evaluation Methods, and Ventilation Mechanisms, *Energy & Buildings* (2020), doi: https://doi.org/10.1016/j.enbuild.2020.110516

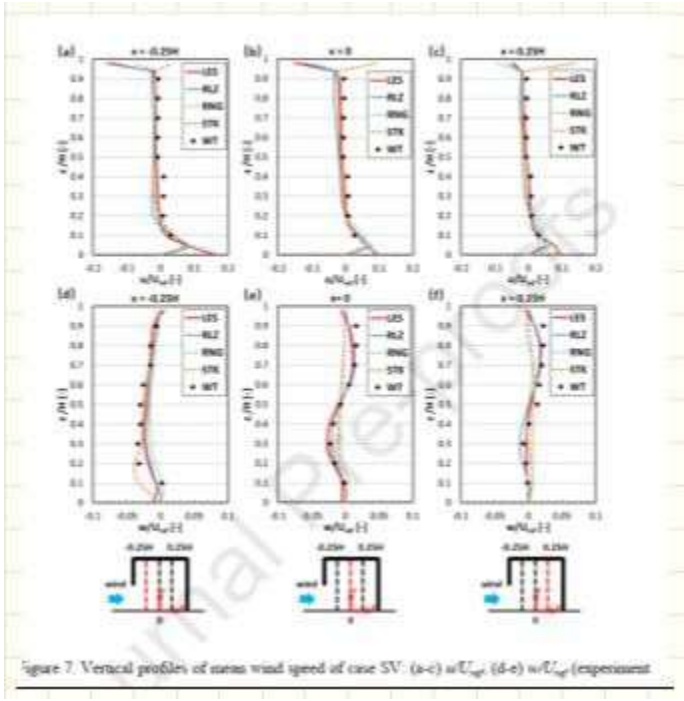

Figure 7. Vertical profiles of mean wind speed of case SV: (a-c) u/U_{ref}, (d-e) u/U_{ref} (experiment

Scale of simulation: district level

模拟规模：地区一级

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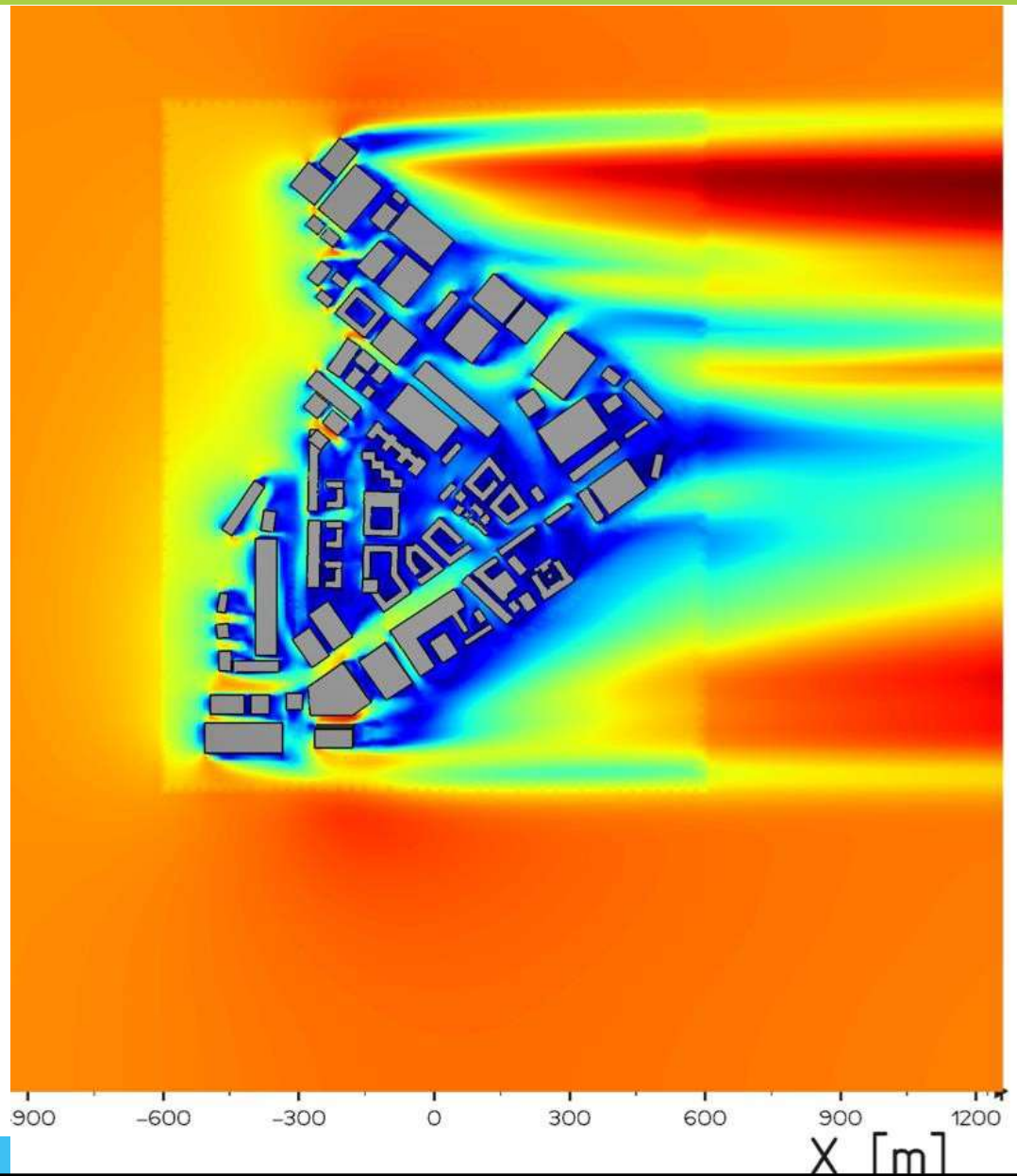
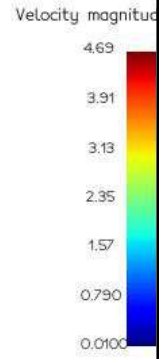
BEEP
BUILDING ENERGY EFFICIENCY PROJECT

- Study of wind distribution in a district of a town

城镇地区风力分布研究





Scale of simulation: inside buildings

模拟规模：建筑物内部

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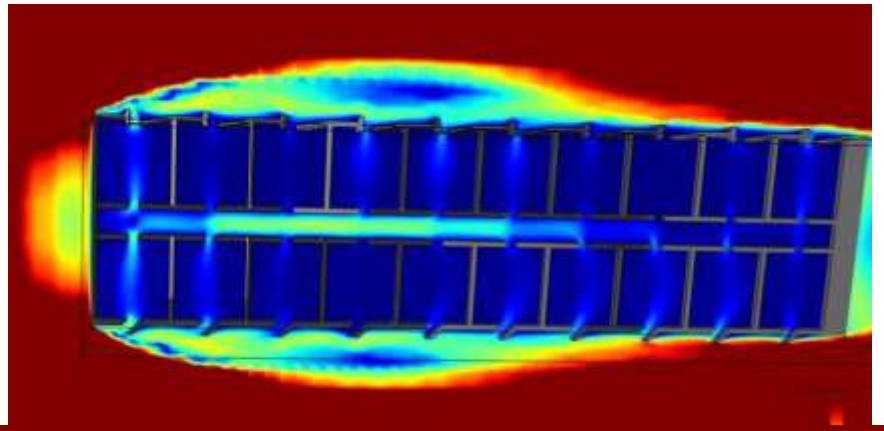
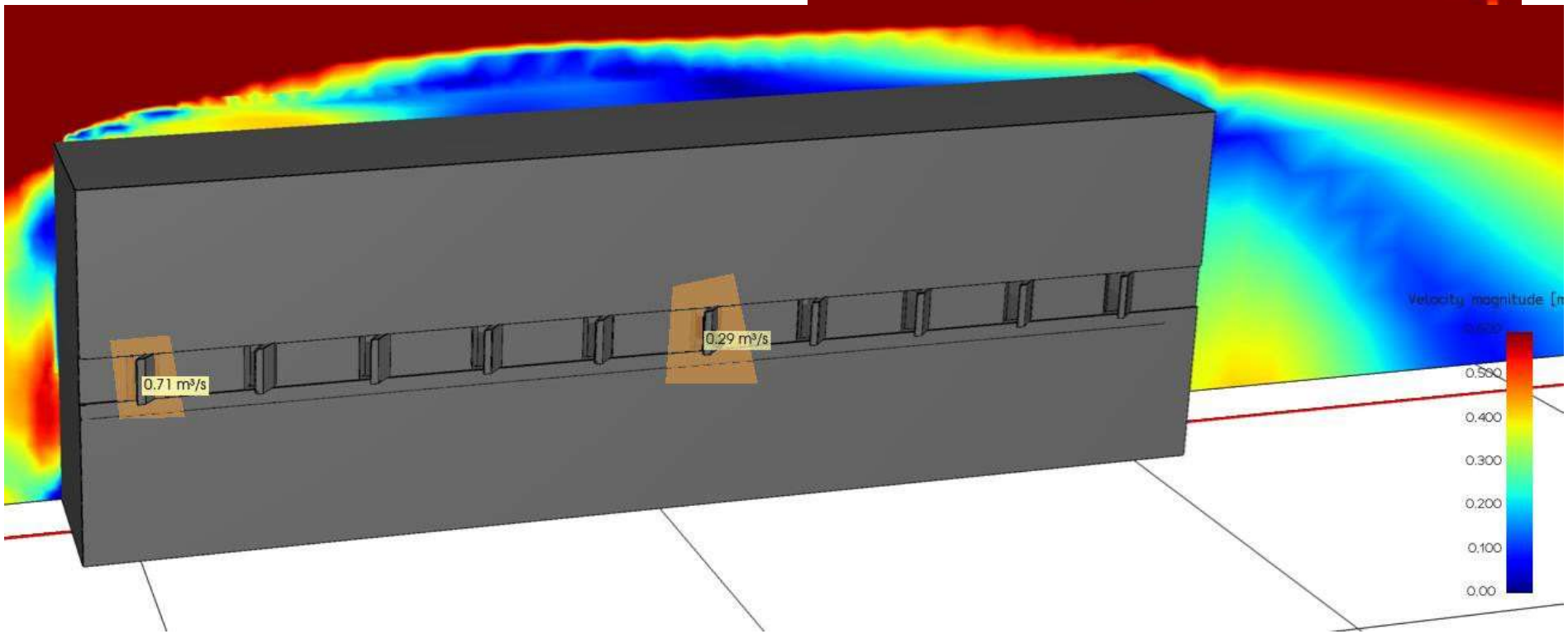
BEEP
BUILDING ENERGY EFFICIENCY PROJECT

- Visualize air flow inside buildings
- Facade design influence
- Estimate the air flow rates by measurement air flow across openings

可视化建筑物内的空气流动
外墙设计影响
通过测量开口处的气流来估算空气流速





A Schematic example, influence of building massing

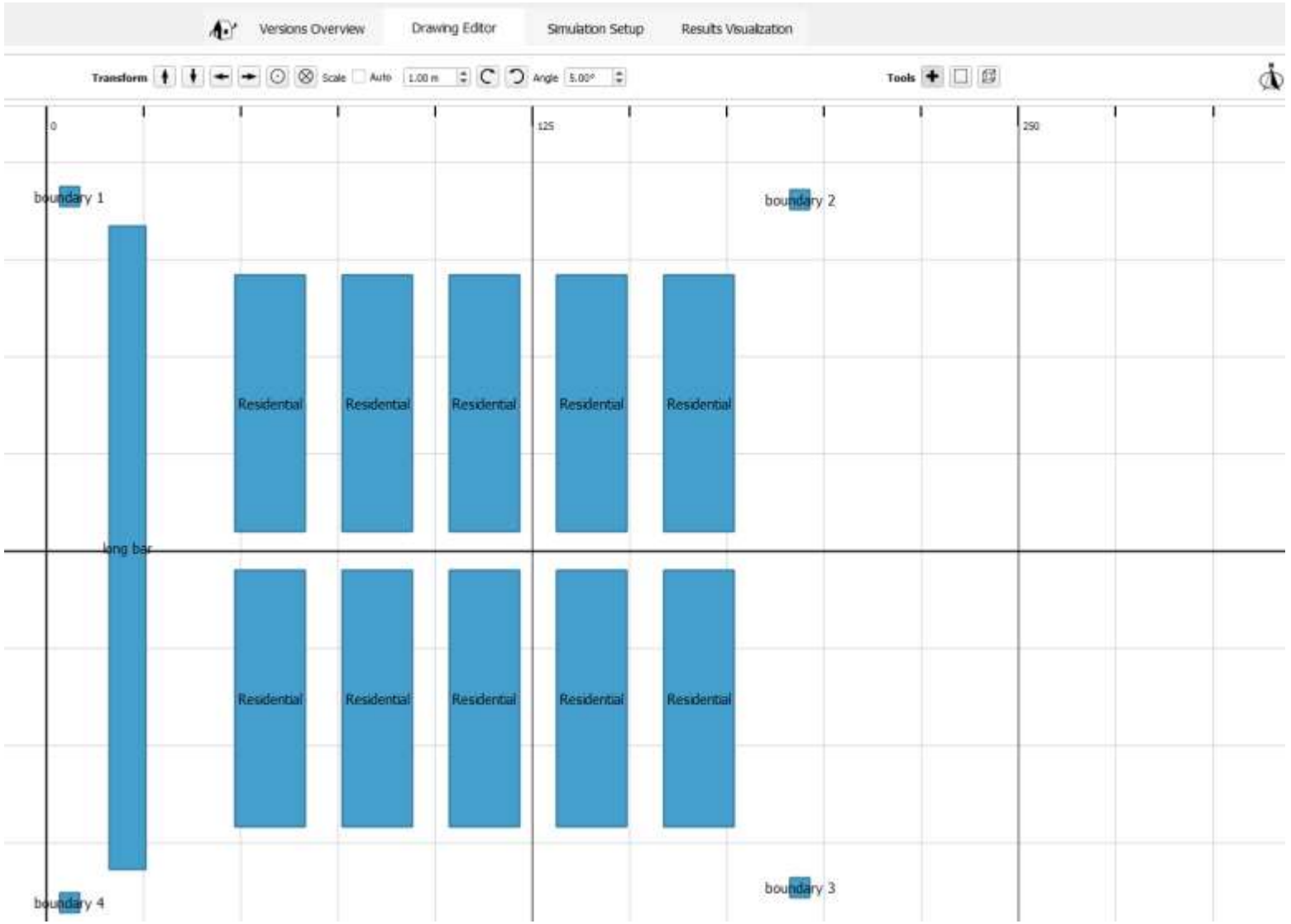
建筑体量的影响

- Dense urban residential project 密集的城市住宅项目
- Building placed with long façades wind ward for the first row

第一排建筑采用长立面风道设计

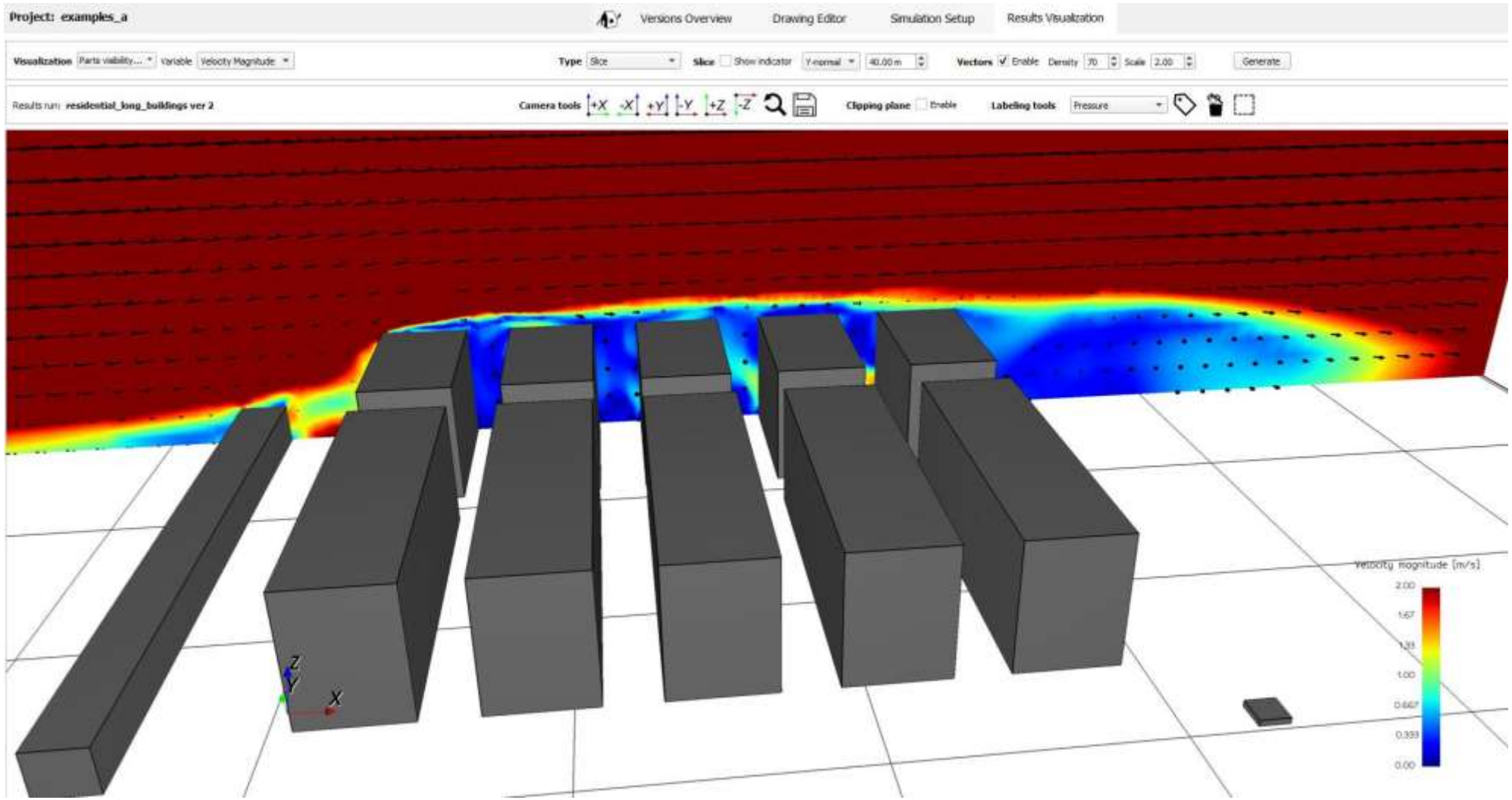
A Schematic example, influence of building massing

建筑体量的影响



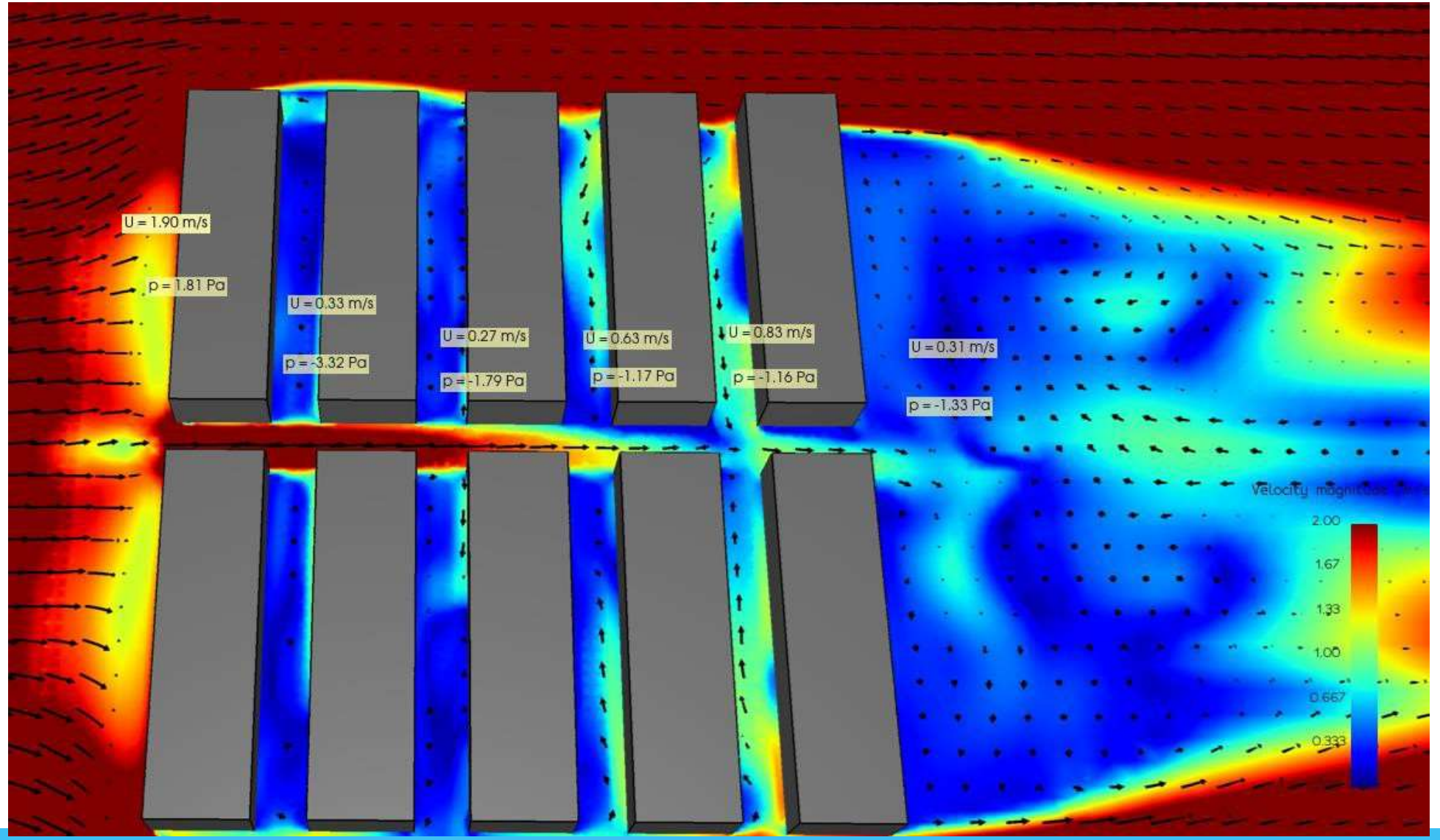
A Schematic example, influence of building massing

建筑体量的影响



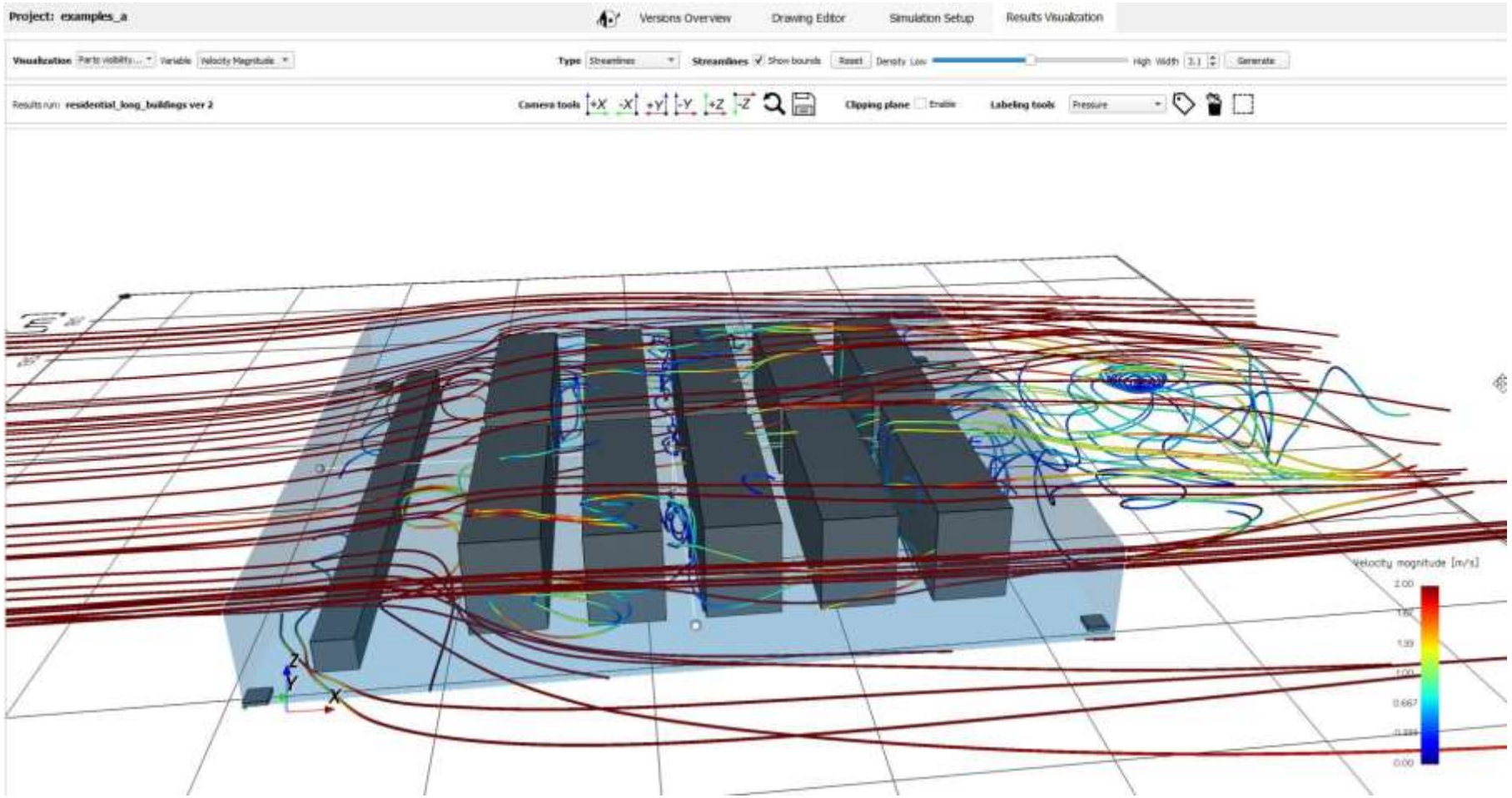
A Schematic example, influence of building massing

Hauteur 12 m



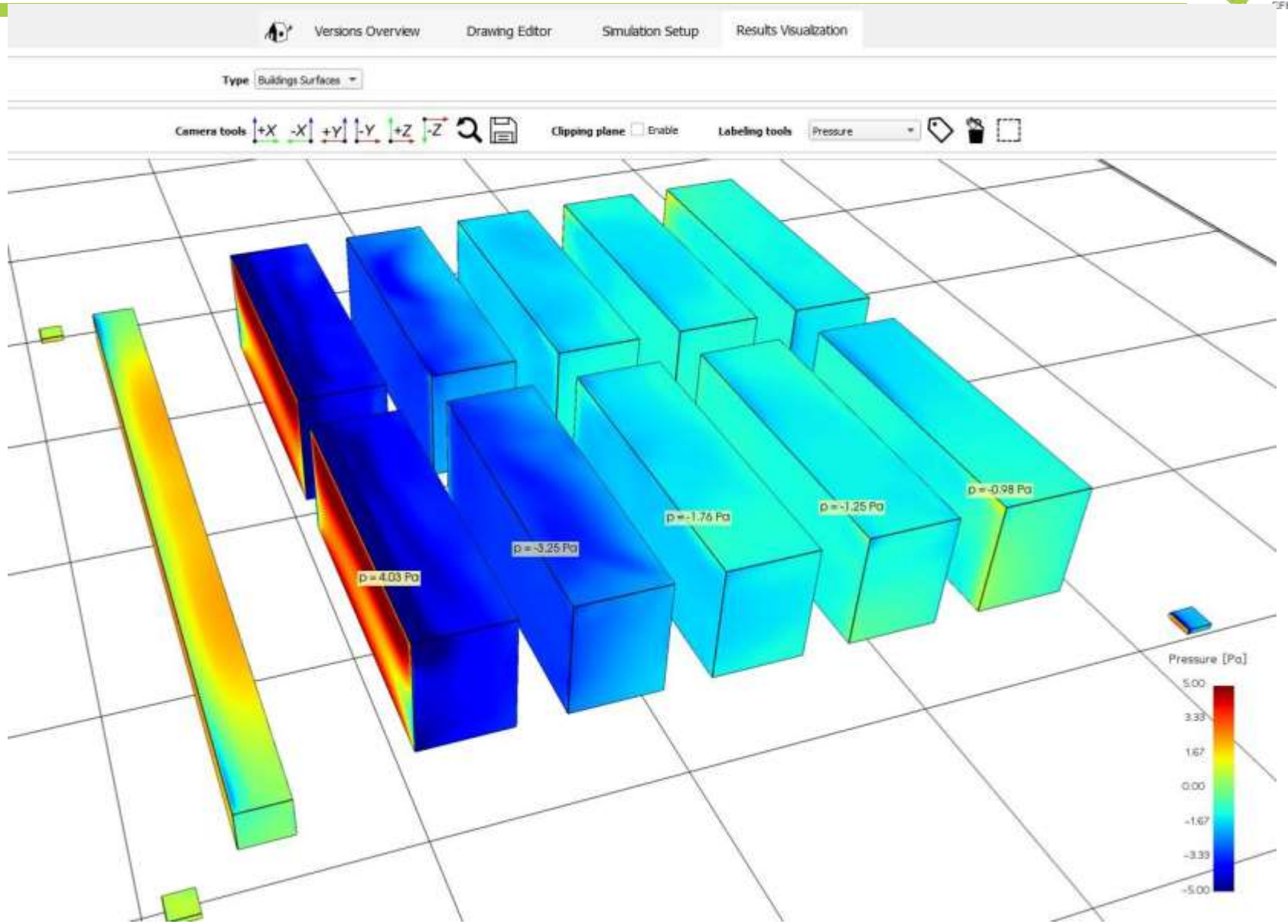
A Schematic example, influence of building massing

建筑体量的影响



A Schematic example, influence of building massing

建筑体量的影响

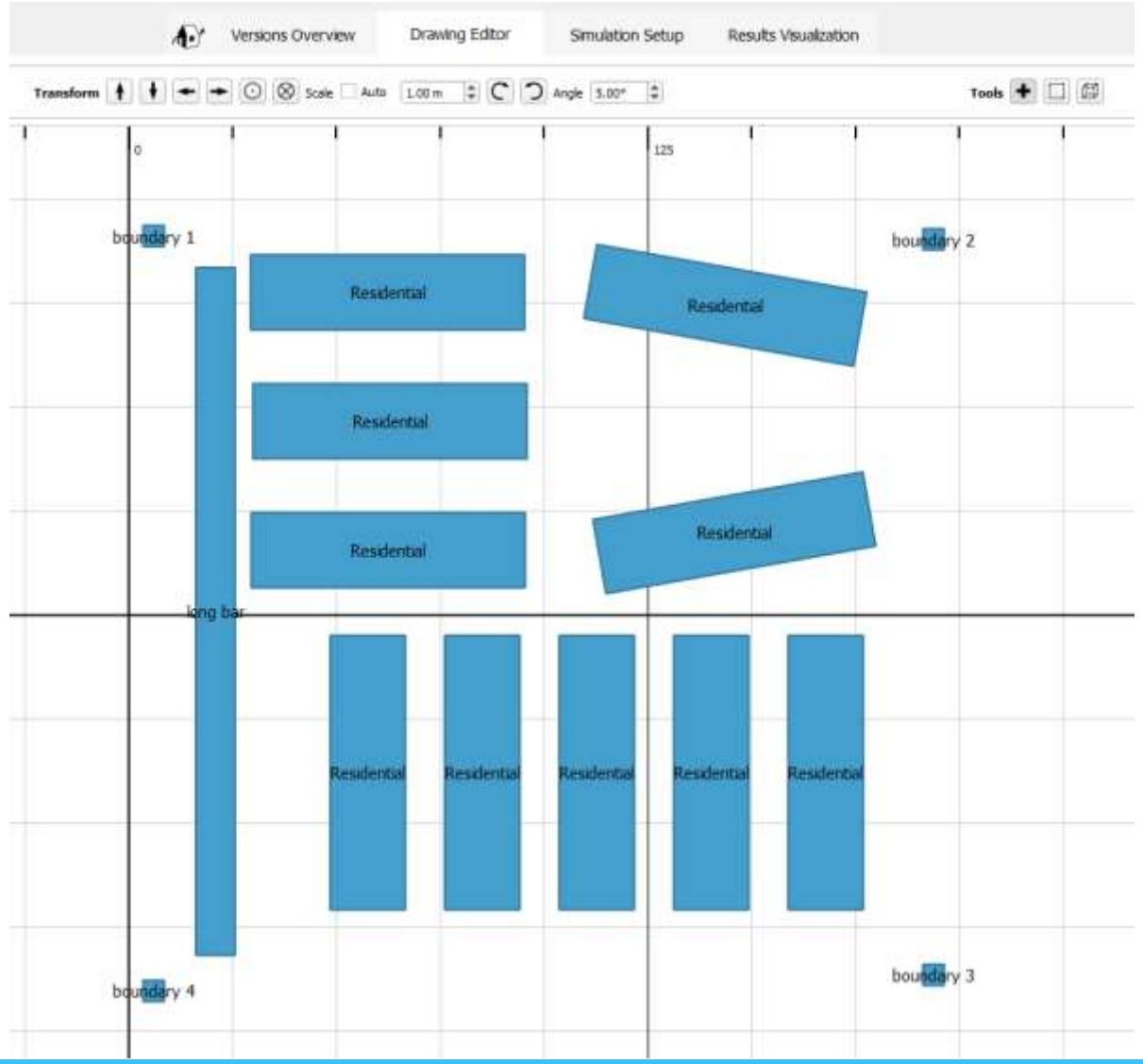


A Schematic example, influence of building massing

建筑体量的影响

- Schematic example of building massing change
- Modification directly in the drawing editor

建筑体量变化示意图例
直接在绘图编辑器中修改

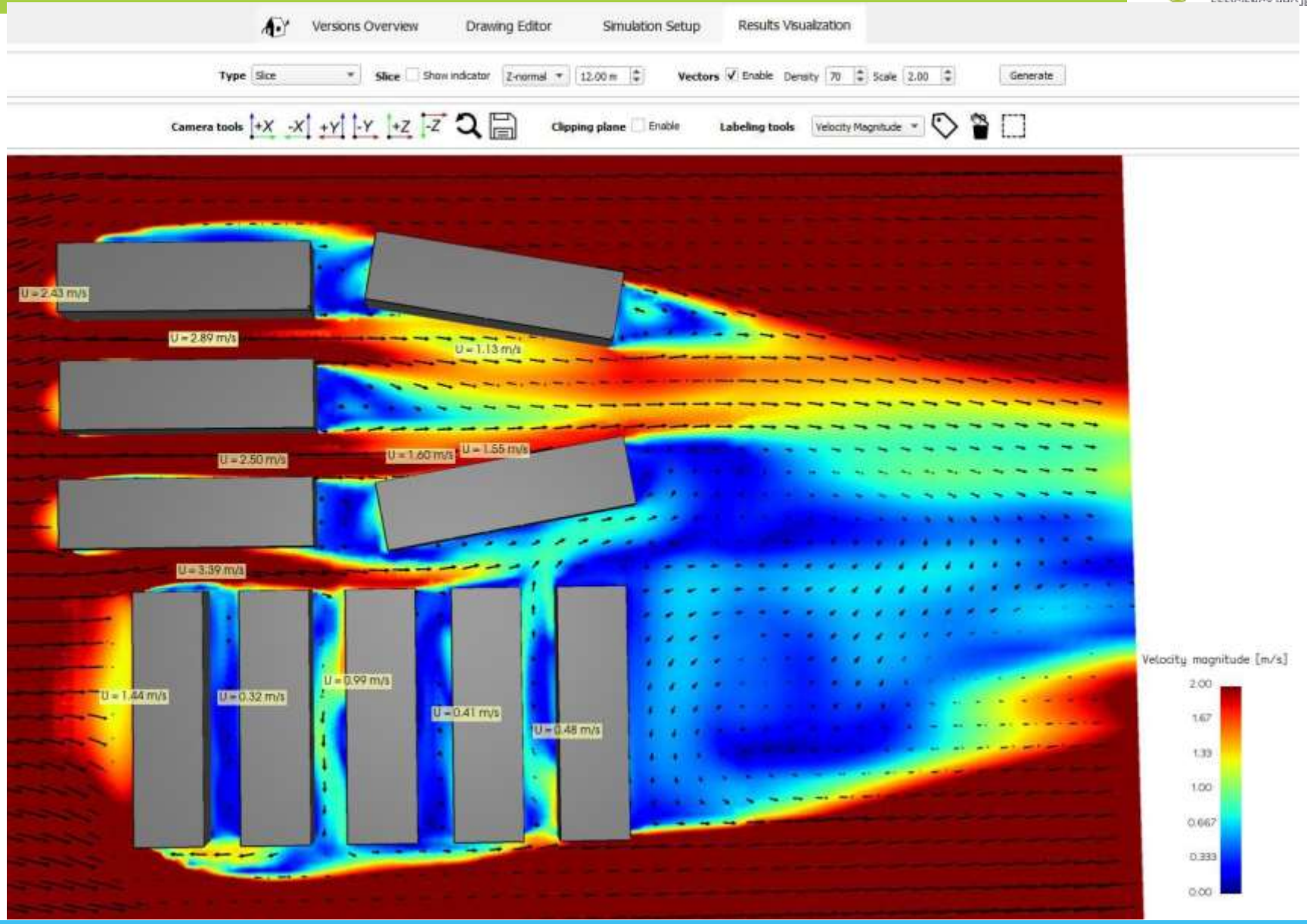


A Schematic example, influence of building massing

建筑体量的影响

- Results after re-arranging
- Compare the difference of wind velocity

新排列后的结果
比较风速差异



A Schematic example, influence of building massing
建筑体量的影响

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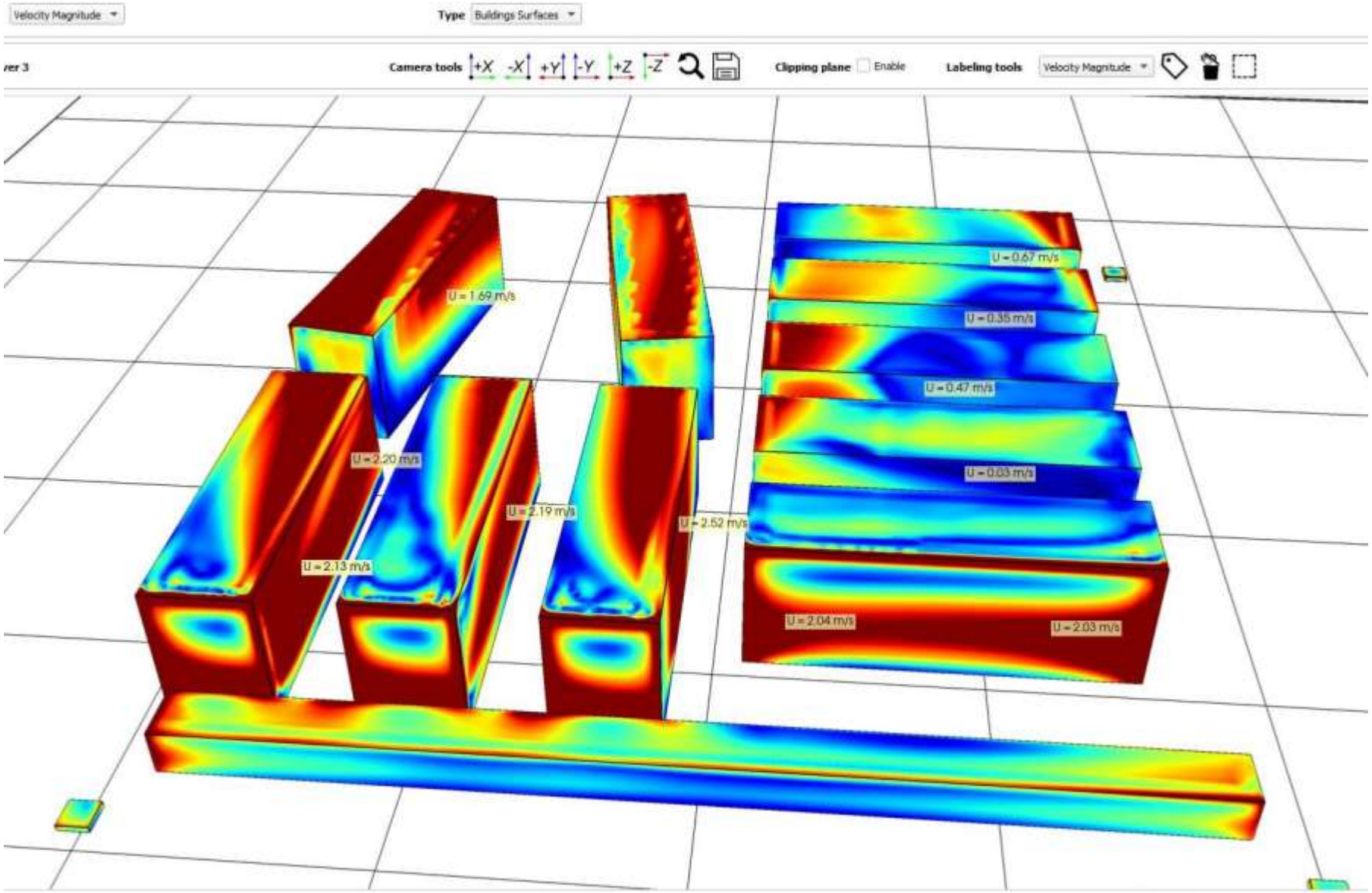
BEEP
BUILDING ENERGY EFFICIENCY PROJECT

- View of the building façades 建筑外墙
- Velocity or pressure 速度或压力

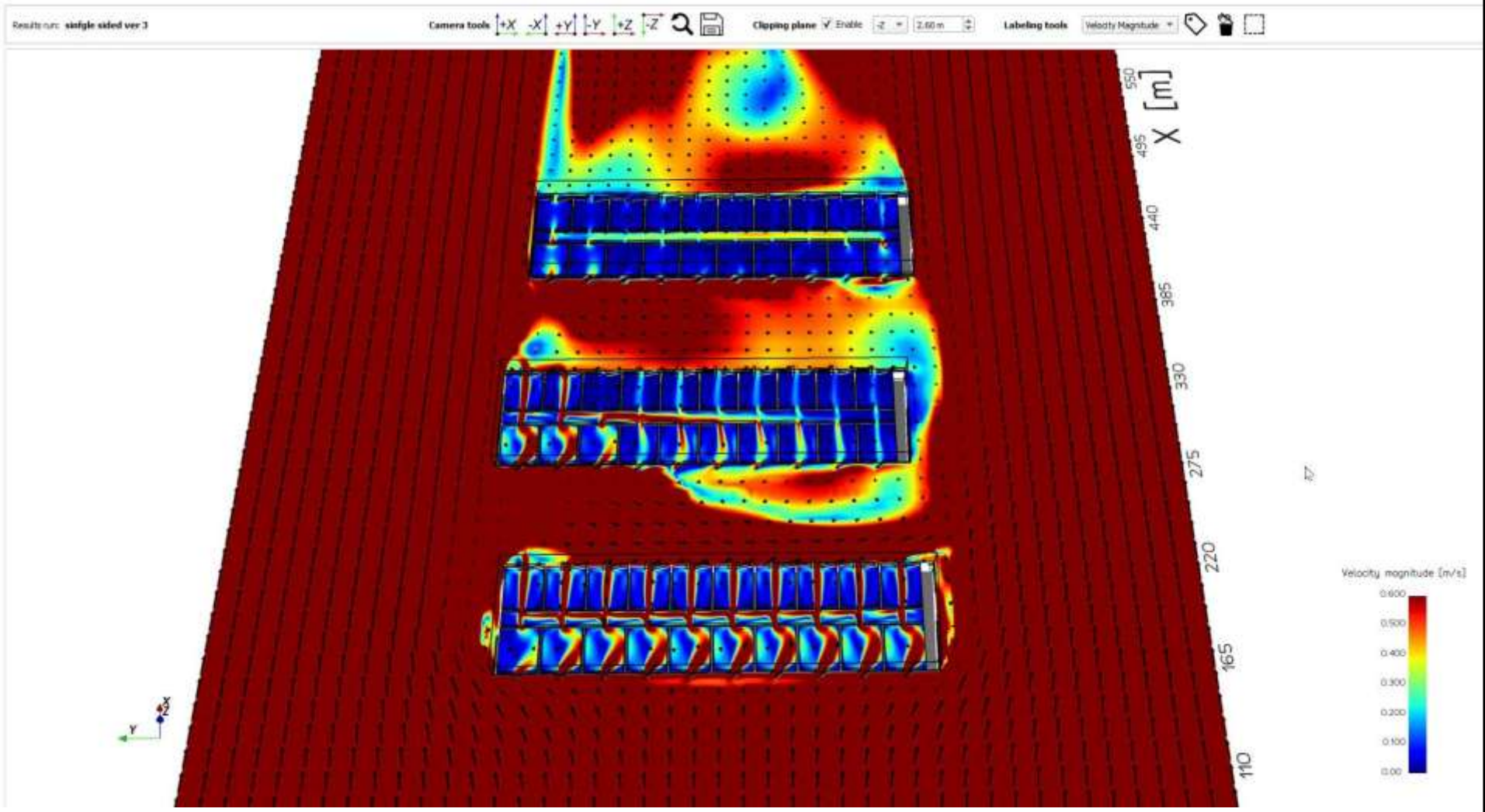


Schematic example of inside air flow in buildings

建筑物内部气流示意图

- Wind perpendicular to the long facades

风向与长外墙垂直

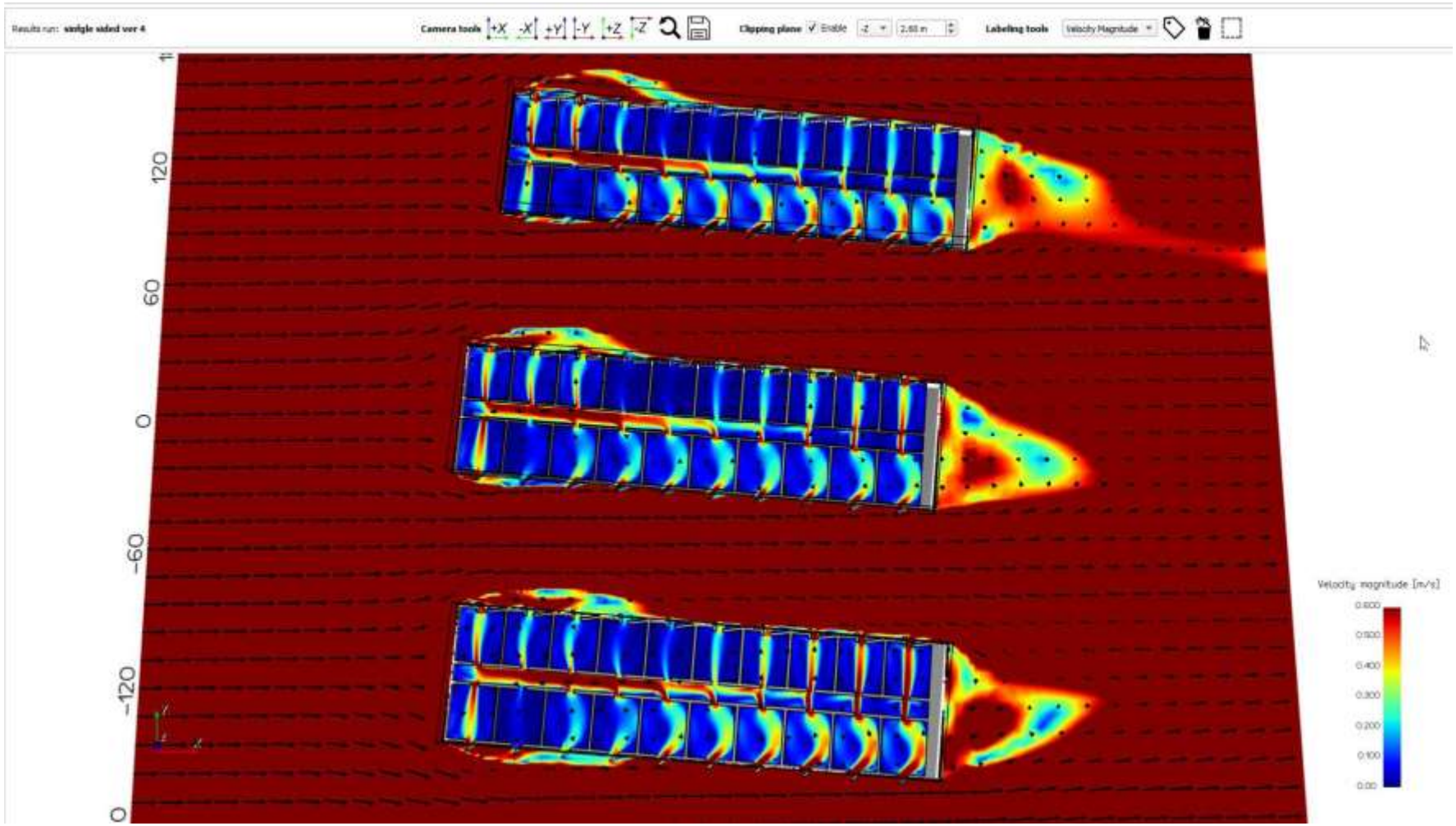


Schematic example of inside air flow in buildings

建筑物内部气流示意图

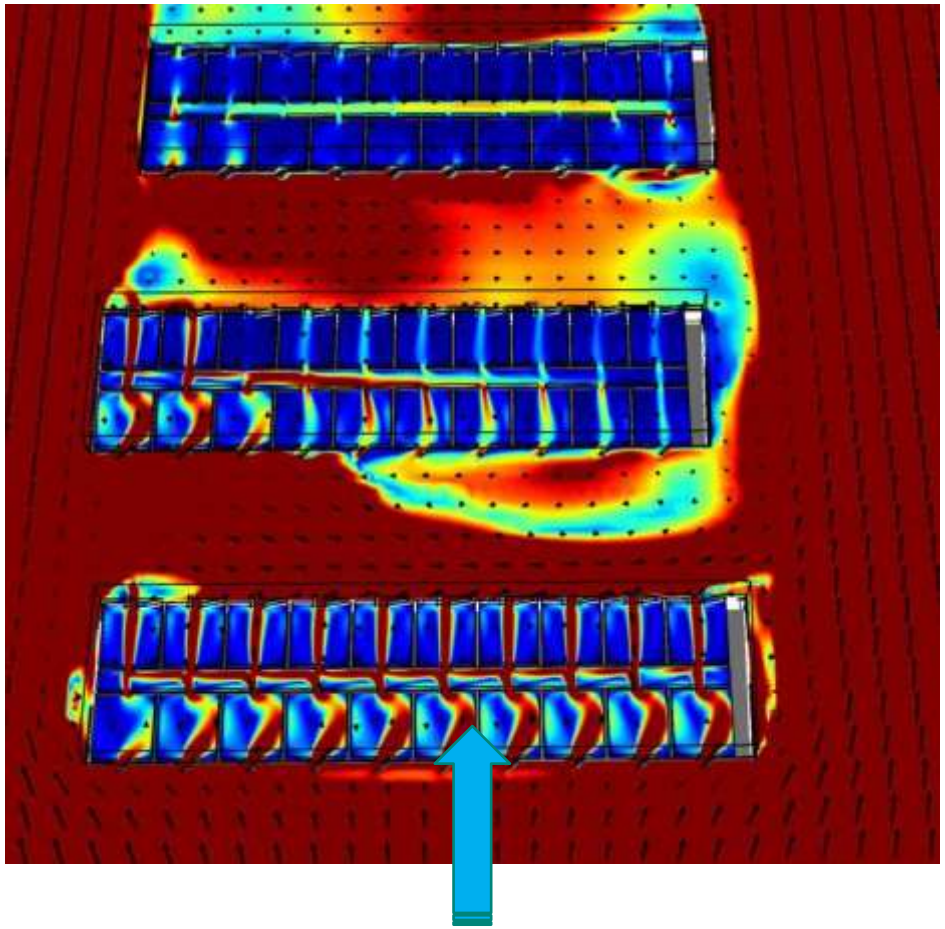
- Wind almost parallel to the long facades

风向几乎与长外墙平行

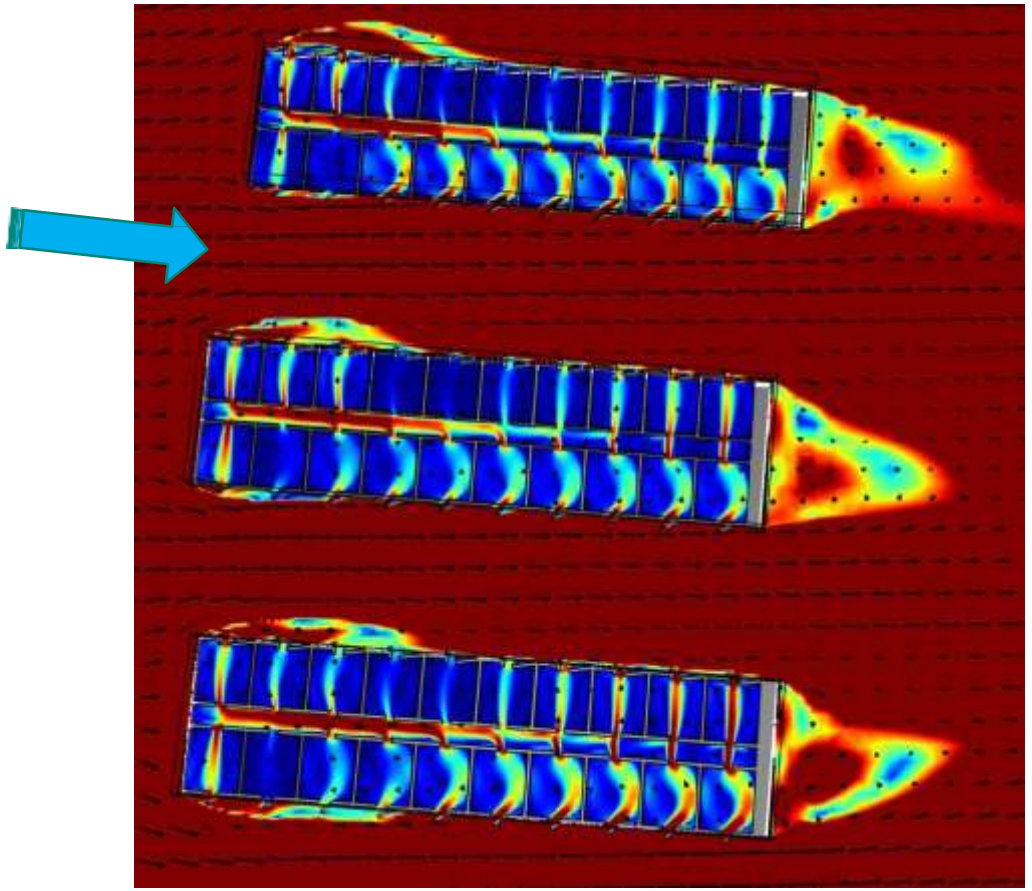


Schematic example of inside air flow in buildings
建筑物内部气流示意图

- Wind (visual comparison)
  - Perpendicular 垂直



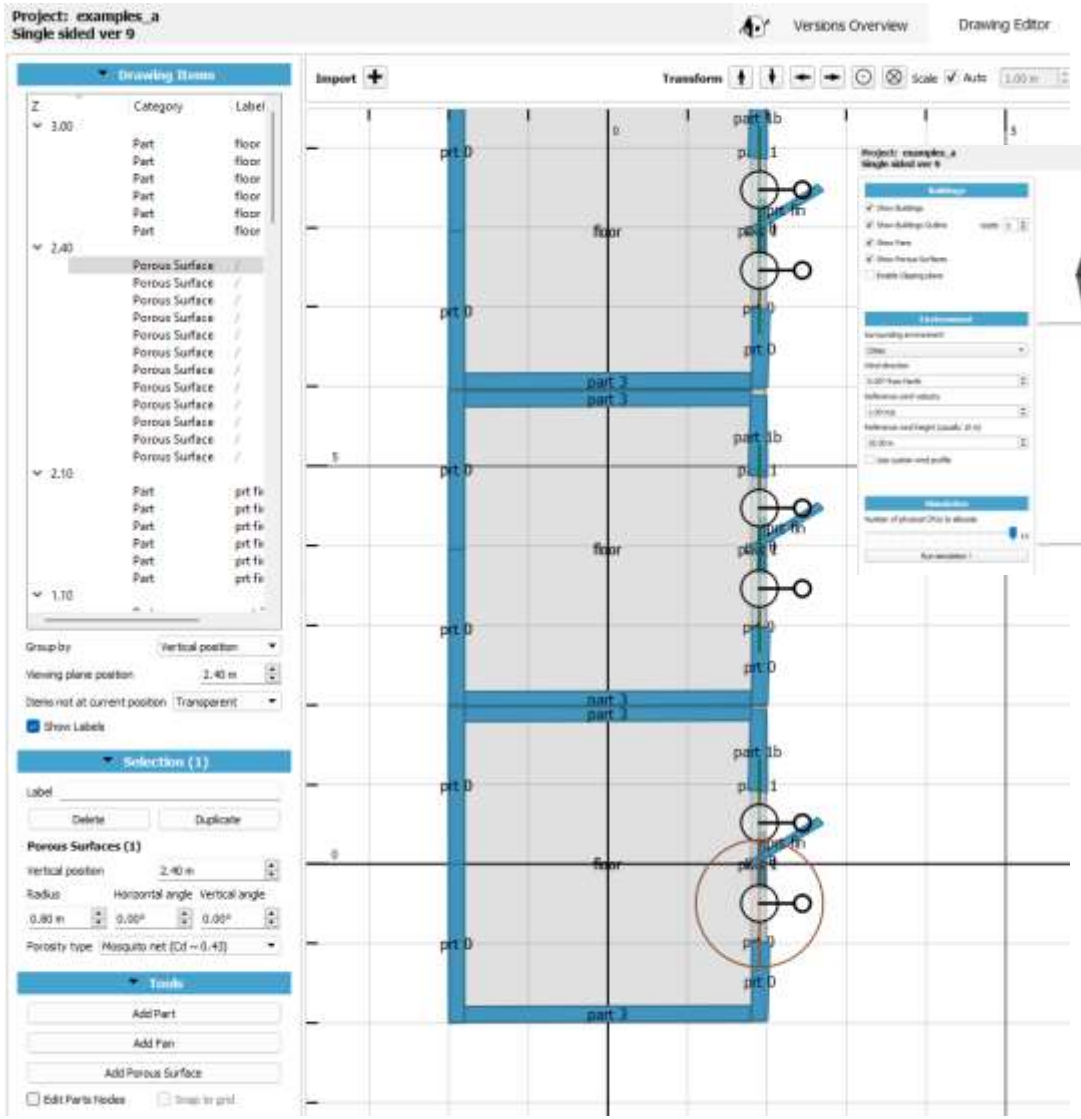
~parallel 平行



Example 1 single sided ventilation

例 1：单侧通气

- Impact of fin éléments
- Example 1

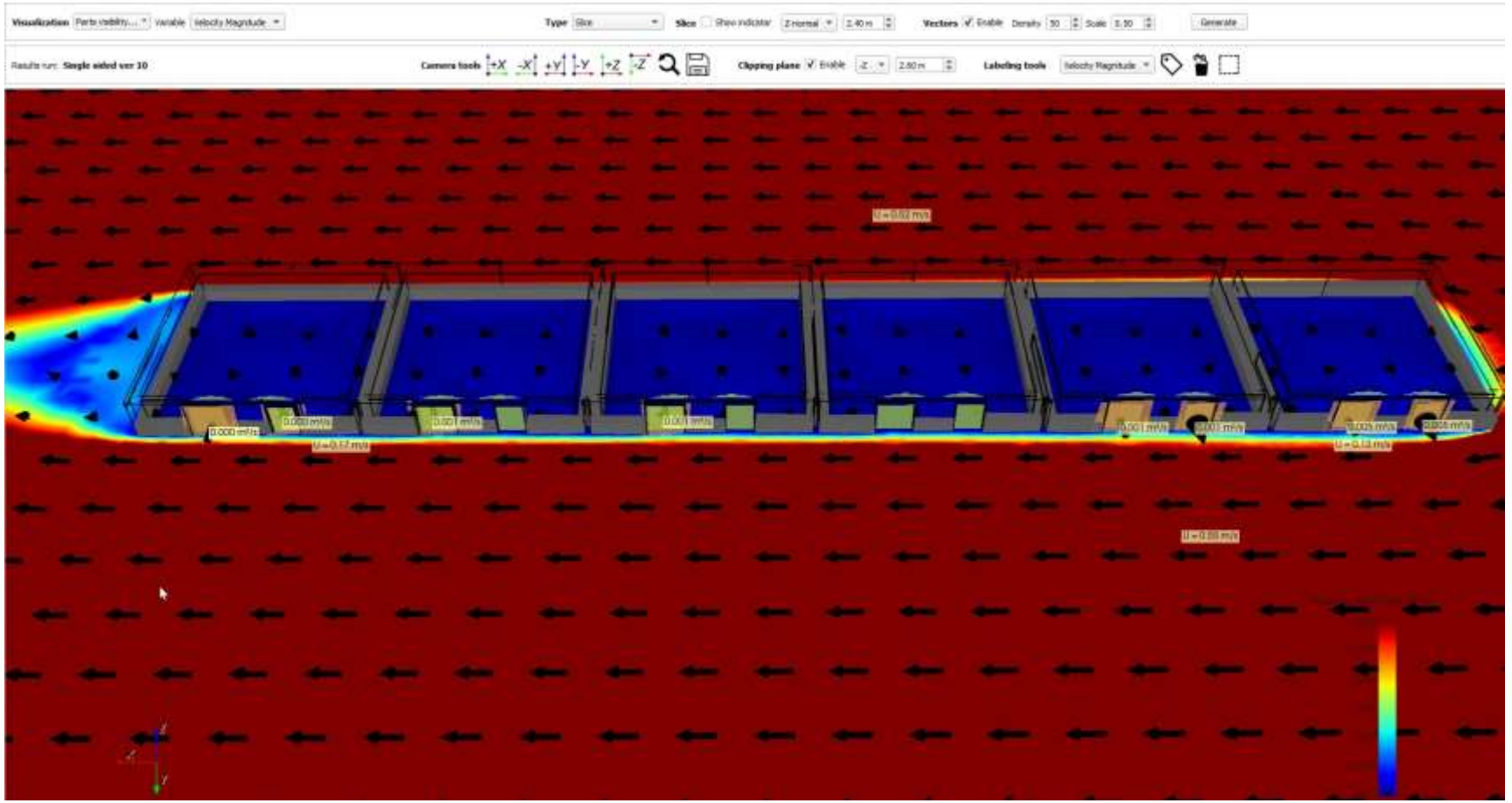


Example 1 single sided ventilation

例 1：单侧通气

- Flow parallel to the long facade
- 2 m/sec
- No wind guide

平行于长立面
2 米/秒
非导风系统

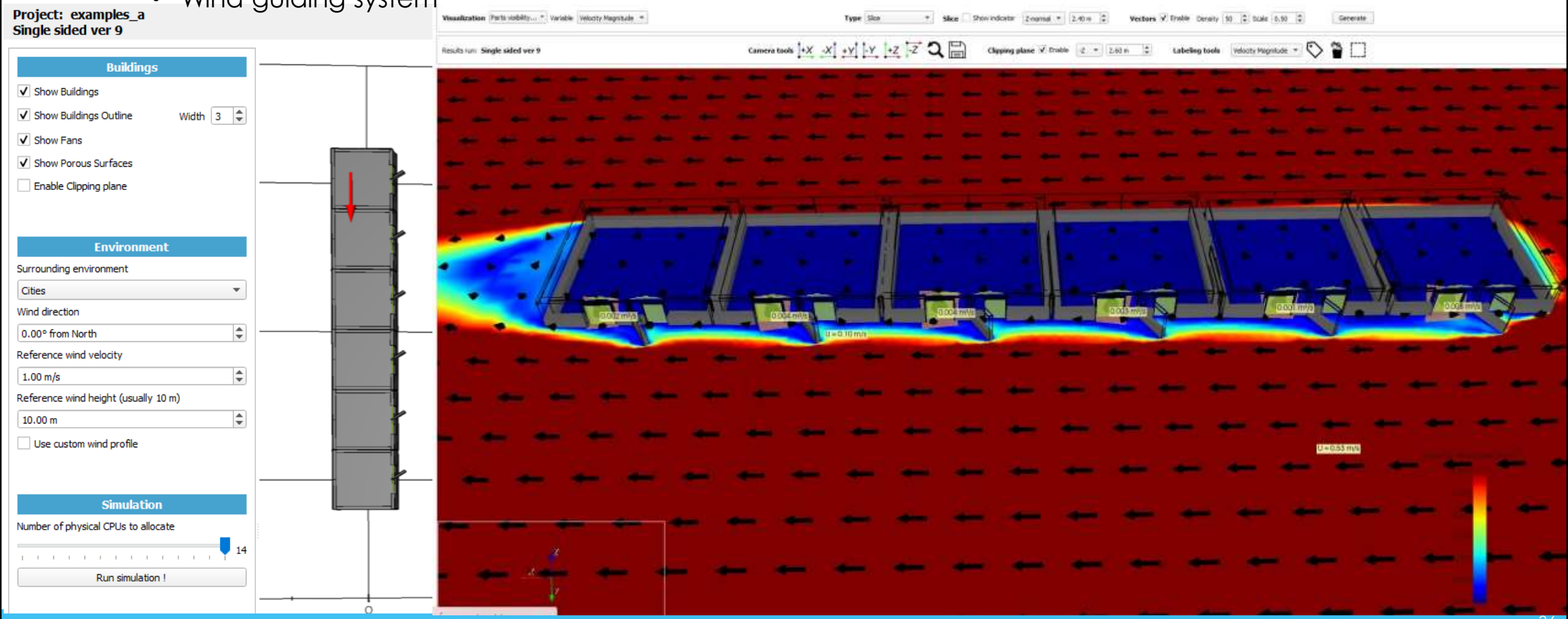


Example 1 single sided ventilation

例 1：单侧通气

- Flow parallel to the long facade
- 1 m/sec
- Wind guiding system

平行于长立面
1 米/秒
导风系统



Example 1 single sided ventilation

例 1：单侧通气

- Flow parallel to the long facade
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平行于长立面
2 米/秒
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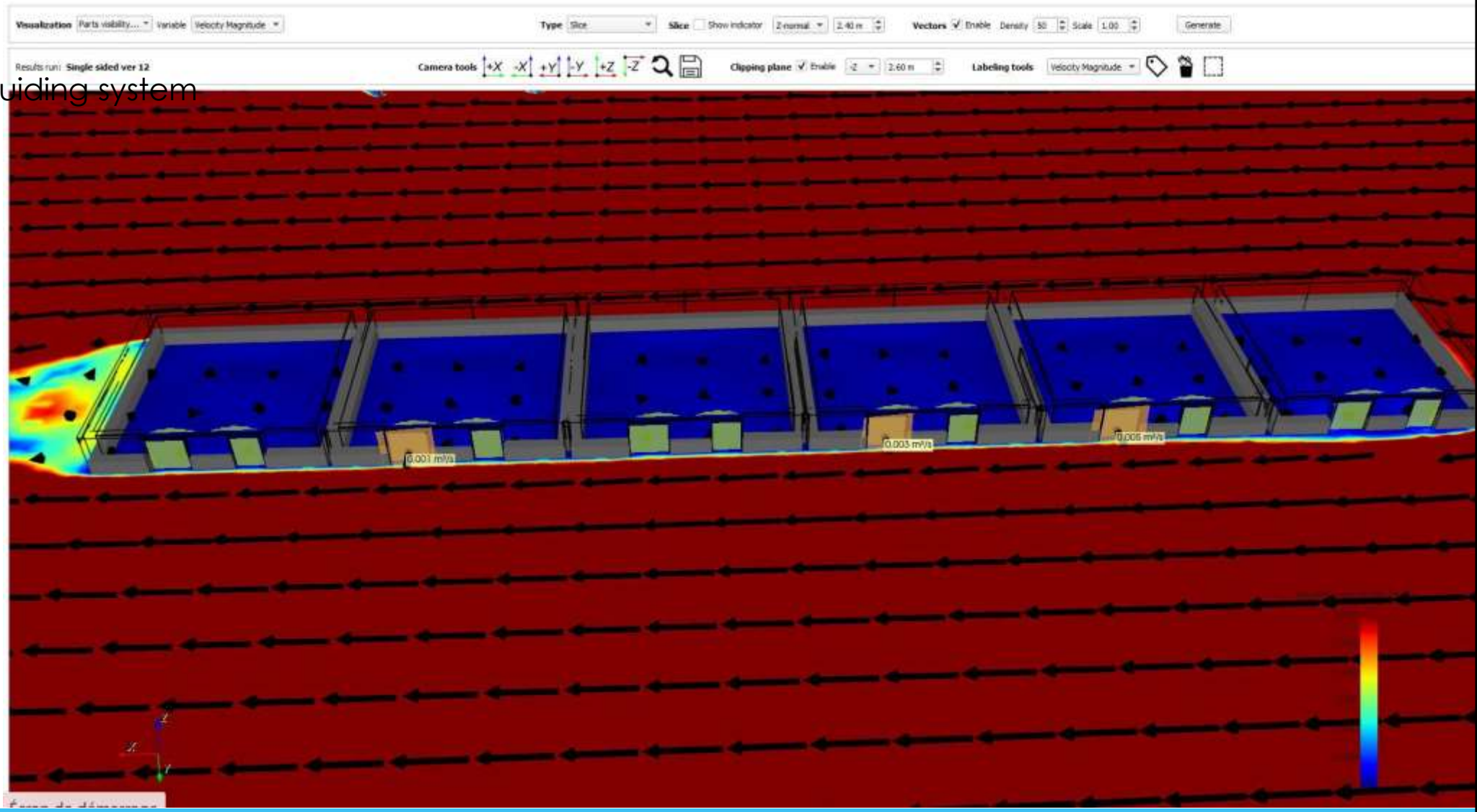
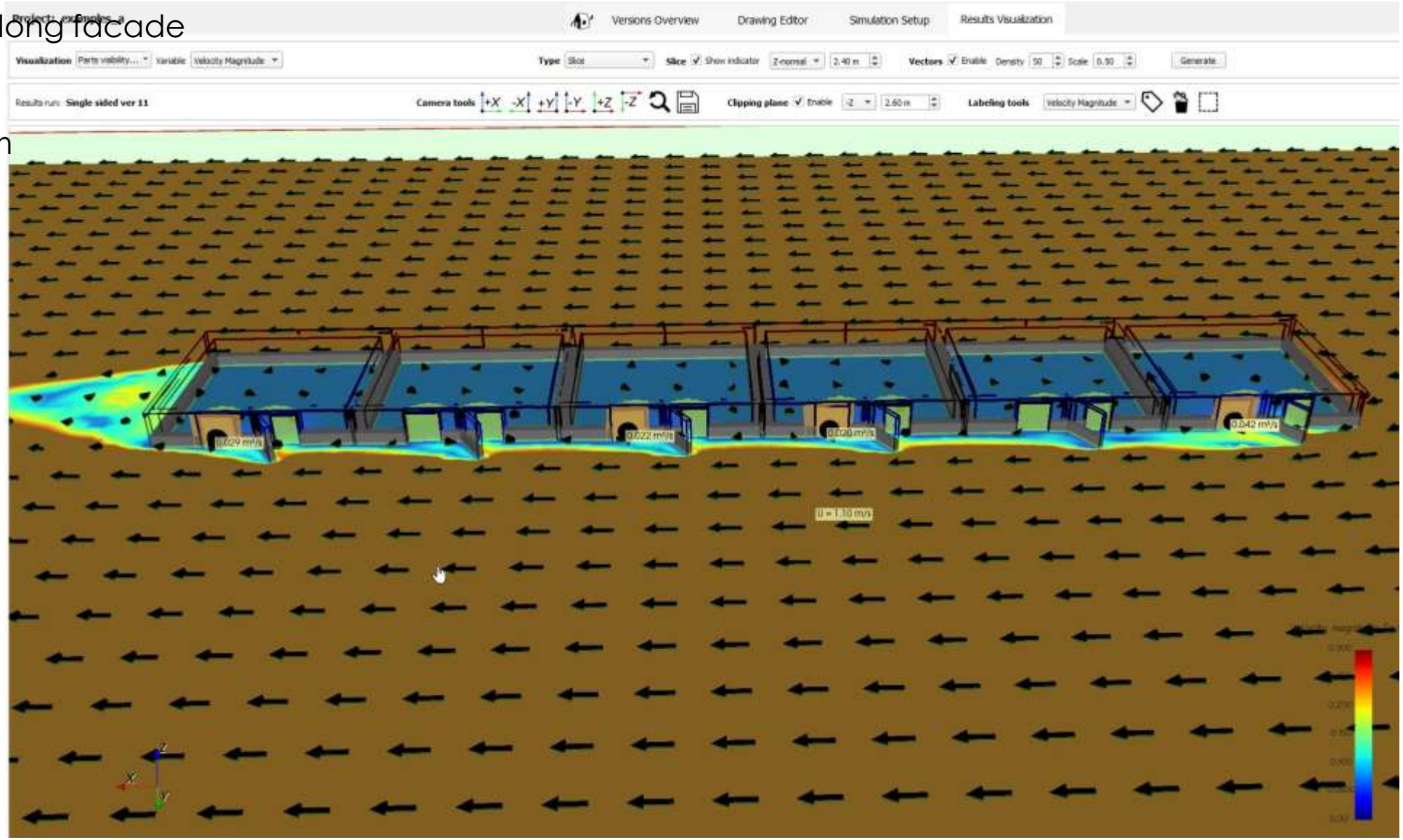


Example 1 single sided ventilation

例 1：单侧通气

- Flow parallel to the long facade
- 1 m/sec
- Wind guiding system

平行于长立面
1 米/秒
导风系统

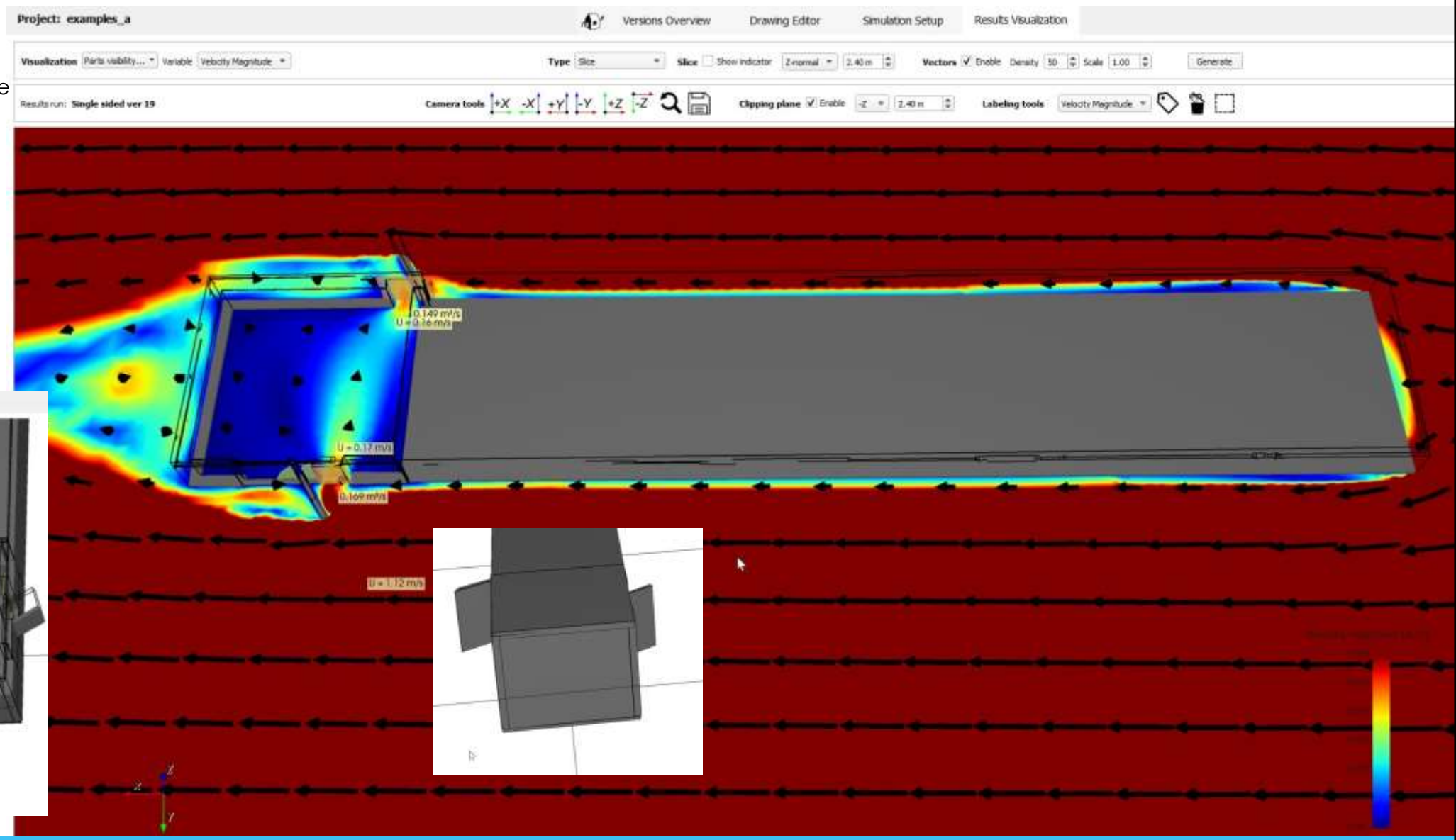


Example 1 modified with cross ventilation

例 1：改为交叉通风

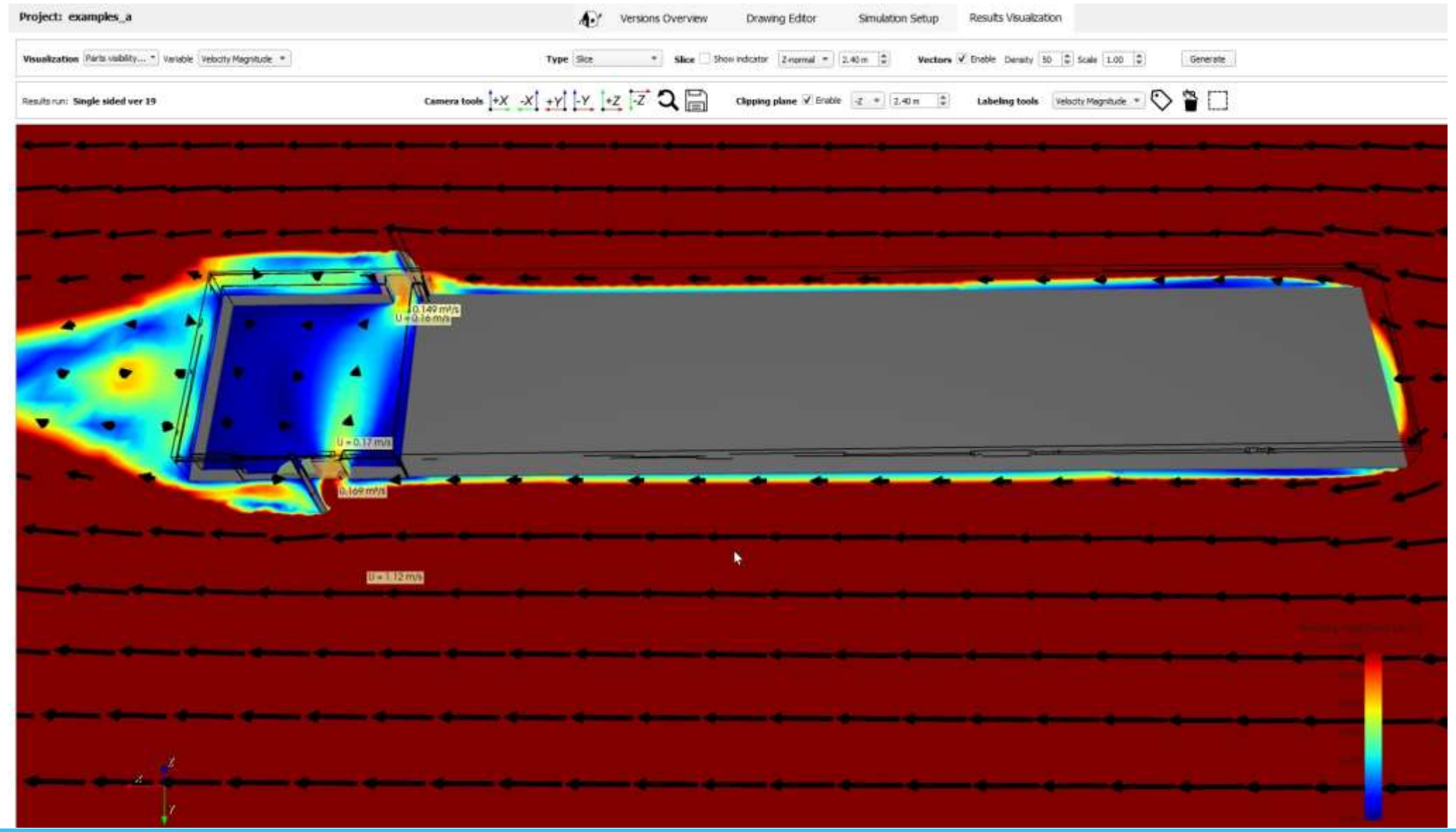
- Flow parallel to the long facade
- 1 m/sec
- Wind guiding system
- ~ 15 ACH

平行于长立面
1 米/秒
导风系统
~ 15 ACH



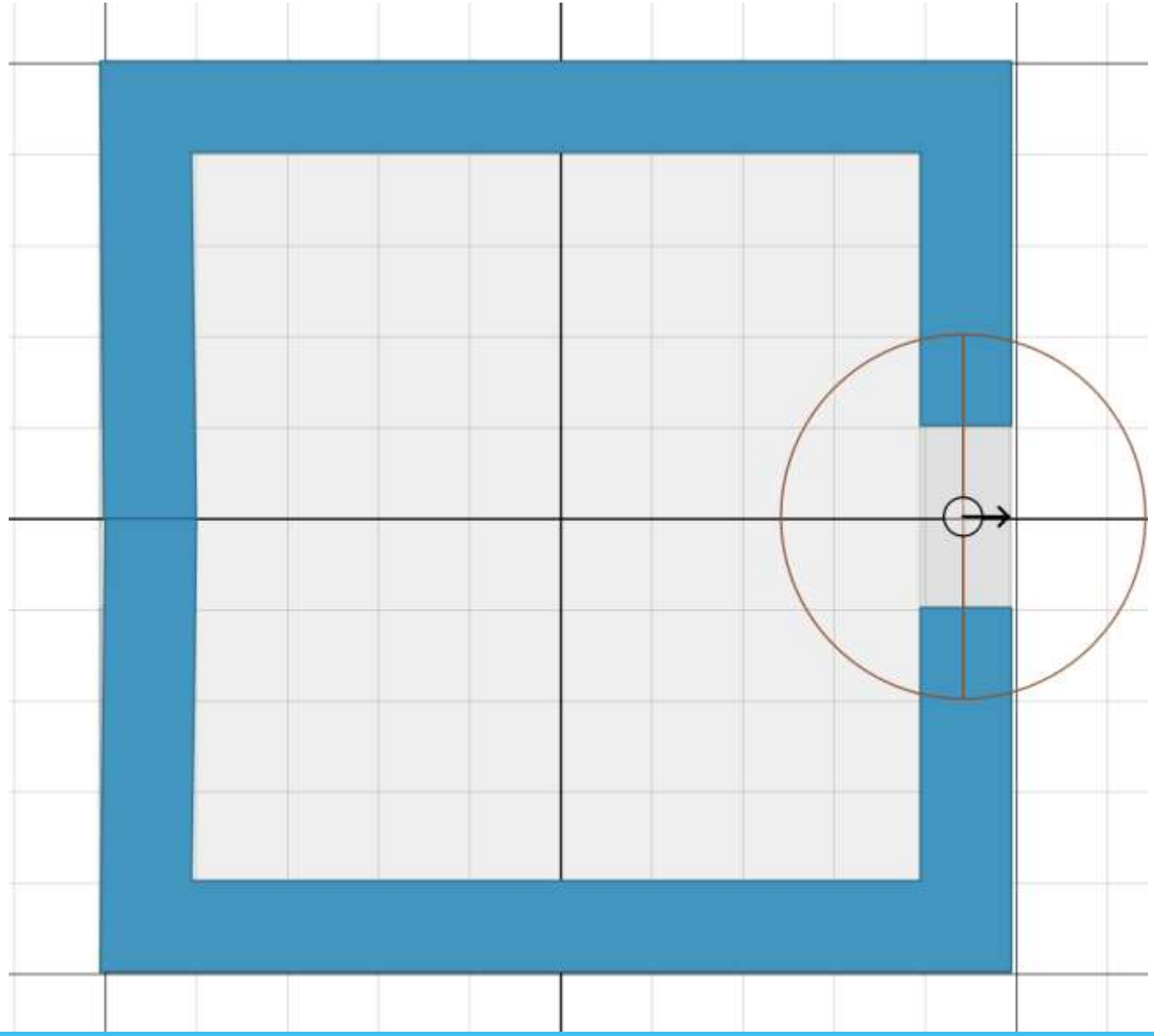
Example 1 modified with cross ventilation

例 1：改为交叉通风



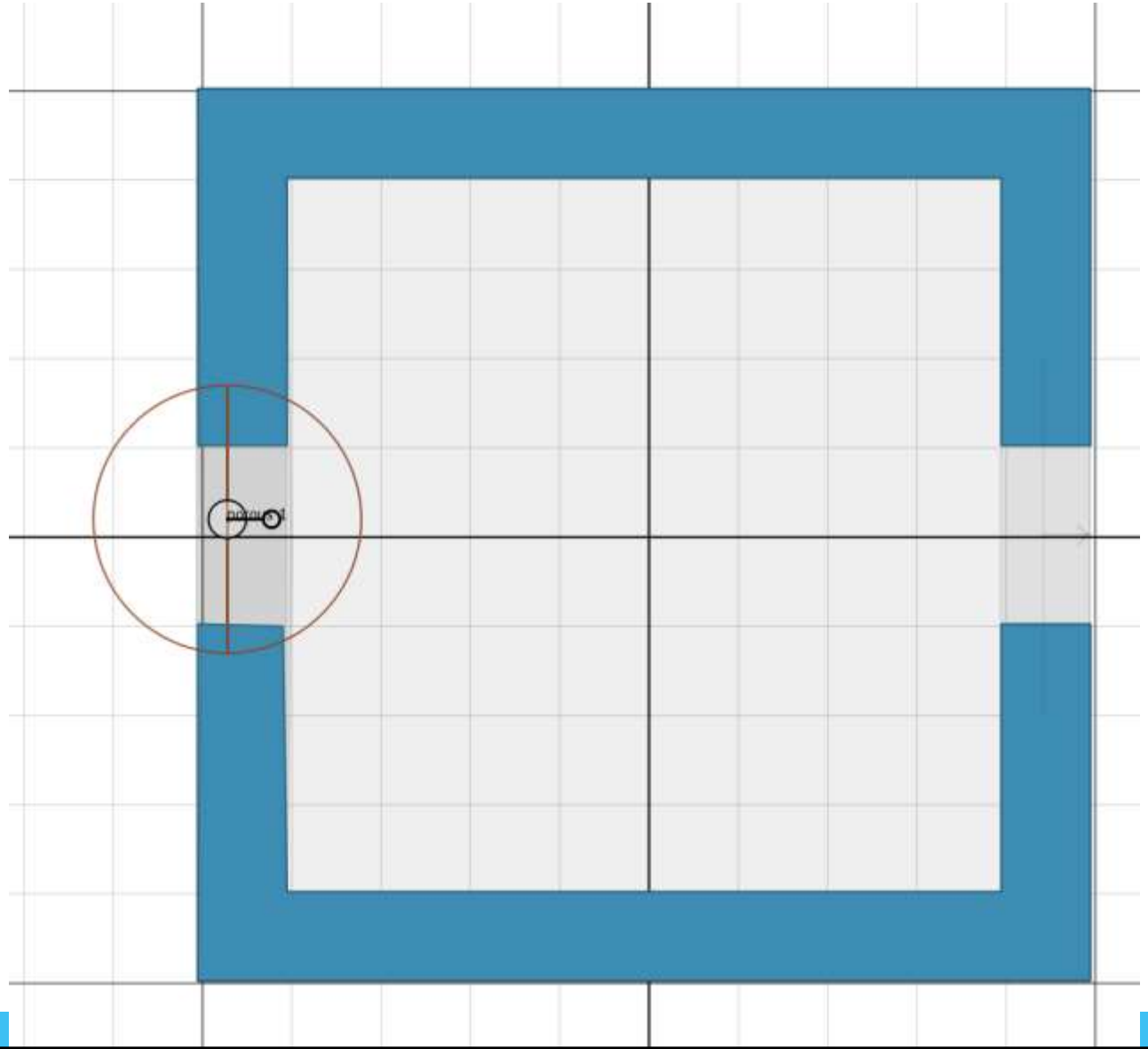
Example 2 add a fan

例 2：加风扇



Example 2 add a porous surface

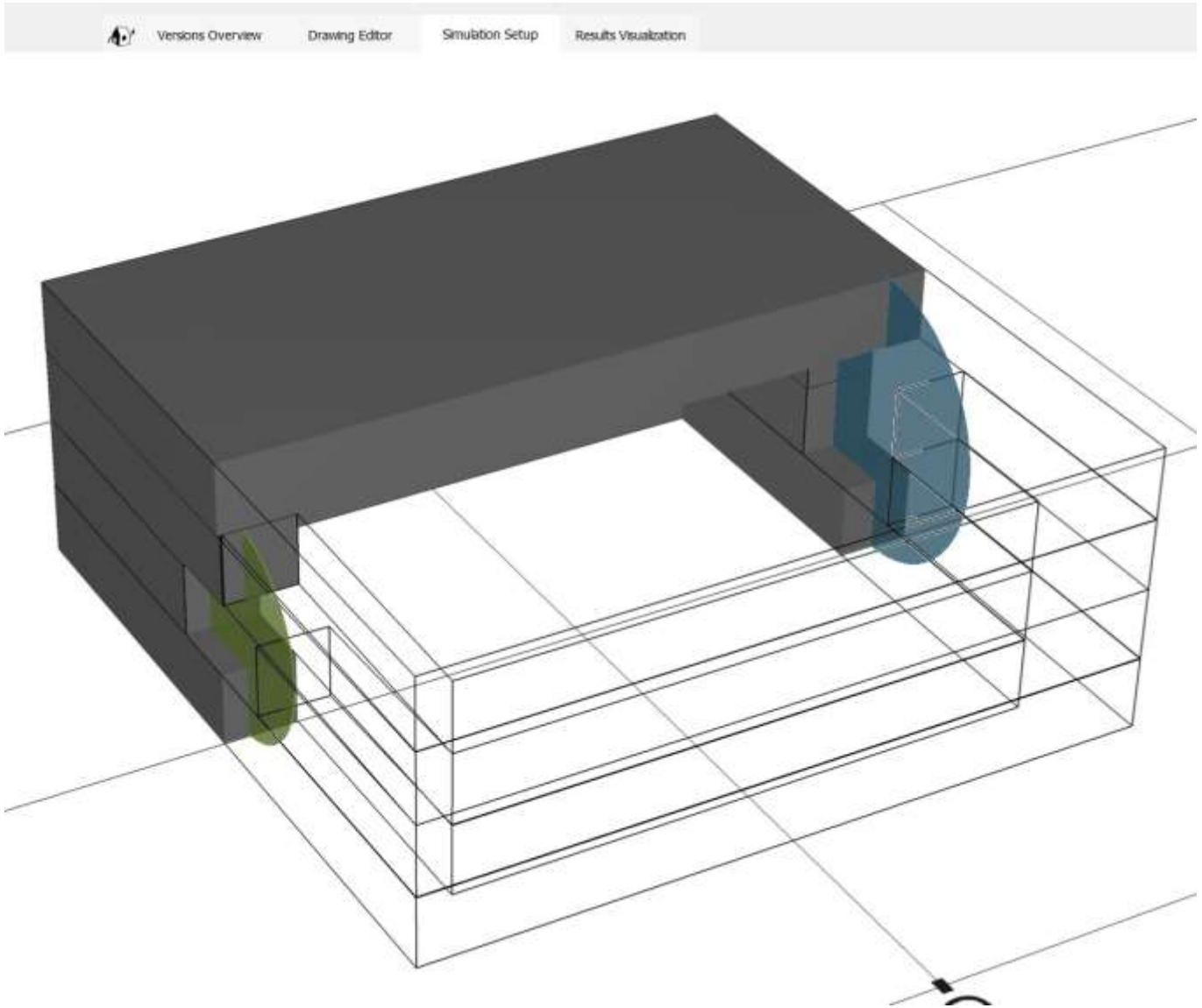
例 2：添加多孔表面



Example 2 visualise in simulation setup

例 2：在模拟设置中可视化

- Cut view (clipping plane)



Example 2: Simple equation for calculation of air across a window

Bernoulli Equation a refresher for an opened window without resistance

例 2：计算空气通过窗户流量，伯努利方程

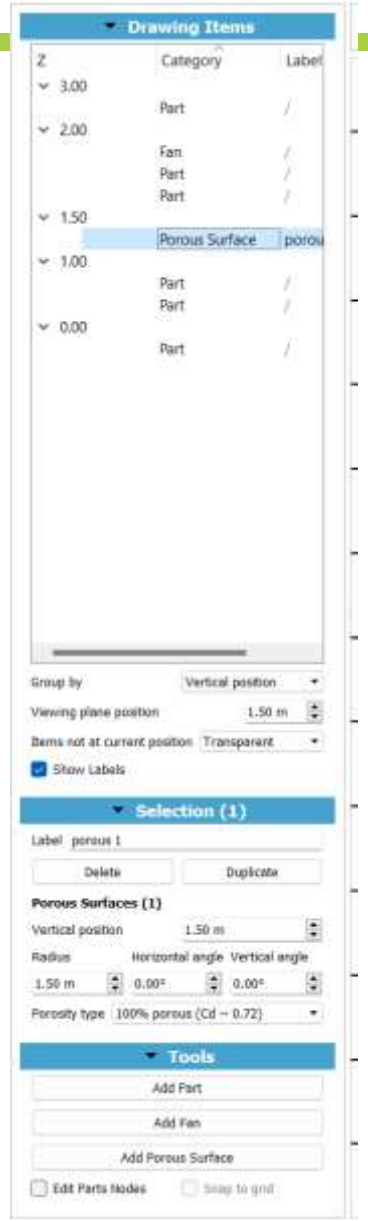
- $p1+1/2 x rho * u1^2 = p2+1/2 x rho * u2^2$
- if one admits that the pressure differential across the opening is from ambient to a negative pressure in the zone then the velocity far away is ~to 0 ➔ so the equation $p1=p2+1/2 \times rho \times u^2$ 如果我们认为开口处的压差从环境压力变为区域内的负压，那么远处的速度就是 ~0
- so the velocity through the opening is equal to $u= sqrt(2 \times DeltaP/rho)$
- by multipliying the velocity by the area of air passage, then one introduces a discharge coefficient (Cd) to take care of the real conditions of the air flow pattern (restriction, edge). Generally for an opened window without any resistance the value of Cd=0.72 is used. 将速度乘以空气通道的面积，然后引入排出系数（Cd），以考虑气流模式的实际情况（限制、边缘）。一般来说，对于没有任何阻力的开窗，Cd=0.72。
- $Q=Cd \times A \times u=Cd \times A \times (sqrt(2 \times DeltaP/rho)$
- Cd=0.72 A=2 m2 DeltaP=5 Pa Rho=1.2 kg/m3
- $Q = Cd * \sqrt{A * \quad 2 * DeltaP/Rho}$ m^3/sec
- $Q = 4.04\ m3/sec$ for a window opened without resistance (simplified Bernoulli equation)

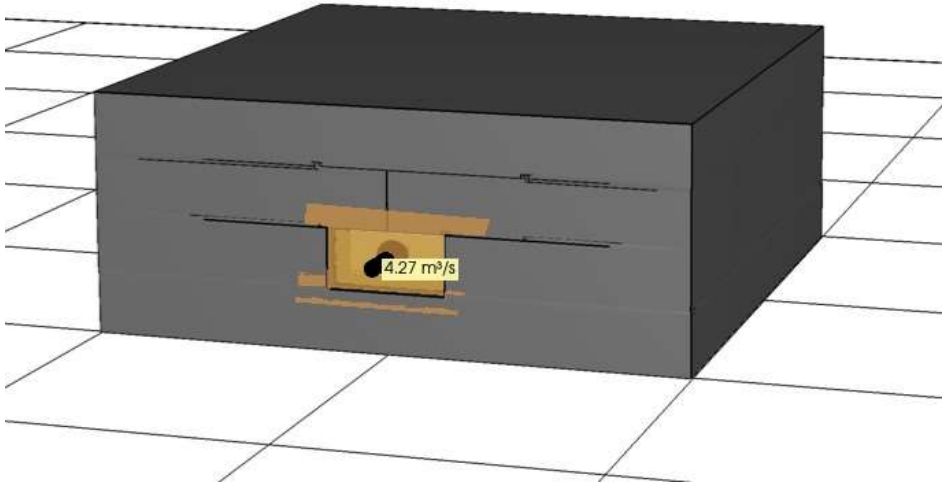
Example 2: results for an opened free window

例 2：开窗计算结果

- Bernoulli equation 伯努利方程
- Cd 0.72
- $Q = 4.04\ \ \mathrm{m3/sec}$ for a window opened without resistance (simplified Bernoulli equation) Q = 4.04 立方米/秒（简化伯努利方程）
- Simulation with Vayu Pravah 4.26 m3/sec

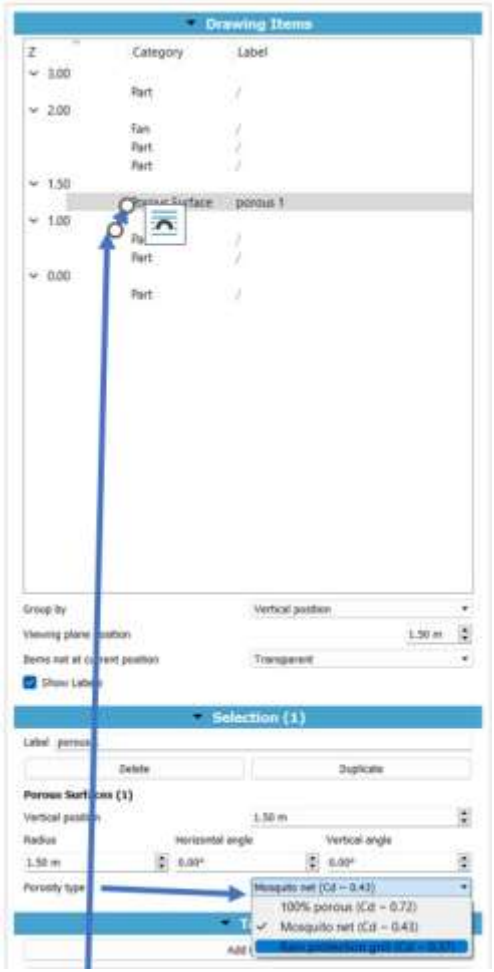
Vayu Pravah 模拟4.26 立方米/秒

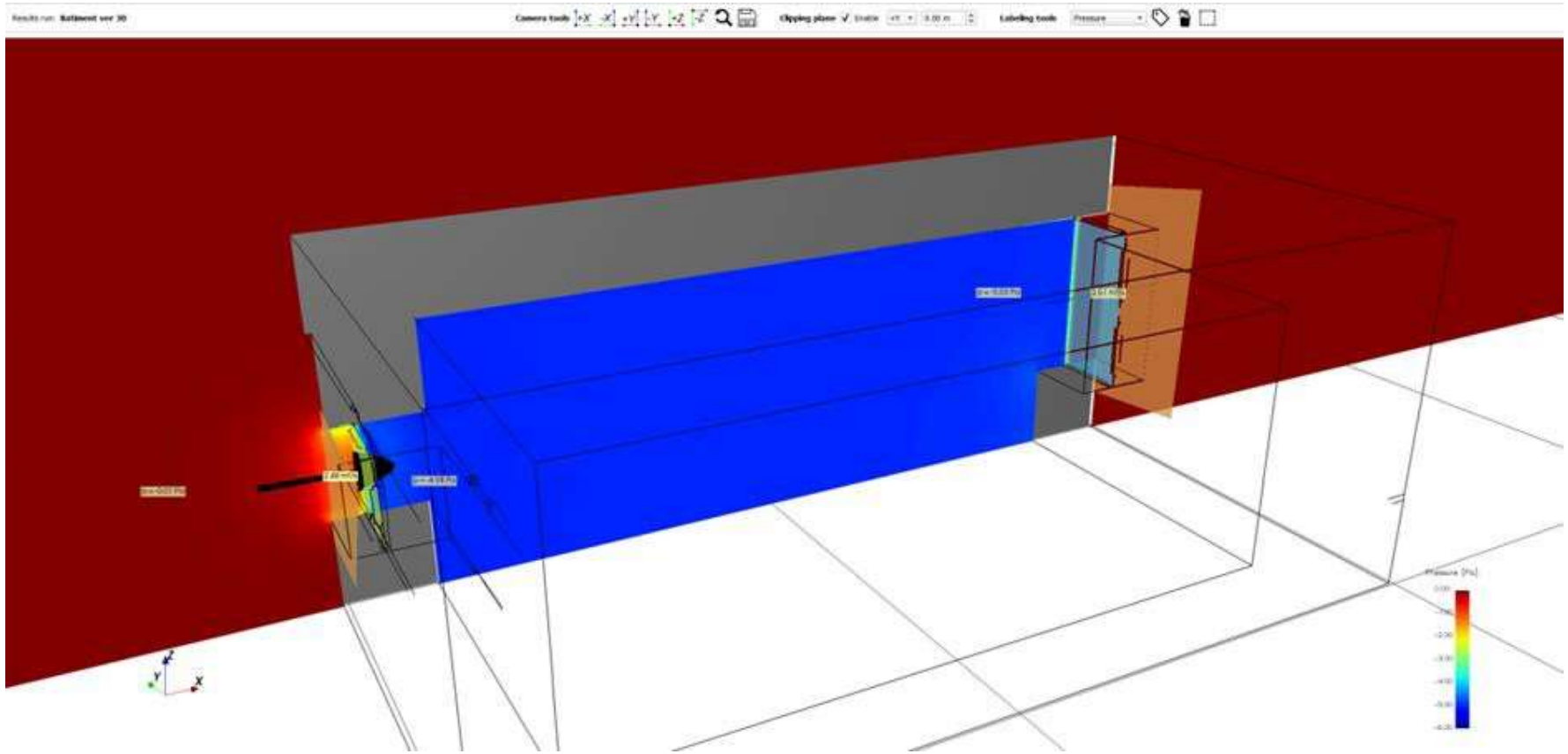




Example 2: with a resistance like mosquito net

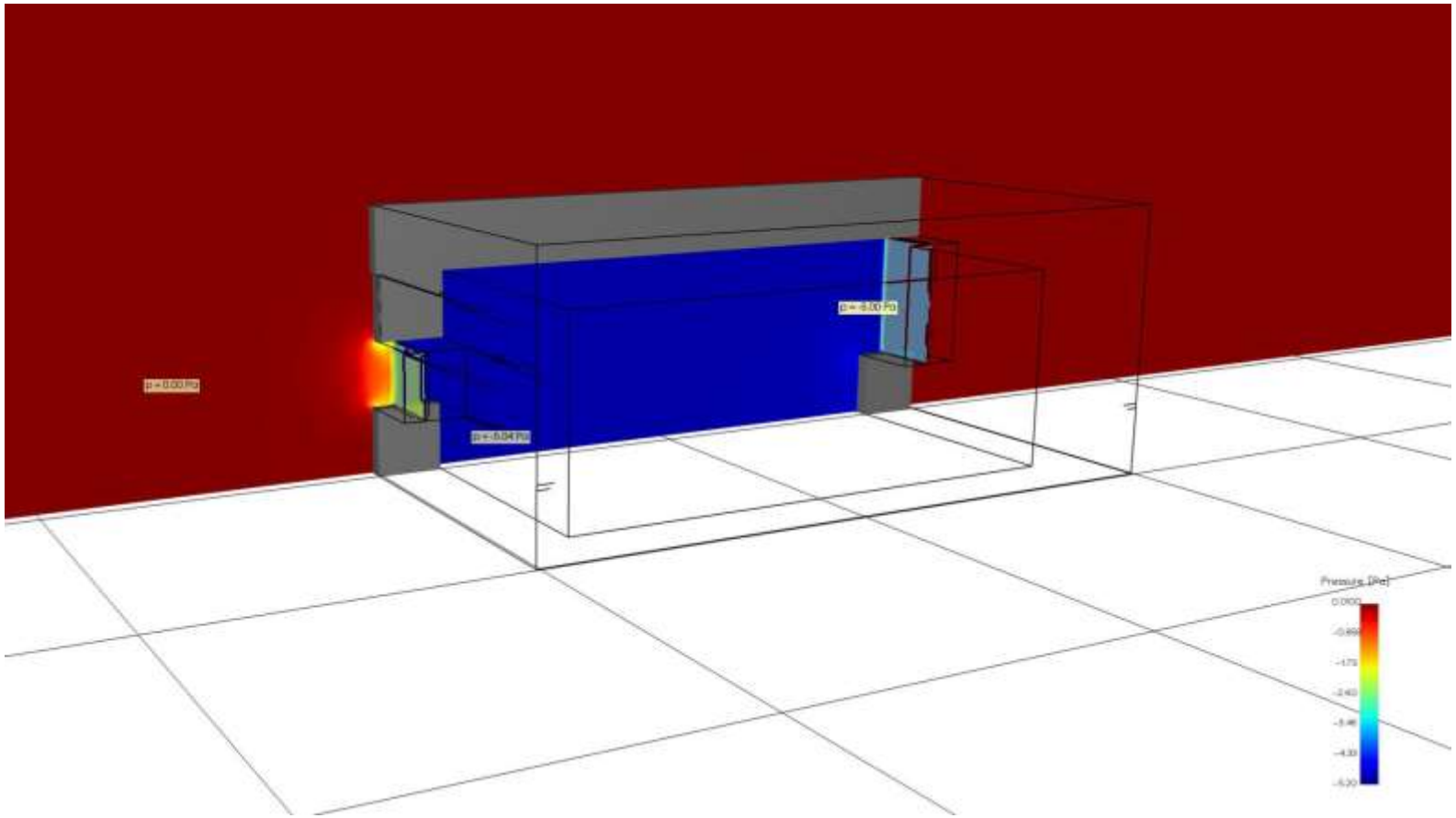
例 2：蚊帐网的阻力





Example 2 visualise results (pressure)

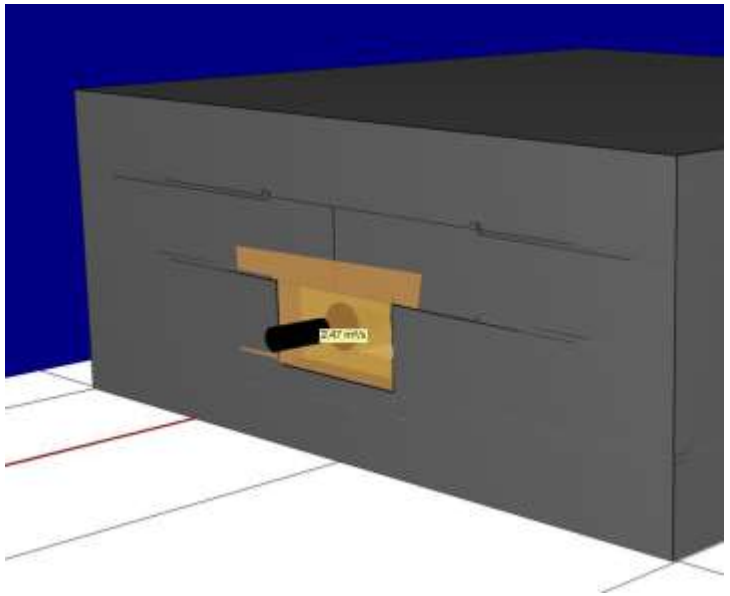
例 2：可视化结果（压力）

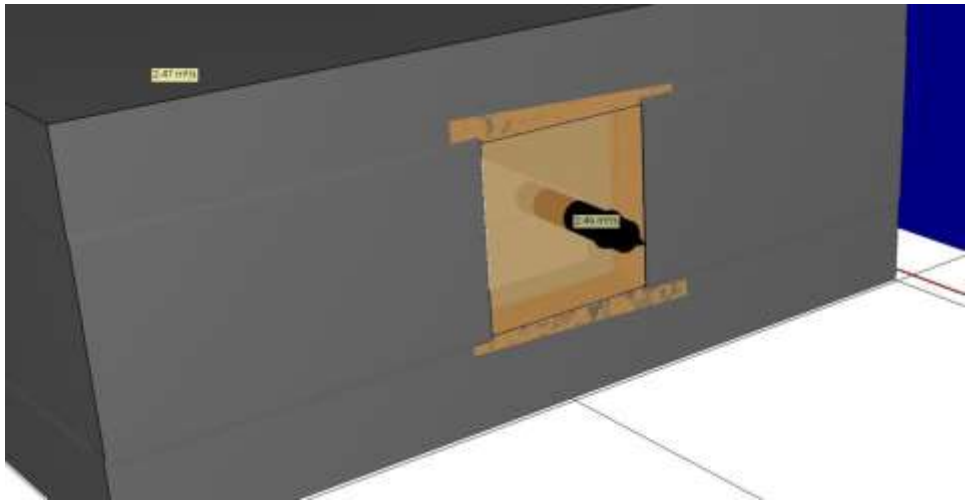


Example 2: with a resistance like mosquito net

例 2：蚊帐网的阻力

- Flow rate 2.47 m3/sec　2.47 立方米/秒





Example 3: Ventilative cooling

例 3：通风冷却

- When the wind is not sufficient to allow natural cross-ventilation one can add a fan ensure a high air change rate with very low power

  当风力不足以实现自然交叉通风时，可以加装风扇，确保以极低的功率实现高换气率。
- The example of a real test and simulation with Vayu Pravah

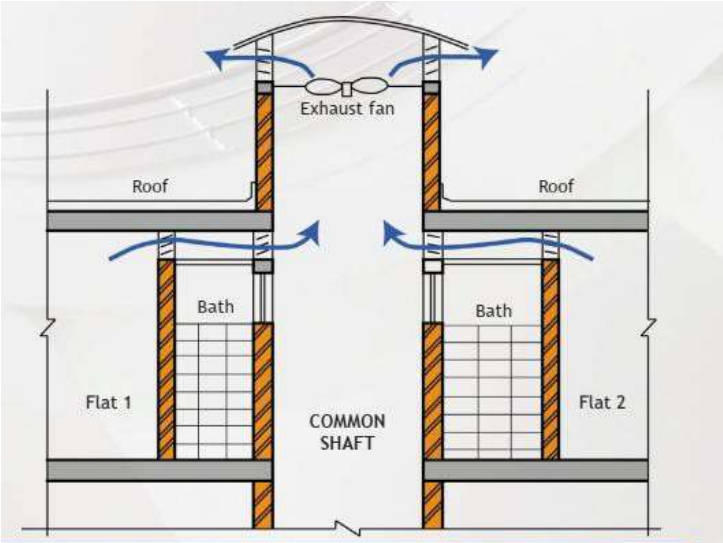
  使用 Vayu Pravah 进行实际测试，在拉杰科特Smart Ghar III进行试验
- The experiment on a real scale at Rajkot (Smart Ghar III)
- Objectives
  - Demonstrate the feasibility of a balanced ventilative cooling system on 7 floors with 14 flats

  试验对象：在 7 层楼的 14 个单元展示平衡通风冷却系统的可行性

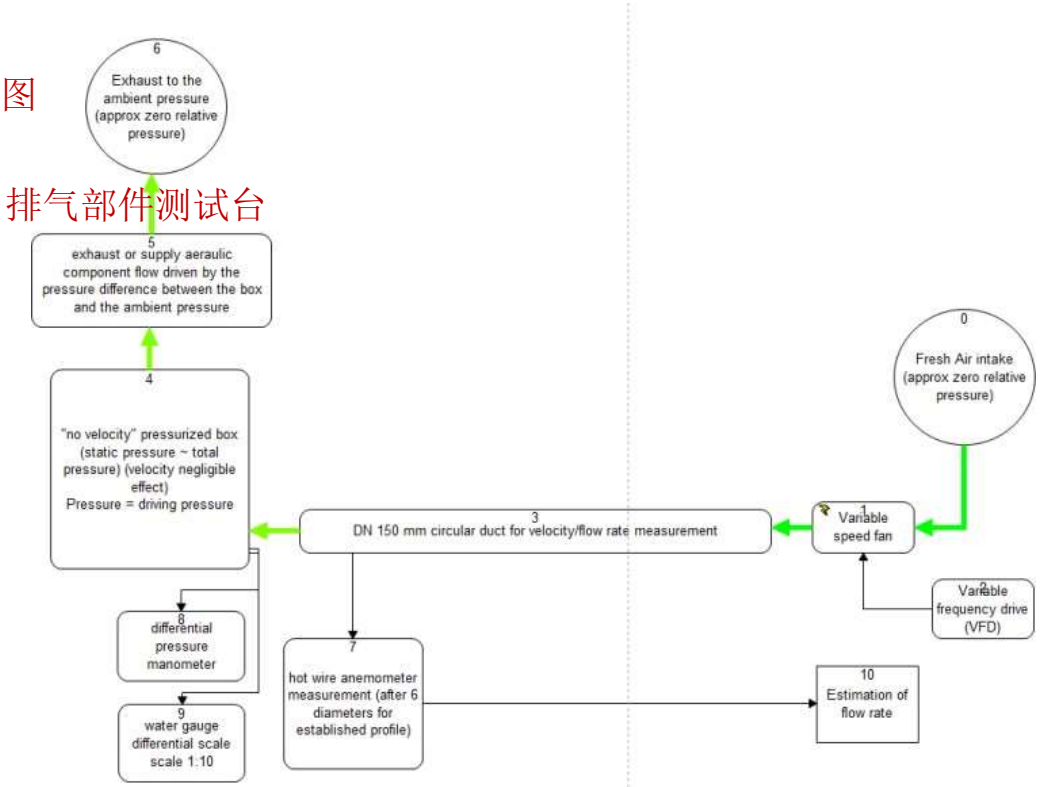
Example 3: Ventilative cooling

例 3：通风冷却

- The principle of the test 试验原理
- Concept and design of a balanced ventilative cooling system wihout any damper or other control system 无风门或其他控制系统的平衡通风冷却系统的概念和设计
- Schematic concept of the system 系统示意图
- Test bench for the exhaust component 排气部件测试台



Conceptual sketch of assisted ventilation through the common shaft between flats



Example 3: Ventilative cooling

例 3：通风冷却

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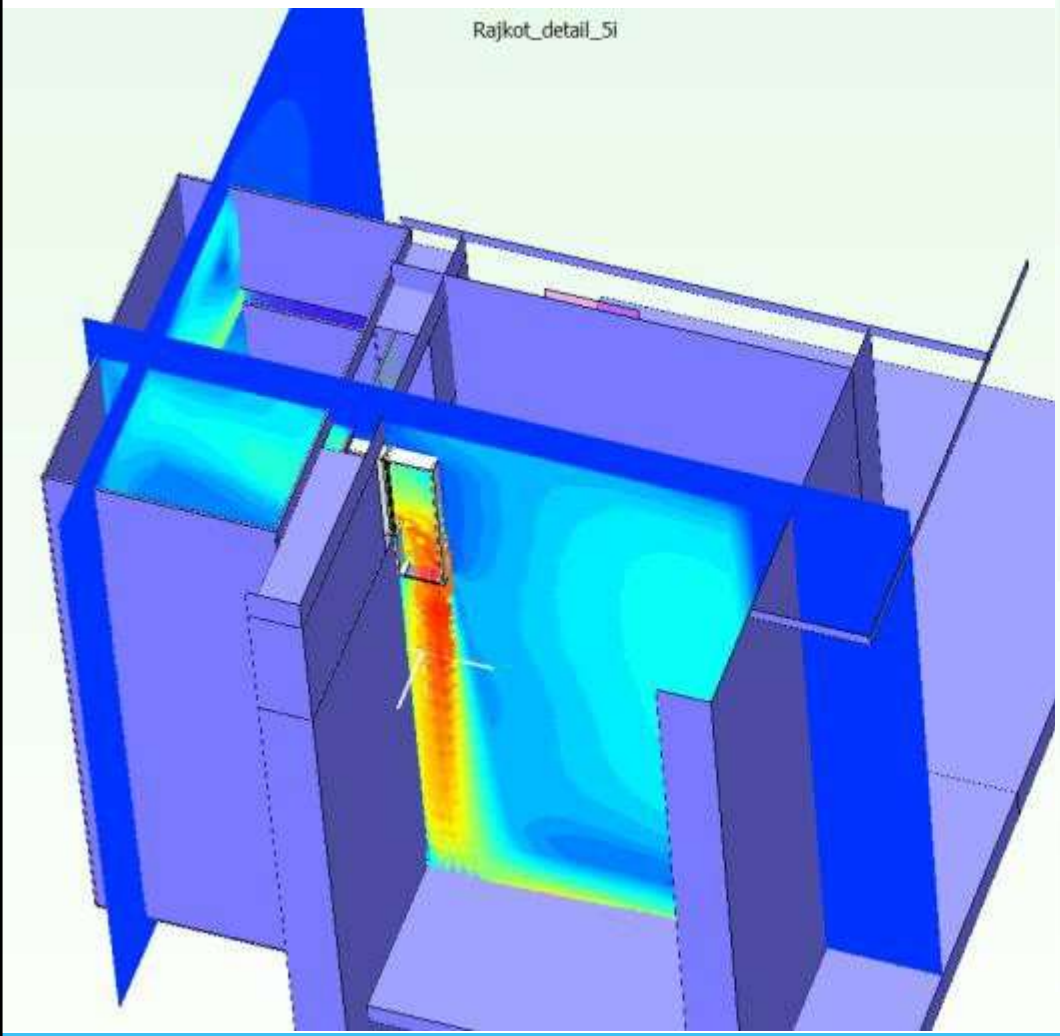
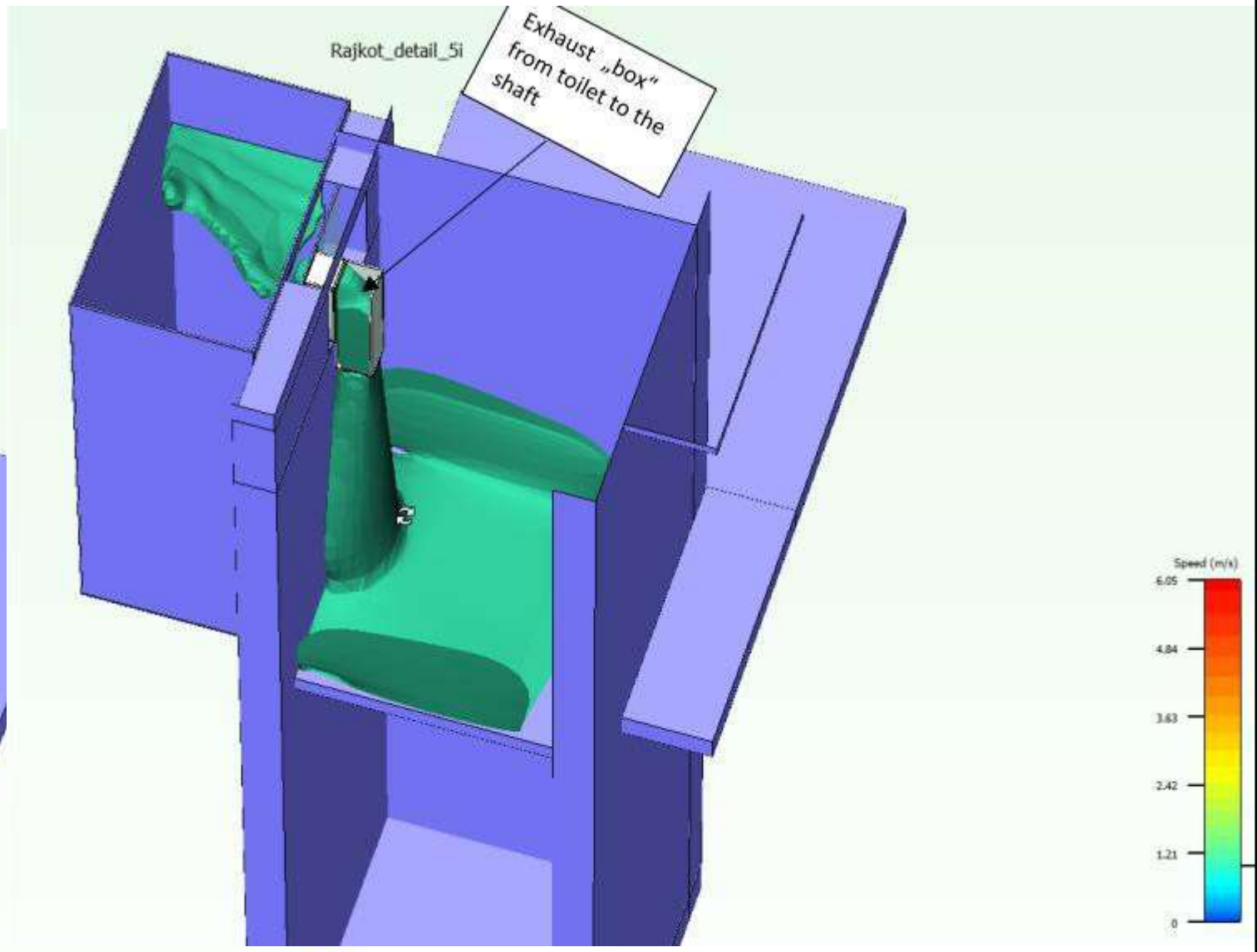
- CFD design (Flovent)





Example 3: Ventilative cooling

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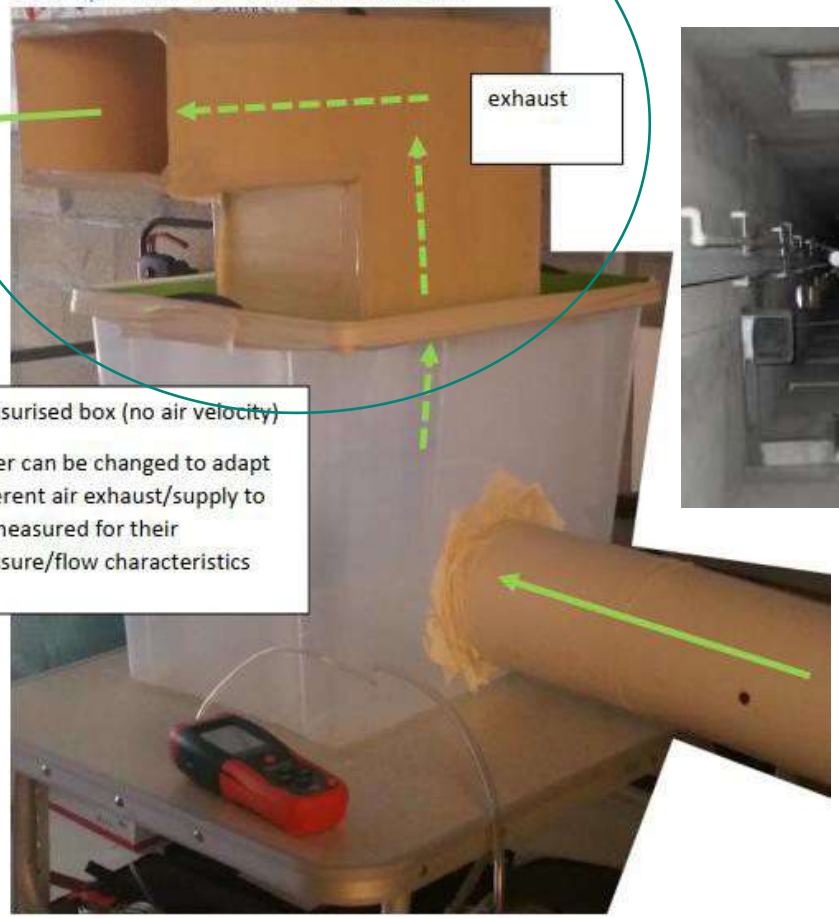
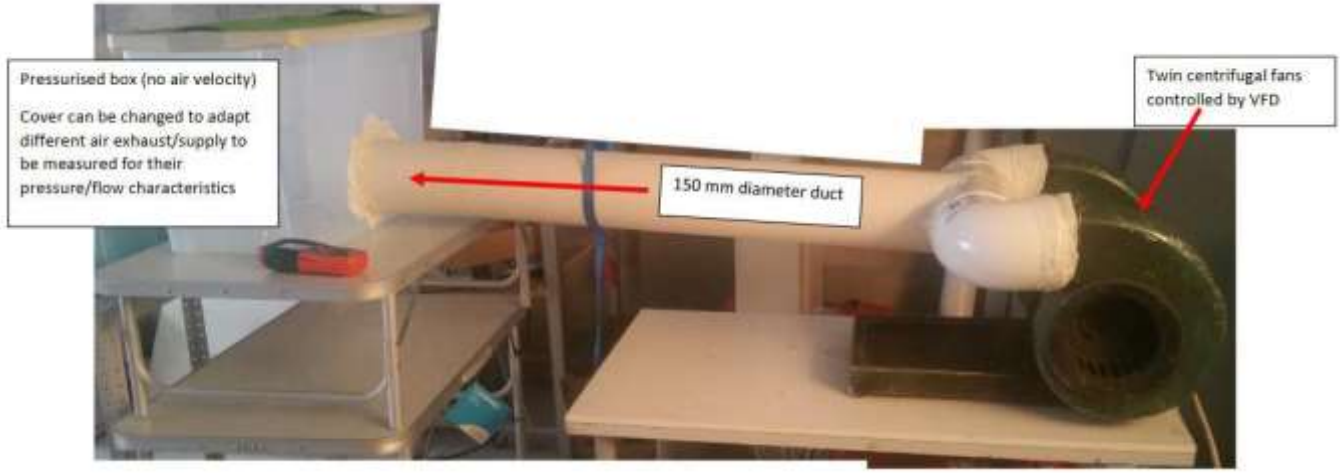
Set-up with the model scale 1:1



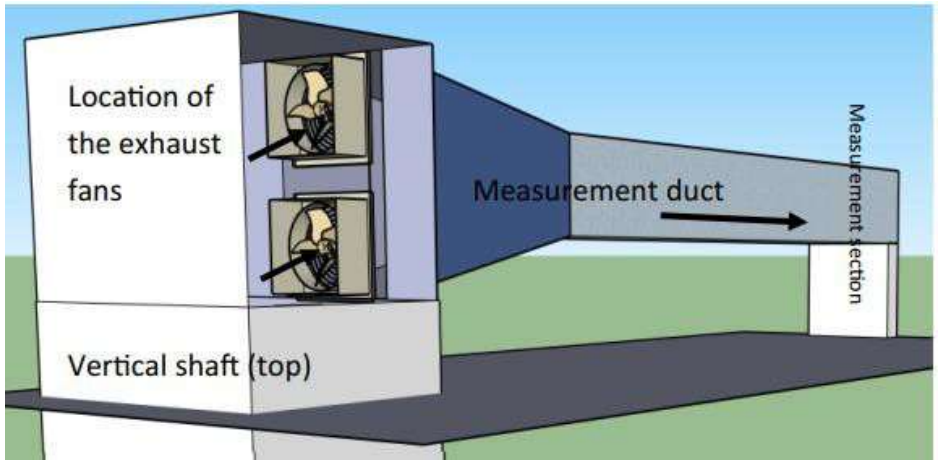
16h38	with net		
speed DN 0.153 m	6.50	m/sec	
diam	0.153	m	
radius	0.077	m	
pi()	3.14		
area	0.018	m2	
debvol	0.120	m3/sec	
debvolhr	430	m3/h	
number of exhausts	2		
total flow rate	860	m3/h	
diff water column 1:10	43		
	46		
	3	cm water at a slope of 1:10	
	3	Water mmG	
Diif manometer	0	0.03	kPa
		30	Pa

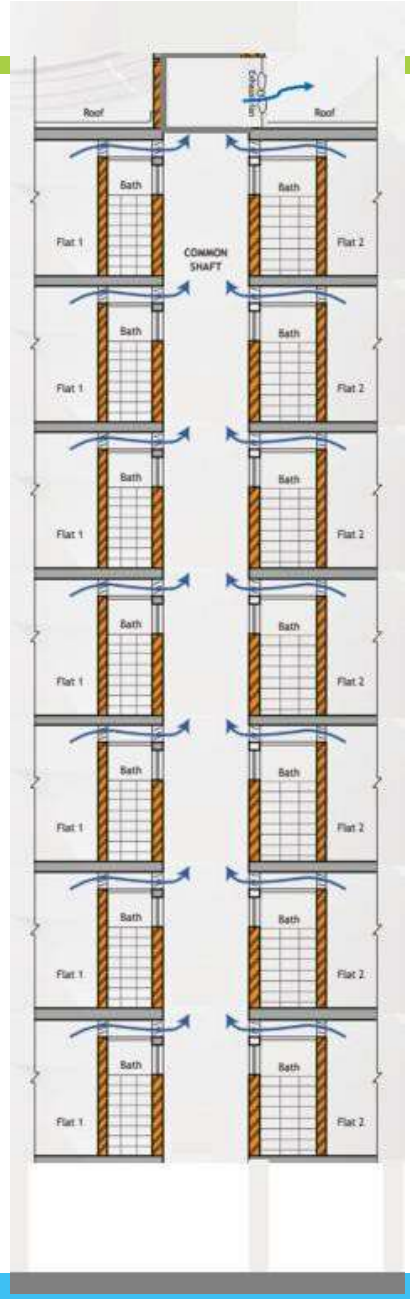
Carpet area	28	m2	
height	2.8	m2	
Volume	78.4	m3	
ACH	11.0	1/hr	

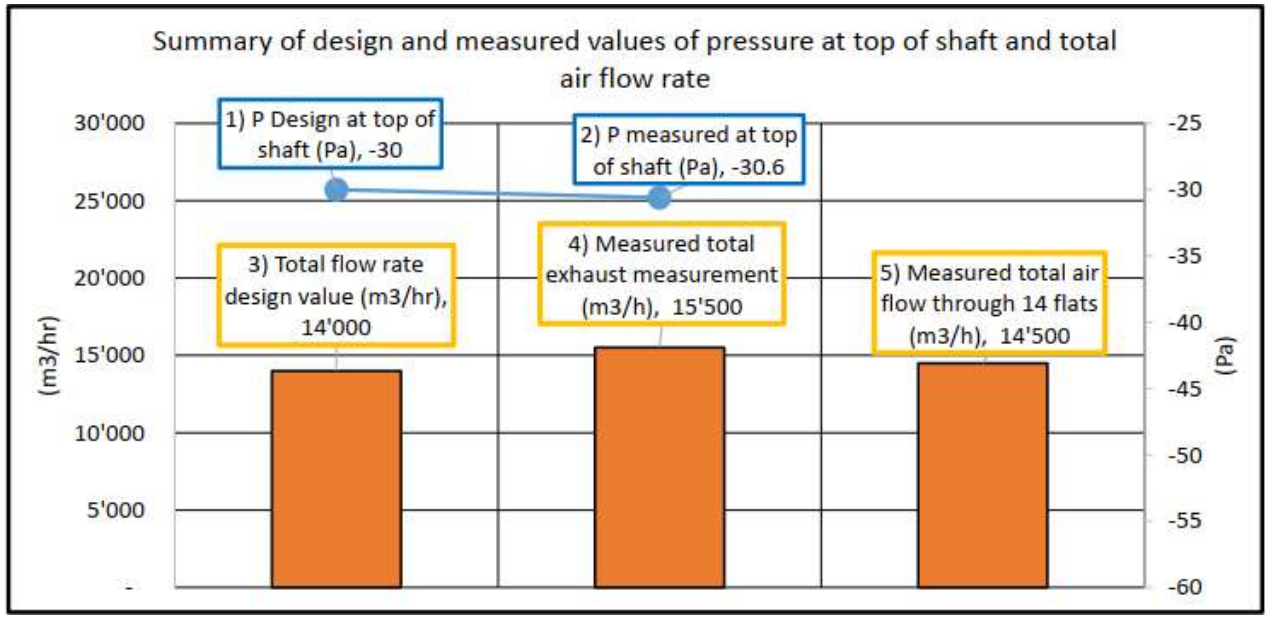


Example 3: Ventilative cooling actual test results

例 3：通风冷却试验结果



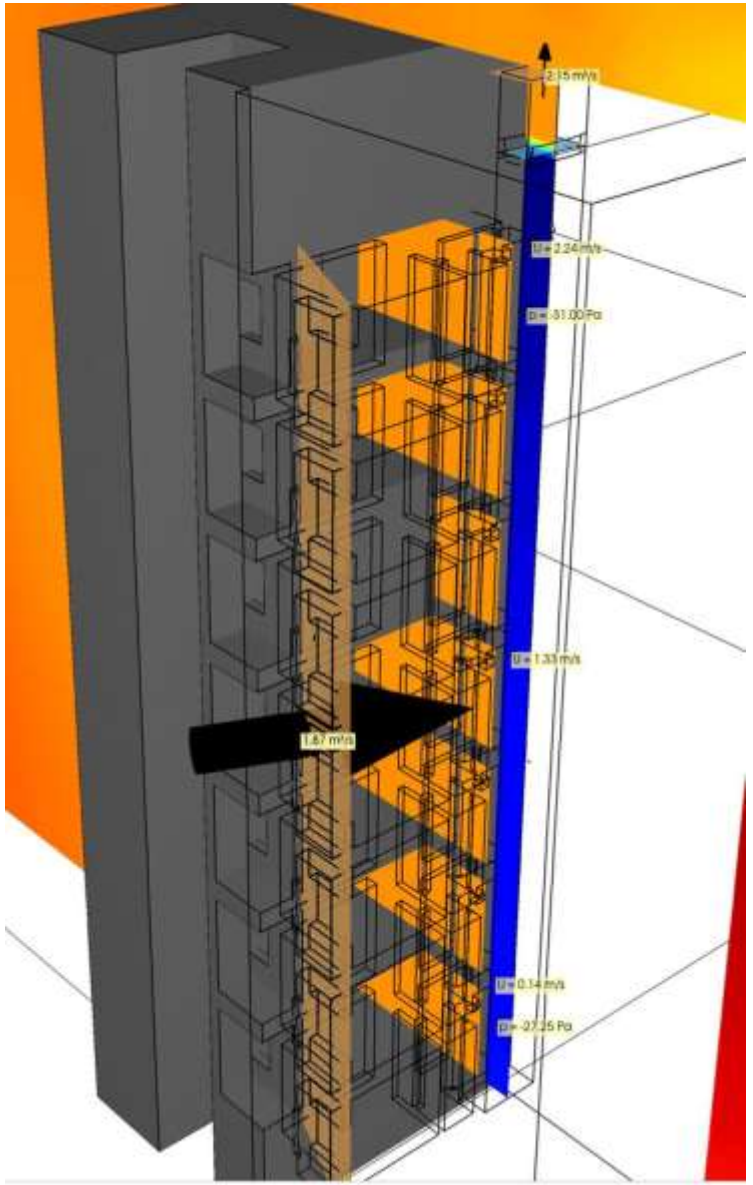




Example 3: Ventilative cooling

例 3：通风冷却

- Modelling with Vayu Pravah
  与 Vayu Pravah 一起建模
- 7 flats with the corresponding system
  7 个单位与相应系统
- A fan which generates a pressure jump of 30 Pa
  产生30Pa压力跃变的风扇
- Calibrated exhaust to the shaft for 30 Pa pressure loss
  经过校准的排气口，压力损失为 30Pa
- Total air flow: 7200 m3/h
  总风量 7200 立方米/小时



Example 3: Ventilative cooling

例 3：通风冷却

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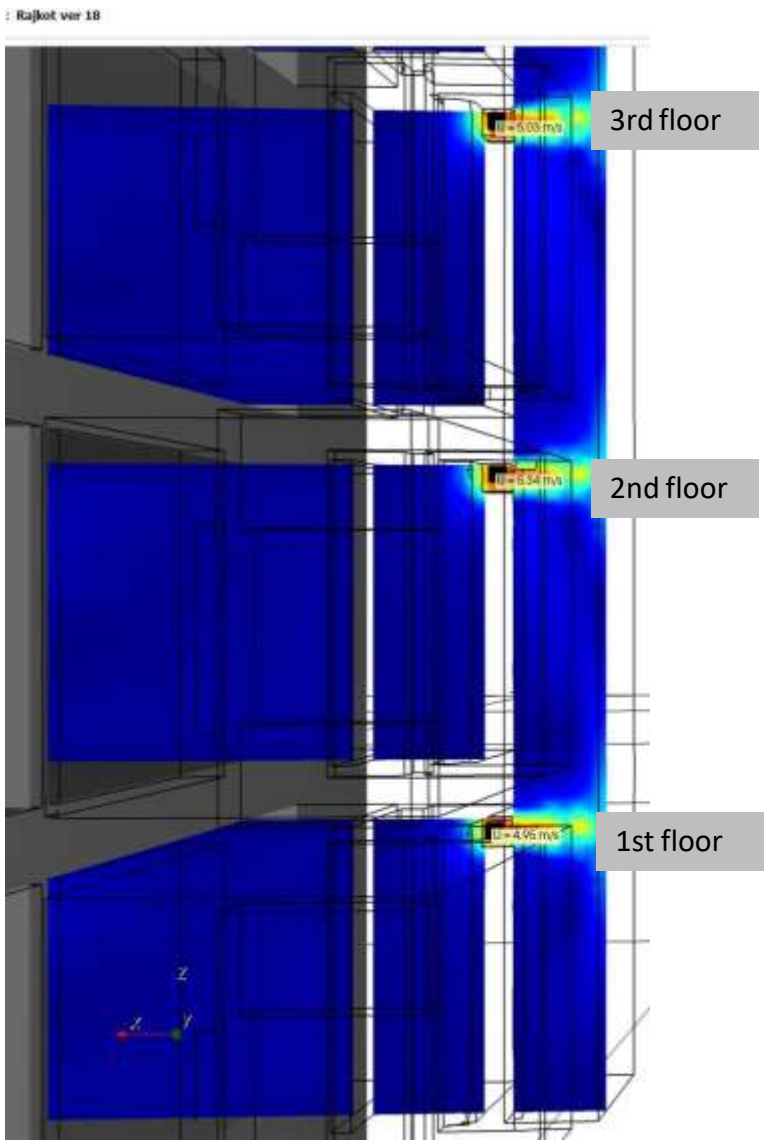

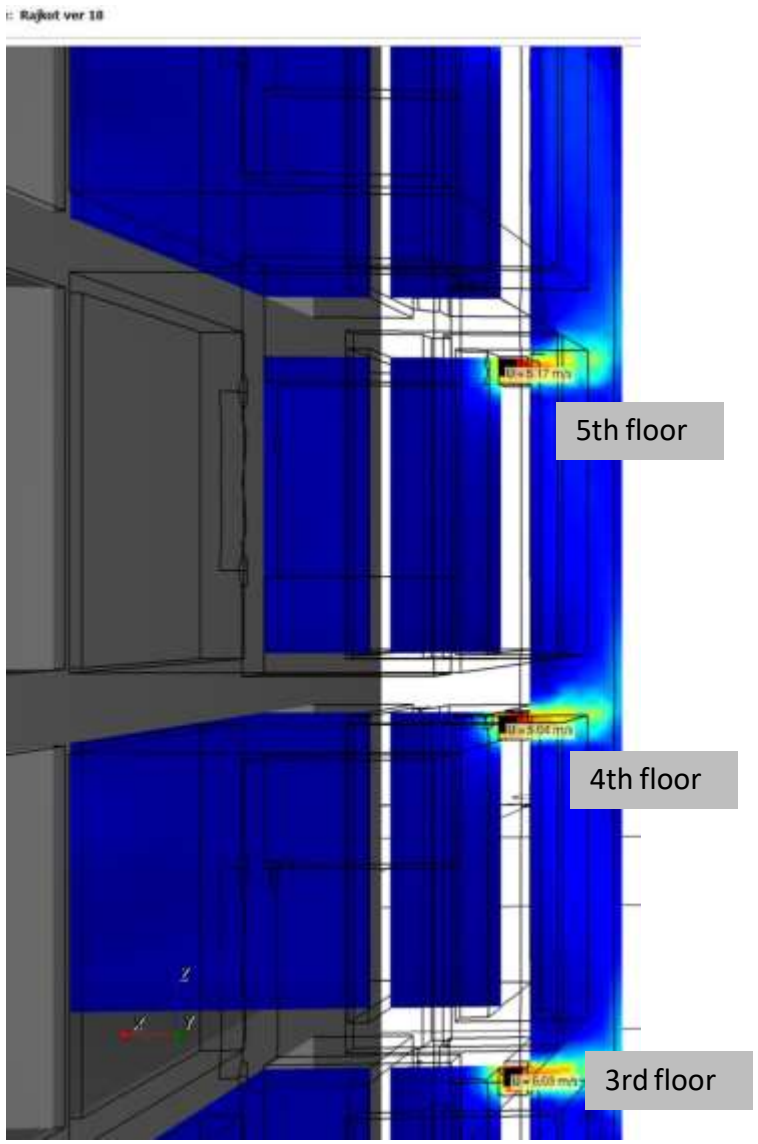

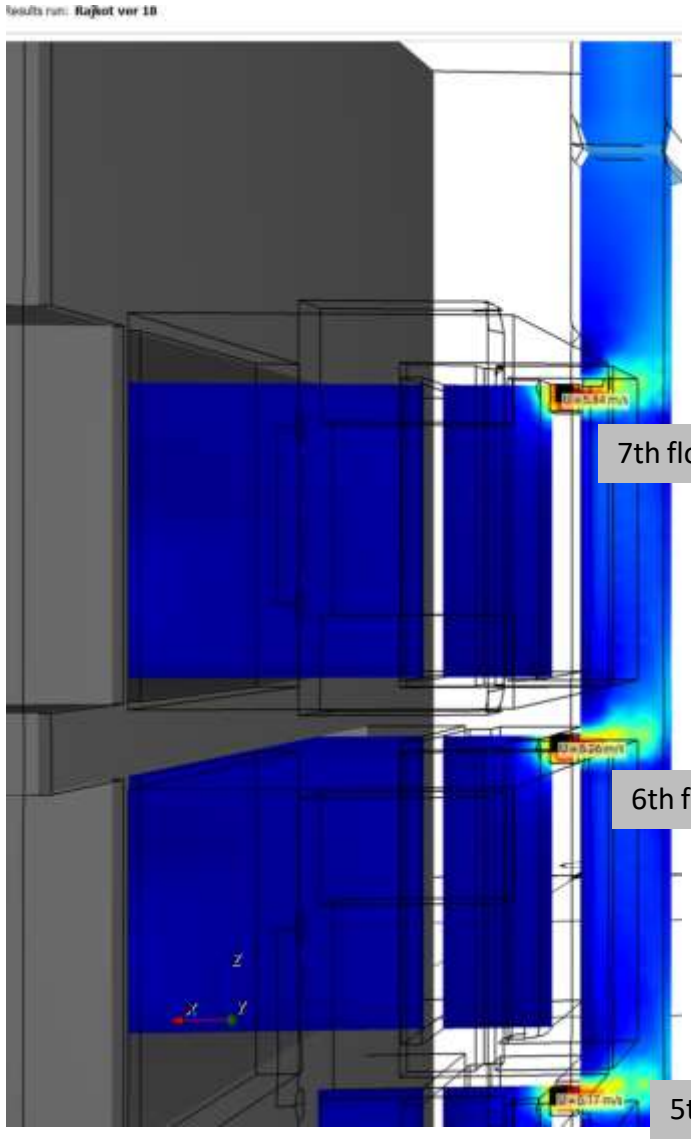

Example 4: analysis of the potential of ceiling fan in cross ventilation 例 4：吊扇在交叉换气中的潜力分析

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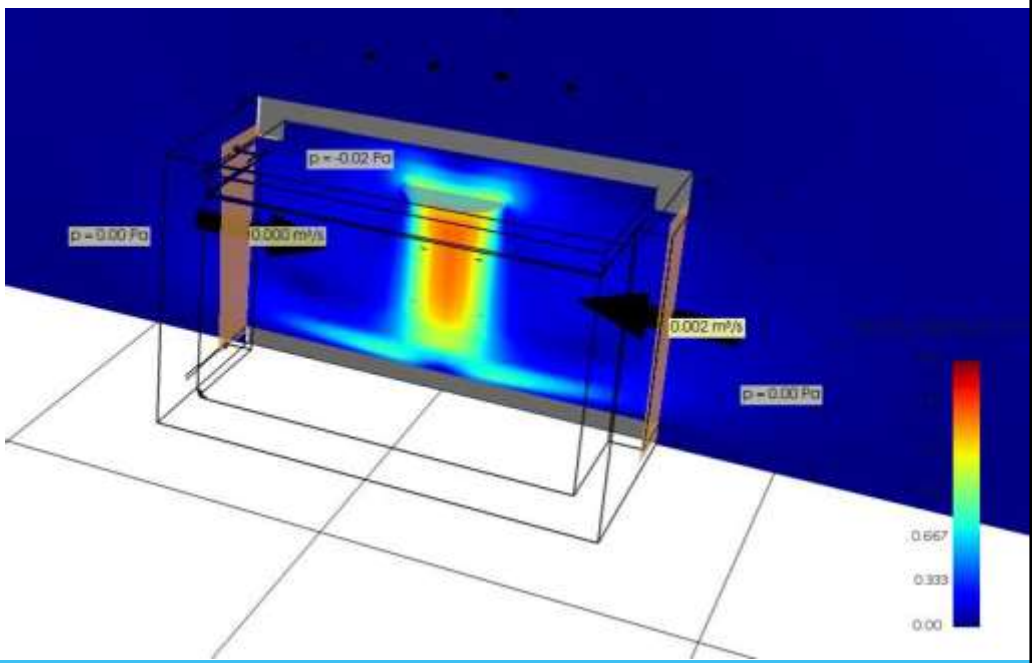
- Ceiling fans are blow air vertically down or upward 吊扇垂直向下或向上吹风除少量空气扩散外，不会产生空气变化
  - They do not generate air change at the exception of a little bit of air diffusion
- Vayu Pravah allows to analyse the concept on slightly inclined option and its impact for improving the cross ventilation 分析了略微倾斜方案的概念及其对改善交叉通风的影响
- If the fan is in vertical position as usual there is no cross flow across a room with two openings 如果风扇像往常一样处于垂直位置，那么在有两个开口的房间里就不会有横流
- It confirms the practice
  - Fan generating 1.5 Pa pressure difference
  - Downward flow
  - No cross flow

证实了：
风扇产生 1.5Pa的压差
向下流动
无交叉流

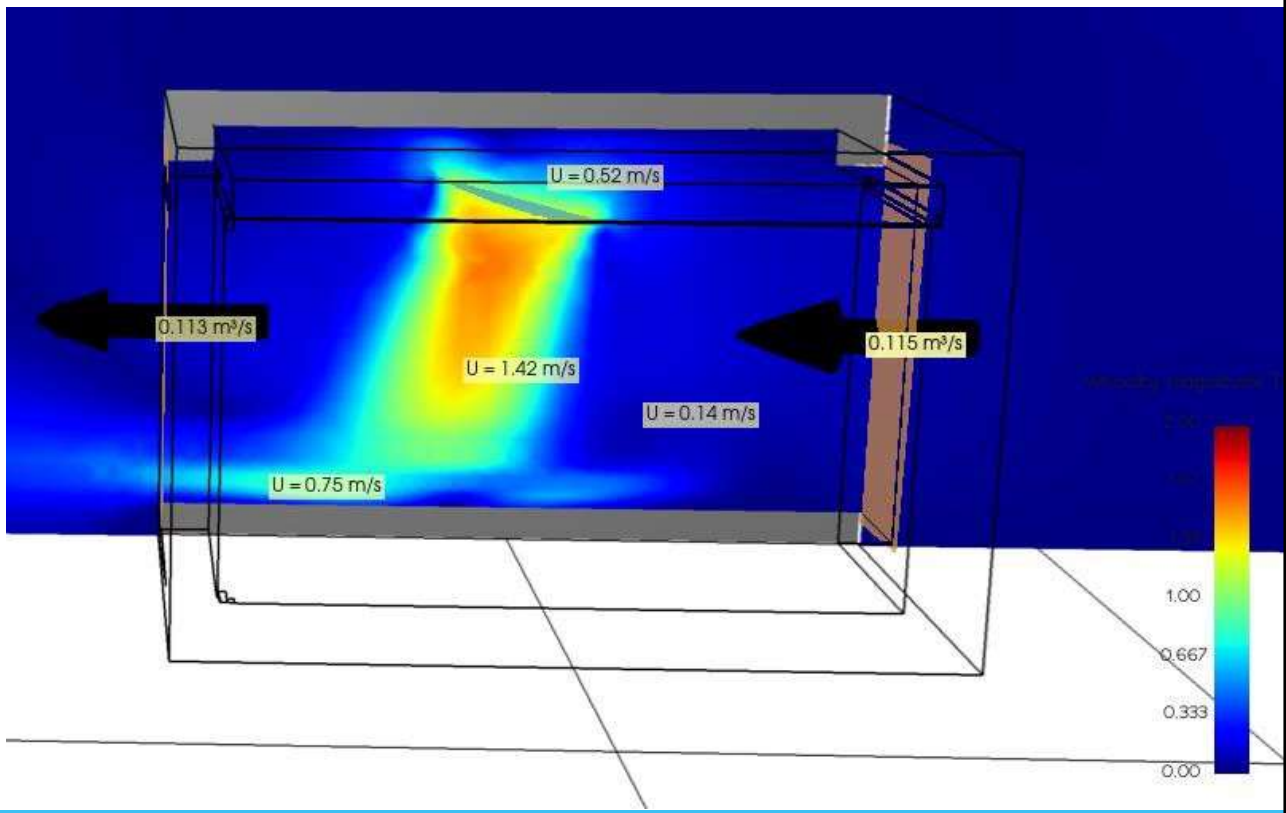


Example 4: analysis of the potential of ceiling fan in cross ventilation 例 4：吊扇在交叉换气中的潜力分析

- Inclination angle of 15° from horizontal downward
- Cross flow generated with the ceiling fan just inclined a little bit
- More than 10 ACH generated
- With a Diameter of 1 meter

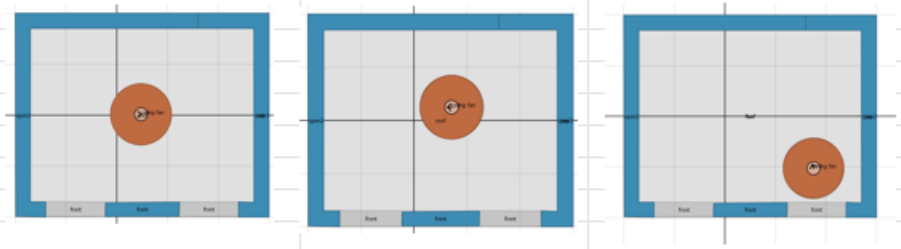
从水平面向下倾斜15°
吊扇略微倾斜产生的交叉气流
产生超过10 ACH
直径为 1 米

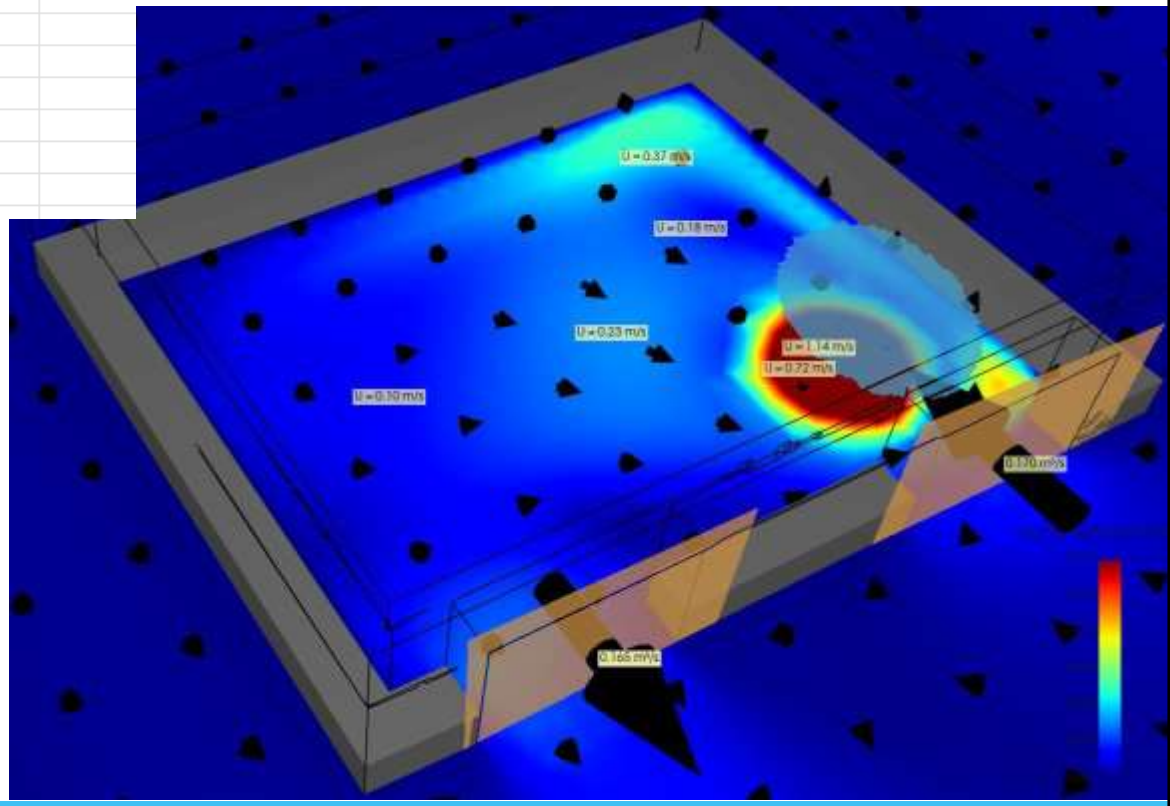
width	4	m
length	4	m
free height	2.4	m
volume	38.4	m3
air flow rate by ceiling fan	0.114	m3/sec
air flow rate by ceiling fan	410	m3/h
Air change rate from ceiling fan	10.7	ACH



Example 5: analysis of the potential of ceiling fan single sided ventilation 例 5：吊扇单面通风潜力分析

	Center normal	center inclined 15°	near window inclined 15°	m
width	5	5	5	m
length	4	4	4	m
free height	2.4	2.4	2.4	m3
volume	48	48	48	
				m3/sec
outdoor air flow rate by ceiling fan	0.001	0.05	0.165	m3/h
air flow rate by ceiling fan	4	180	594	
Air change rate from ceiling fan	0.1	3.8	12.4	ACH





Thank you