感谢耶鲁大学与南信大李旭辉教授邀请

建筑环境与城市气候的若干研究与思考 Some research and thinking on Urban micro-climate and built environment

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贡献者：李玉国、林满、王群、陈谢元、林元元、陈岚、陈冠文、王东阳、陈钛涵、张勇、杨霞、杨宏宇、张可儿等

CV of Dr Jian Hang

时间 Period	University/大学	Degree 学位/职称
1998.09~2002.08	**University of Science and Technology of China (USTC) 中国科技大学**	Bsc 学士
2002.09~2005.08	**Chinese Academy of Sciences 中国科学院** Majoring in Fluid mechanics	Mphil 硕士
2005.09~2012.08	**The University of Hong Kong (HKU)**, 港大 Majoring in **Built Environment**	PhD, Postdoc (Supervisor: Prof Yuguo Li)
2012.09~2018.04	**Sun Yat-sen University 中山大学** (百人计划)	Associate Prof 副教授
2018.04~present	**Sun Yat-sen University 中山大学**	**Professor**

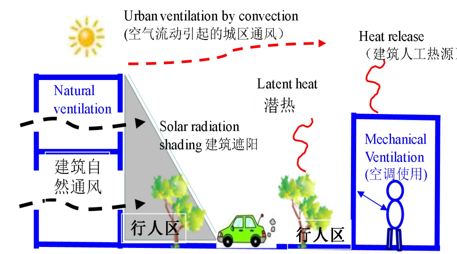
- 2016，National Natural Science Foundation of China (NSFC)--Outstanding Youth Foundation，Urban climate (Project No, 41622502) **国家优青-城市气象学**

Research topic： Urban micro-climate and built environment

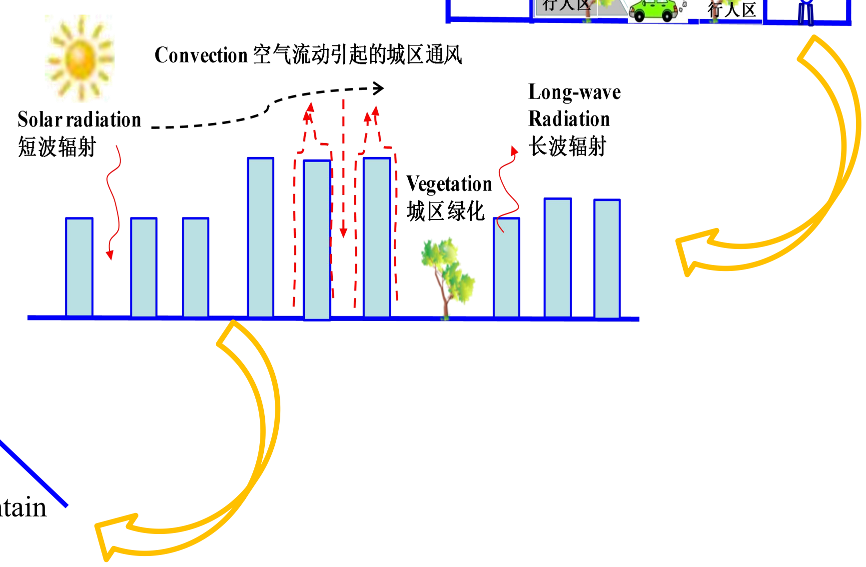
建筑环境 built environment(0.1m-10m)

城市微气候 Urban micro-climate (100m-10km)

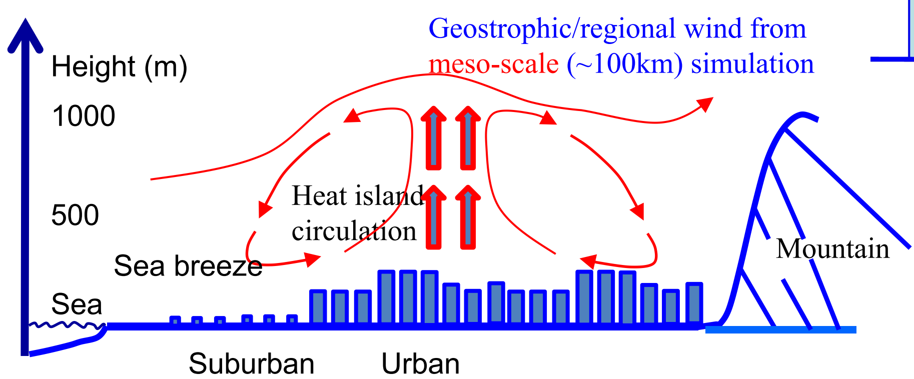
building-street scale(~10m-100m)

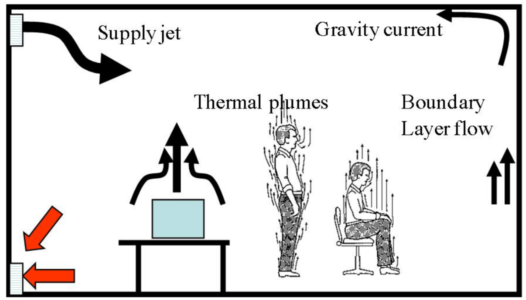


neighbor-hood scale (~1-2km)

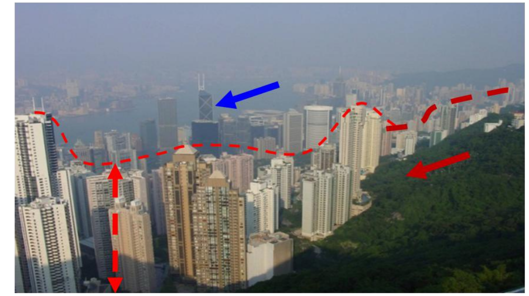


城市尺度 City-scale (~10km)





Room scale (~10m)



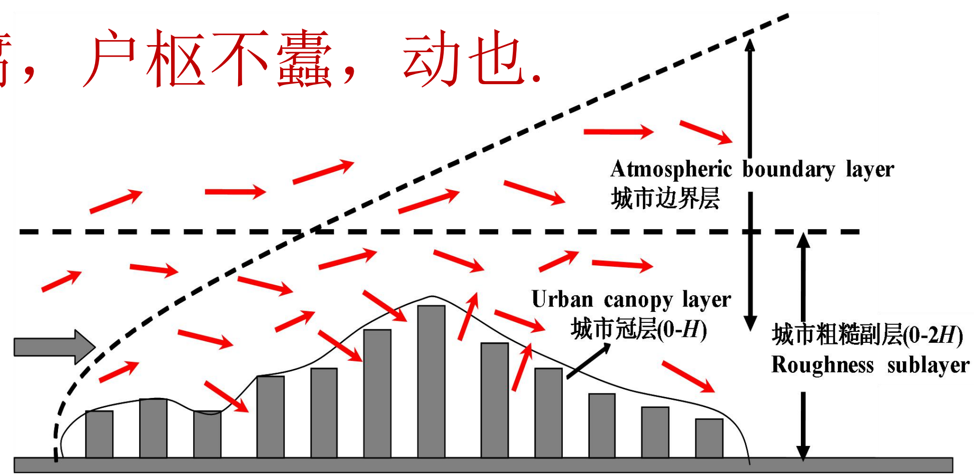
Street/Neighborhood/City scale
(~100m/1km/10km)

Similar with room/building ventilation: 相似性与区别

Street/urban/city Ventilation refers to the process of supplying external (rural)air into the urban canopy layer and distributing it within it.

通风：流水不腐，户枢不蠹，动也.

《吕氏春秋·尽数》

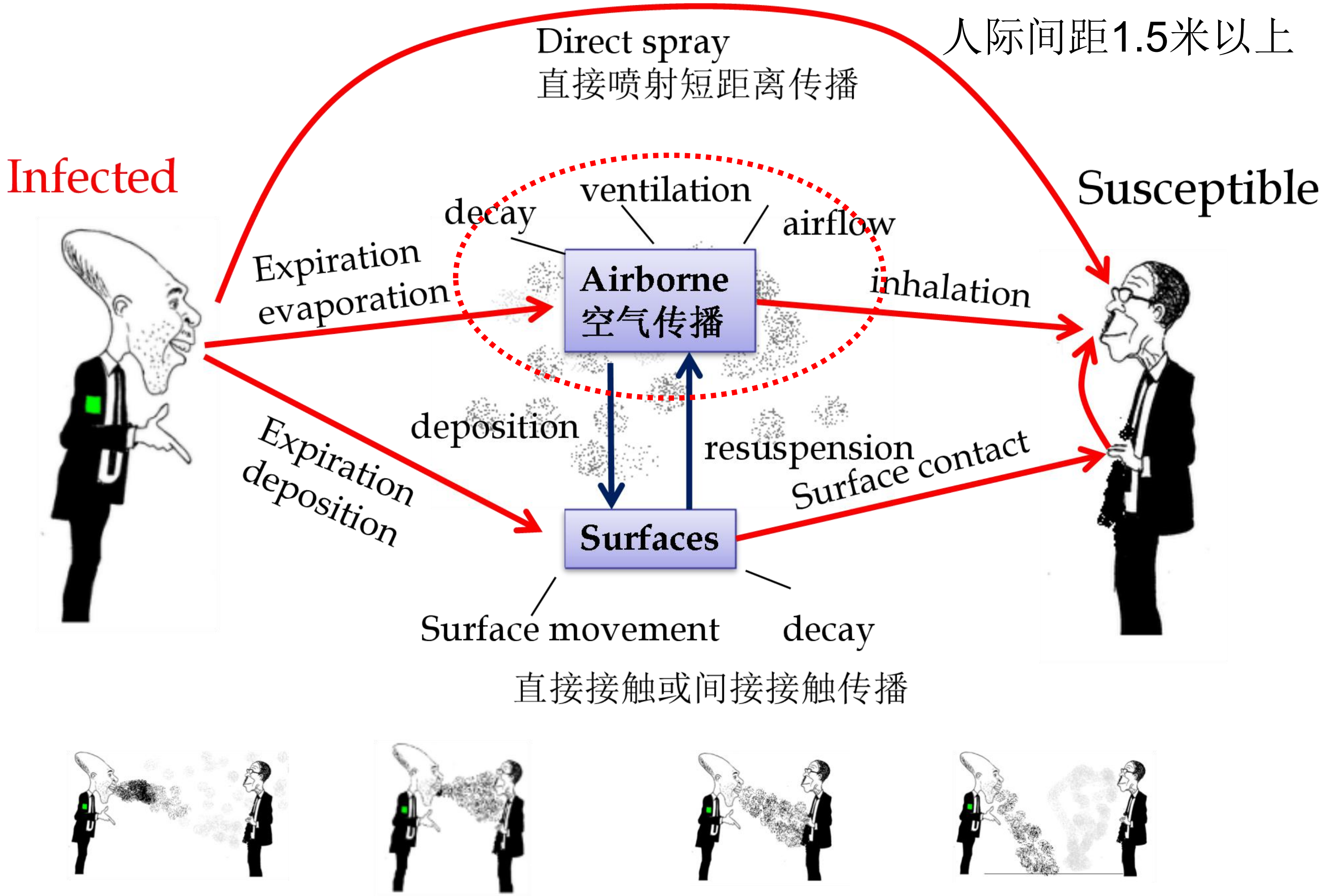


- 非典、中东呼吸综合征、流感、新型肺炎等易在室内环境中通过空气快速传播。
- 飞机、高铁、长途巴士、教室、医院病房等更受到关注。通风影响呼吸性疾病的扩散。

勤洗手

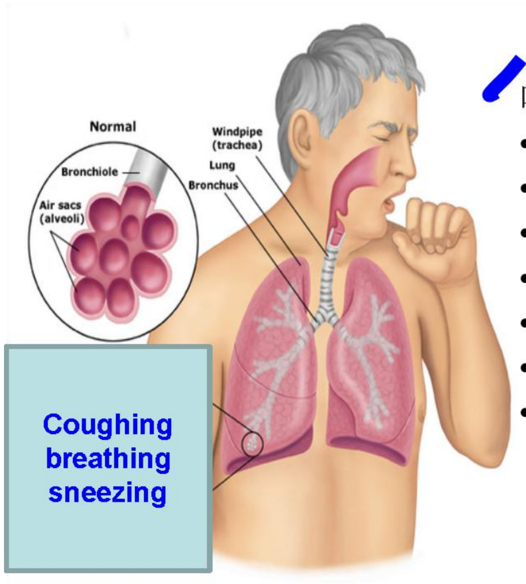
时常开窗通风

戴口罩

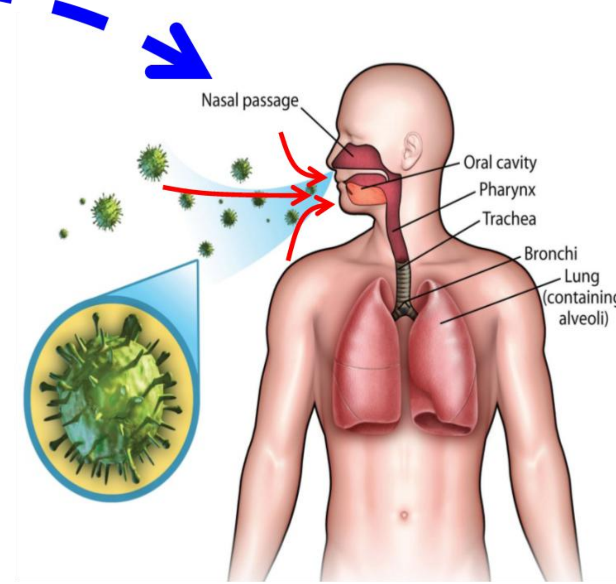


Modified from Atkinson and Wein, Bulletin of Mathematical Biology, 2008, 70:820-867

What's happened in between is more of an engineering issue in built environment?



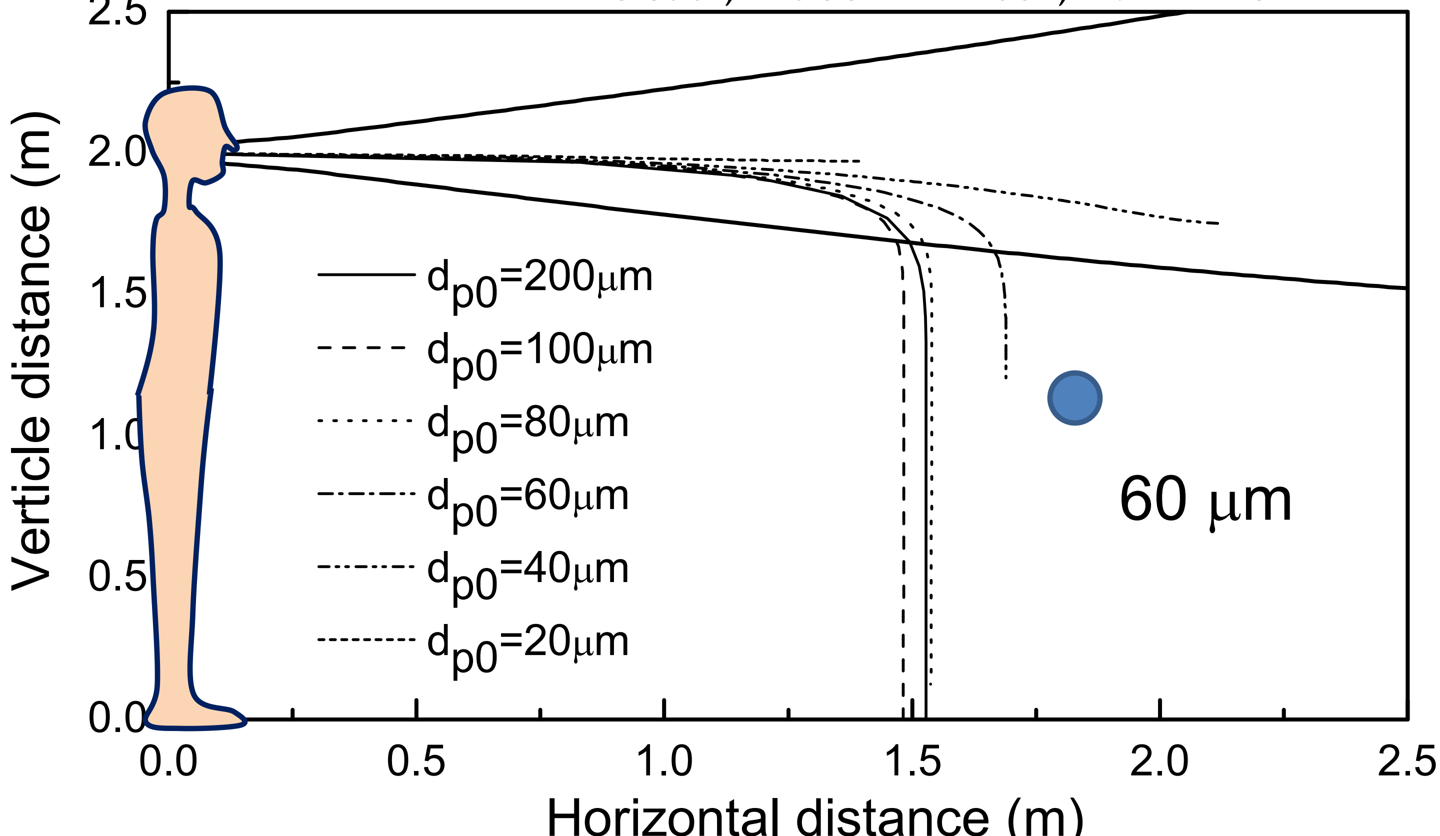
呼出飞沫传播包括许多科学问题：
- 飞沫的产生、扩散和蒸发
- 咳嗽中的射流问题
- 通风和空气湍流流动
- 飞沫的化学特征
- 飞沫核扩散、沉降、再悬浮等
- 病毒和病菌的存活性
- 人体呼吸特征



Modified from Web images

- 呼出飞沫是非典、流感、肺结核、新型肺炎等疾病病毒或病菌的重要载体。人们呼吸、谈话、咳嗽、打喷嚏时，人体分泌物在呼吸道中雾化形成飞沫(1-100μm)，由嘴或鼻呼出，在空气中传播蒸发。足够大的飞沫可沉降到地面、衣服、人体等表面上，而小飞沫迅速干燥收缩形成更小的飞沫核，可在空气中长时间悬浮
- 以流感为例，其病毒的暴露地点，主要发生在两个地方，一个是呼吸道内、一个是鼻子、嘴巴和眼睛的粘膜处。

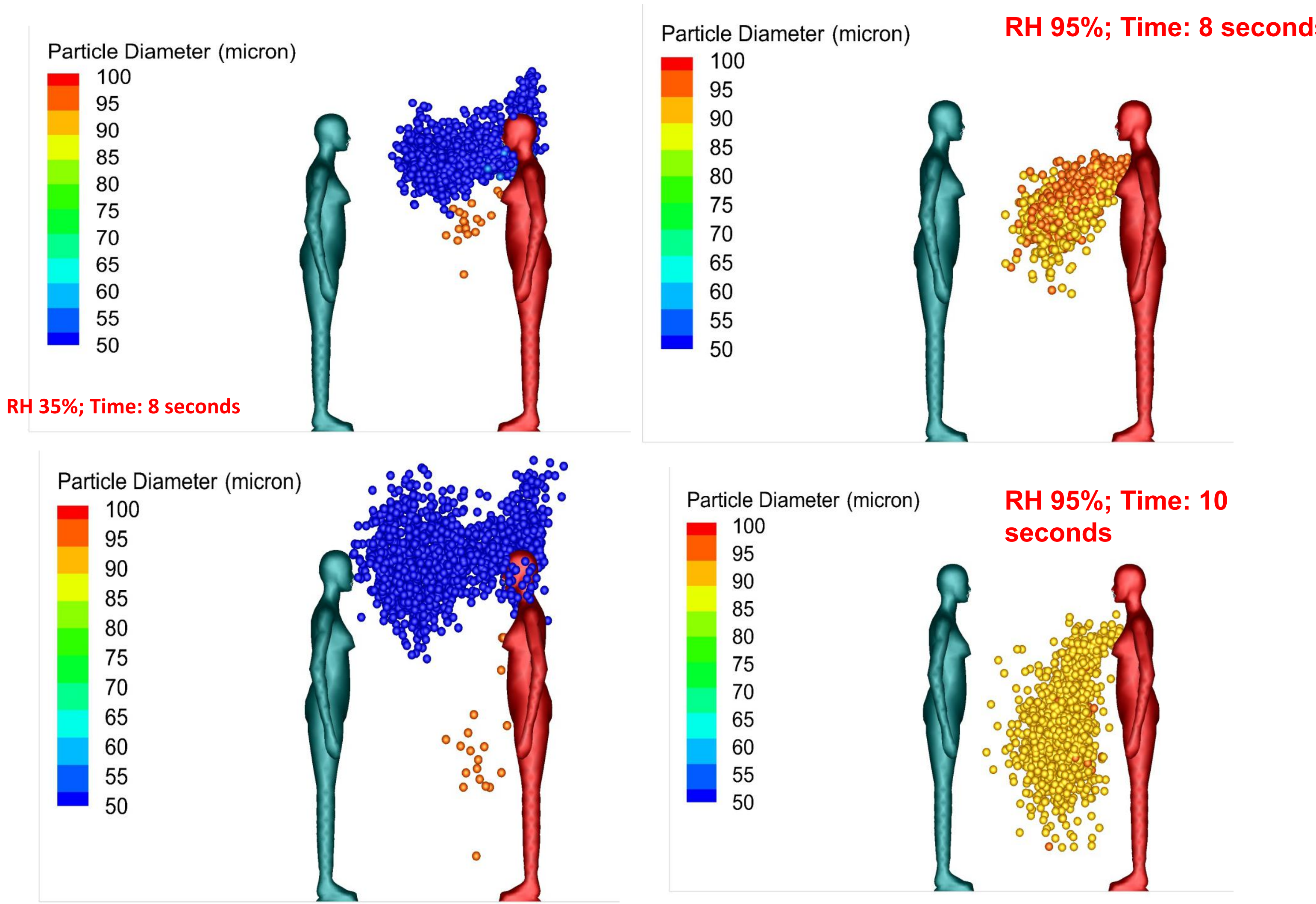
Xie et al, Indoor Air 2007;17:211-225



Trajectories of coughing droplets (Tp = 33°C, T∞ = 20 ° C, RH = 50%, U_0 = 10 m/s, d_0 = 0.04 m, Re = 24,640).

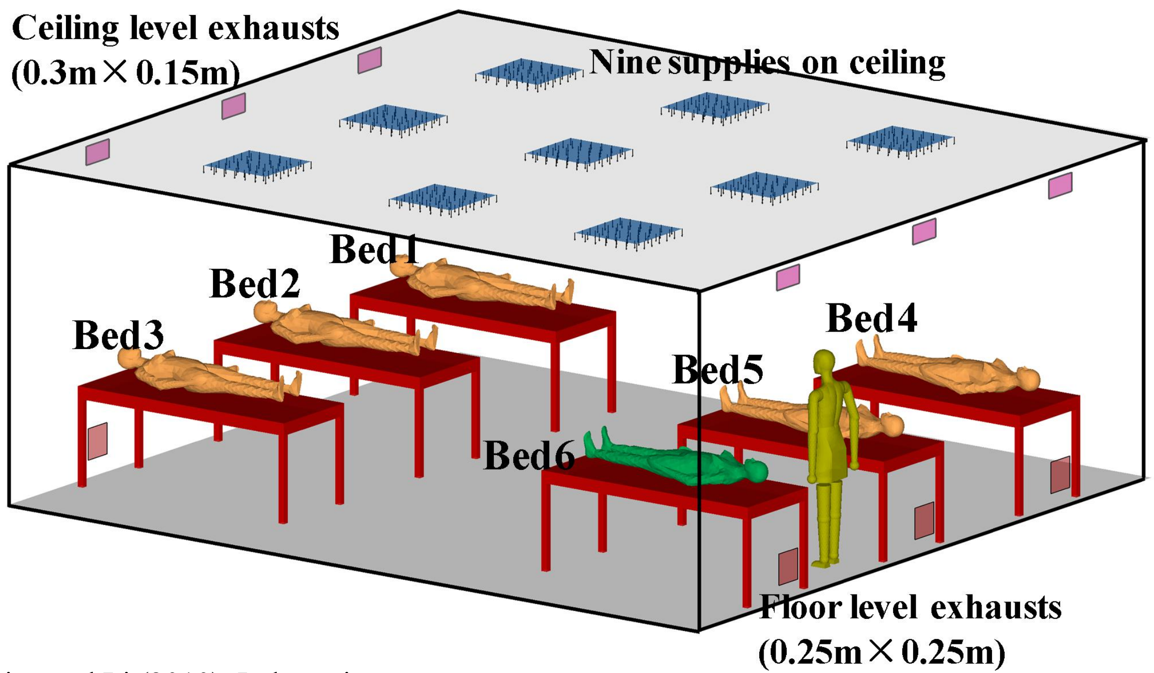
•通过实验观测和建立数学模型，定量研究飞沫初始大小、蒸发和凝结、含杂质和不含杂质、空气湿度等对飞沫核粒径大小和传播距离的影响。

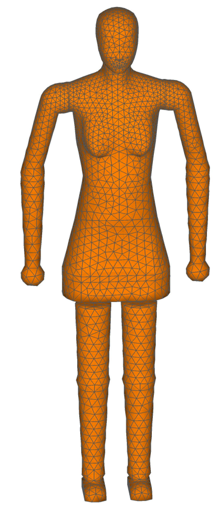
•大飞沫在1.5m内就从咳嗽射流中脱离，初始直径20-40微米的飞沫的传播距离远大于2米。



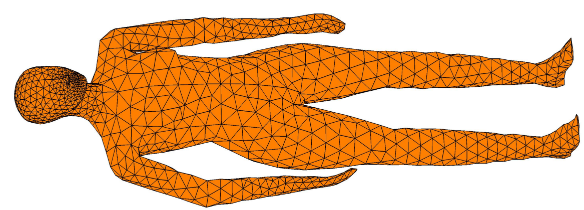
RH 35%; Time: 10 seconds

研究一　医院病房通风和飞沫扩散研究





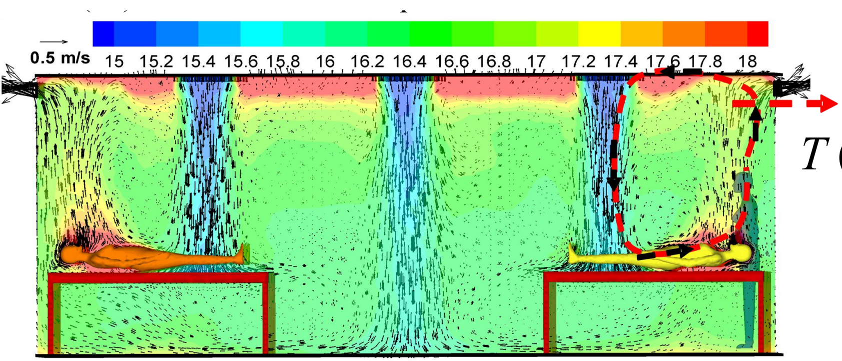
Qian and Li (2010), Indoor air



➢室内通风存在风与热的相互作用
➢通风设计对飞沫扩散有重要影响

From Prof Julian Tang

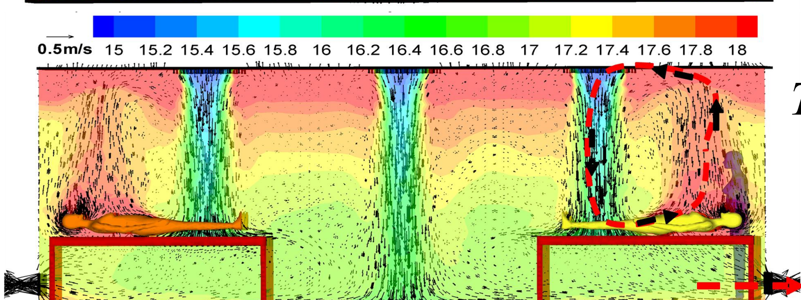
Jian Hang, Yuguo Li*, Ruiqiu Jin. Building and Environment 2014; 77: 119-134



T (°C)

HKU

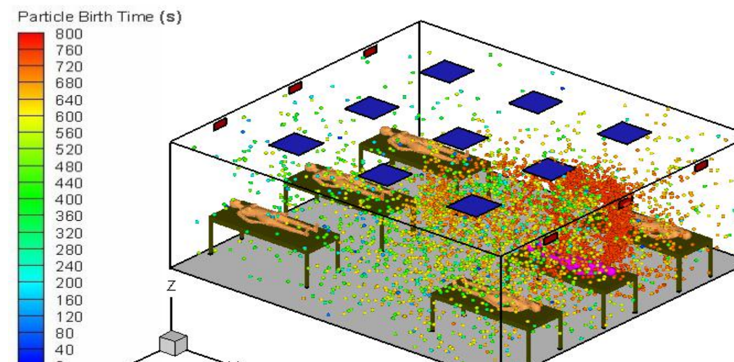
顶部出风口



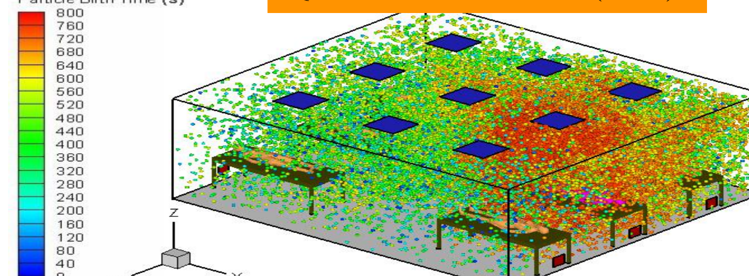
T (°C)

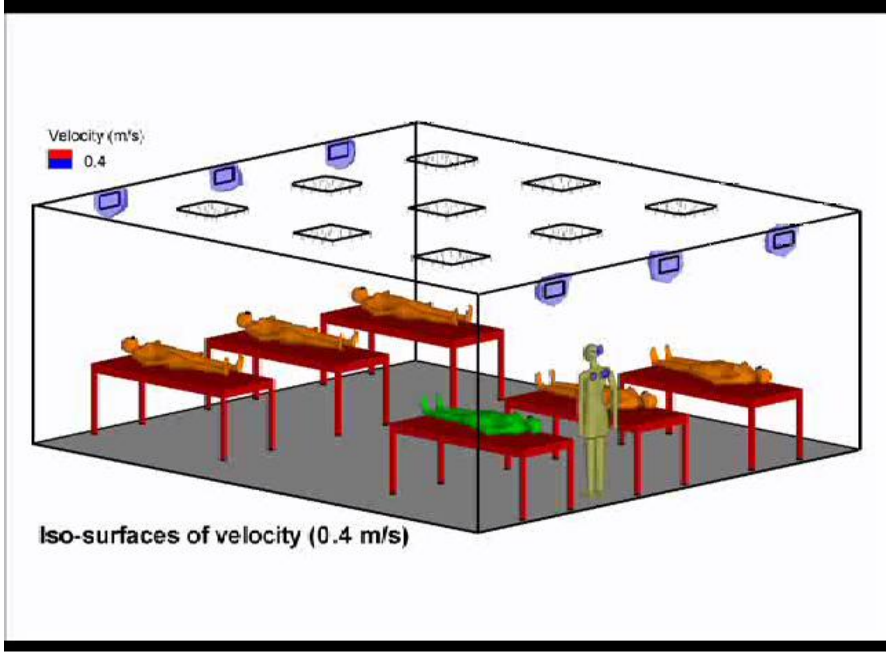
CDC

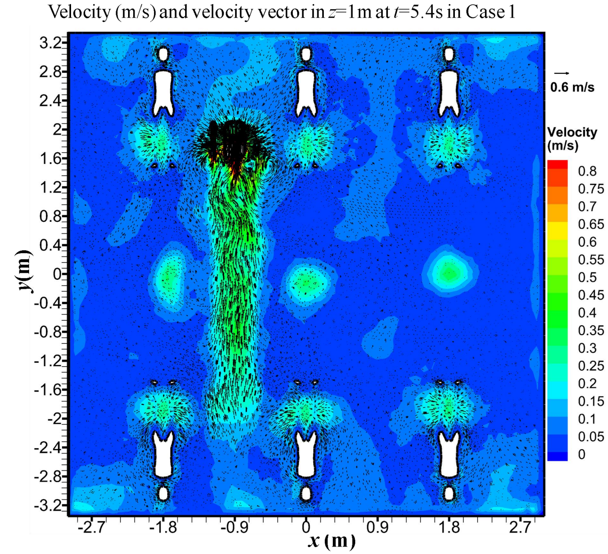
底部出风口

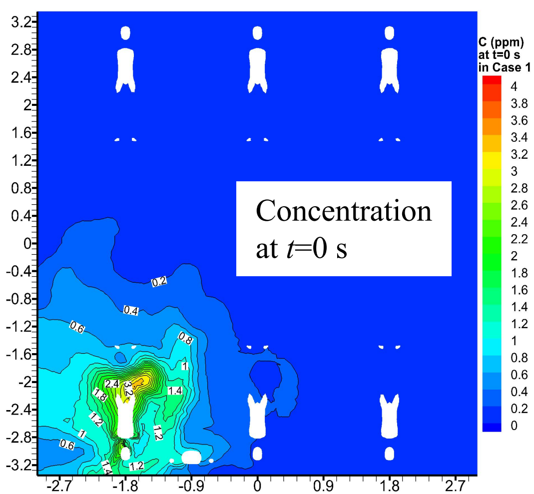


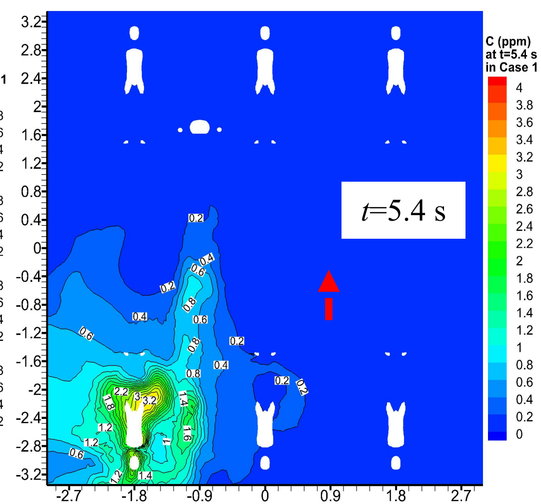
Qian and Li, Indoor air (2010)

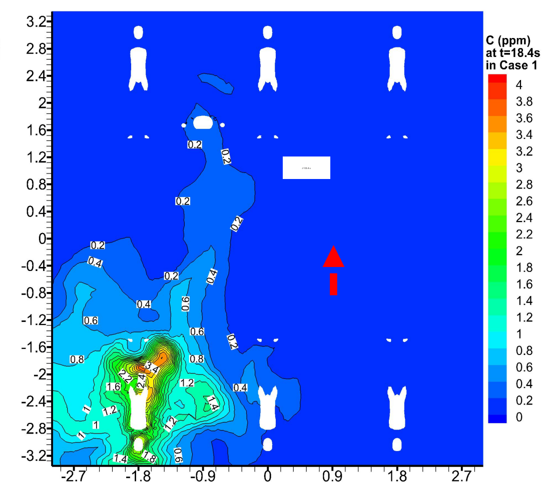



Velocity (m/s)
0.4
Iso-surfaces of velocity (0.4 m/s)

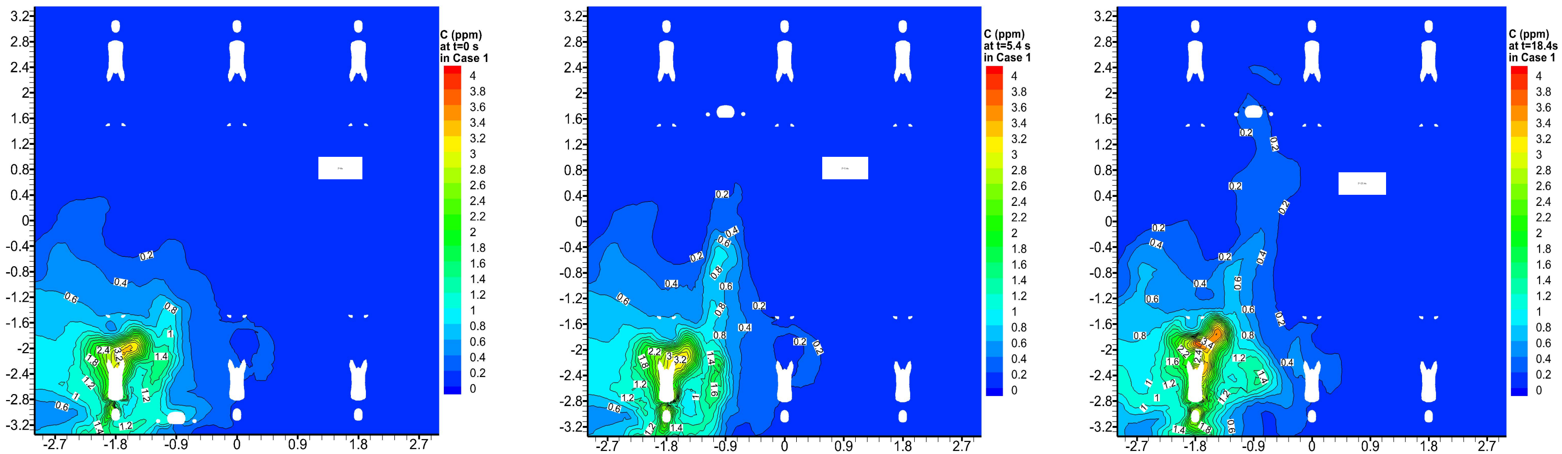

Velocity (m/s) and velocity vector in z=1m at t=5.4s in Case 1
0.6 m/s
Velocity (m/s)
y (m)
x (m)


C (ppm) at t=0 s in Case 1
Concentration at t=0 s

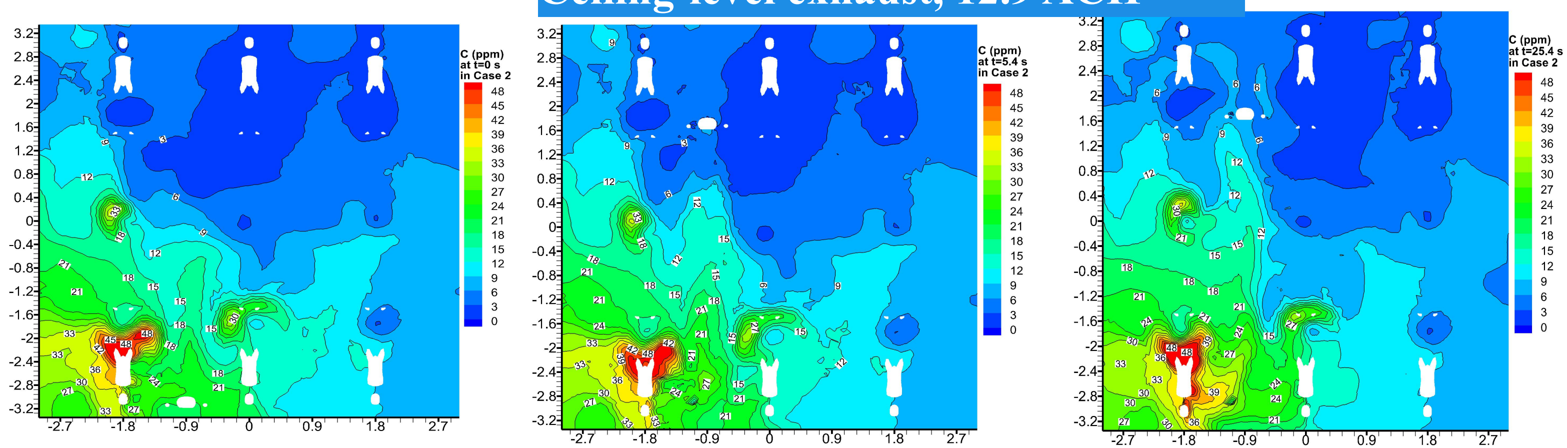

C (ppm) at t=5.4 s in Case 1
t=5.4 s


C (ppm) at t=18.4s in Case 1

人的走动有影响，但通风方式更重要：每小时换气次数ACH=3600q/Vol



Ceiling-level exhaust, 12.9 ACH



Floor-level exhaust, , 12.9 ACH

门的开关可导致病房之间通过共用缓冲室的空气传播

Jian Hang, Yuguo Li*, et al. Potential airborne transmission between two isolation cubicles through a shared anteroom. Building and Environment 2015. 89, 264-278.

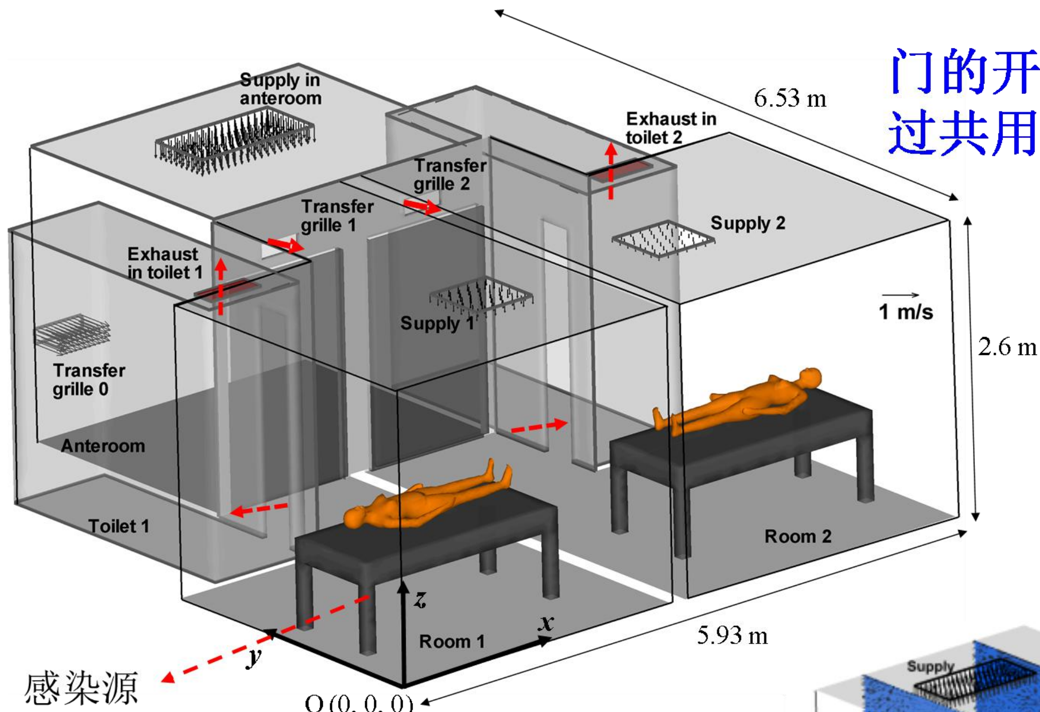
关键参数：每小时换气次数

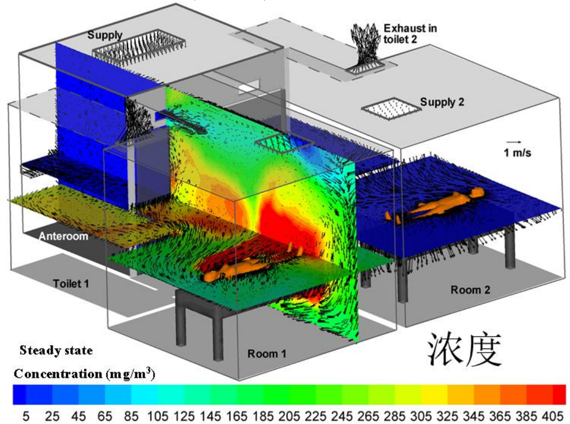
air change rate per hour- ACH=3600q/Vol

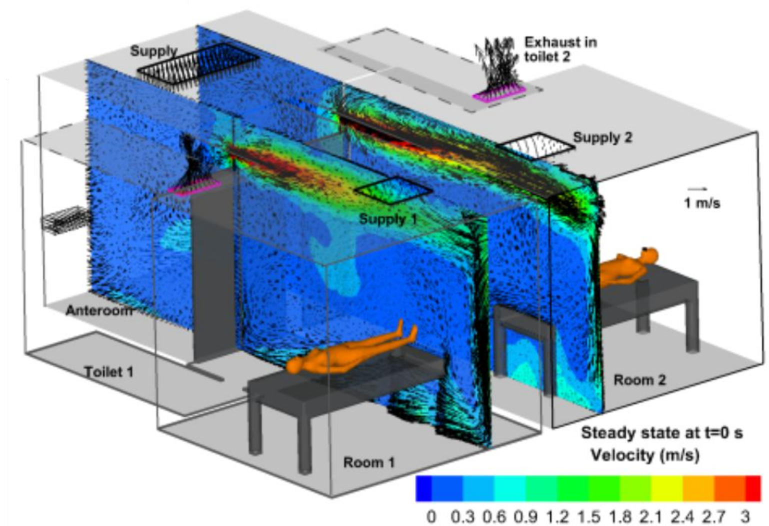
Negative isolation room:

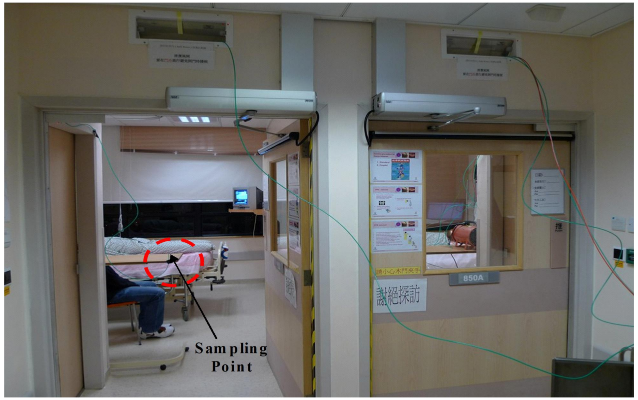
85 ACH for anteroom,

32 ACH for Room 1 and 2

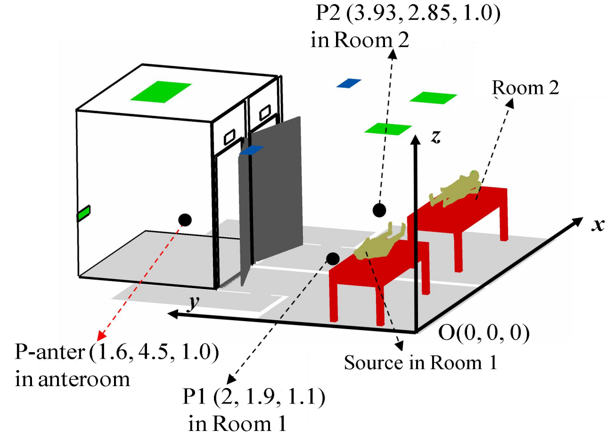






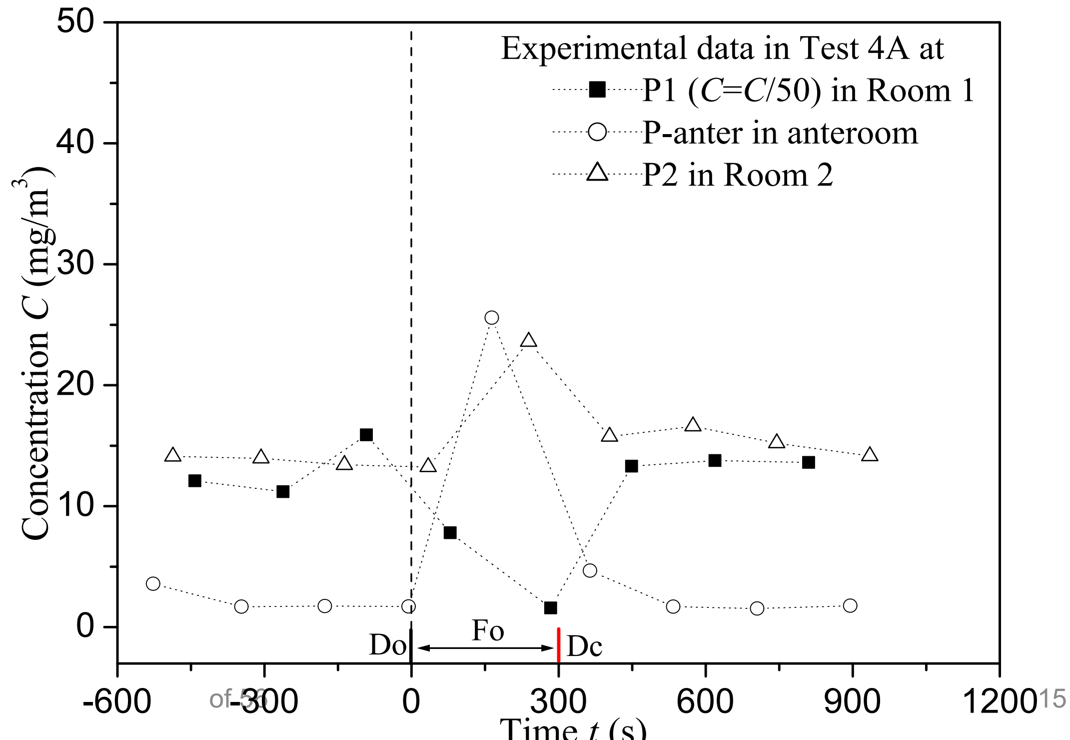


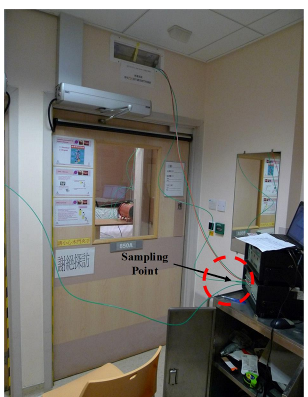
Sampling point at P2 in Room 2



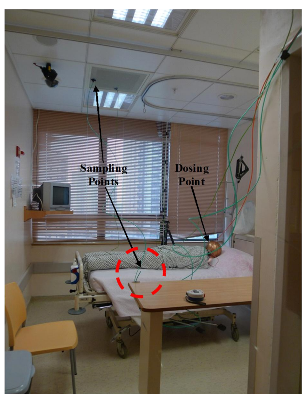
多点采样分析仪 Type 1302 & 1303 (Brüel & Kjær, Denmark)，示踪气体：N_2O;

四点采样，每次约3分钟。



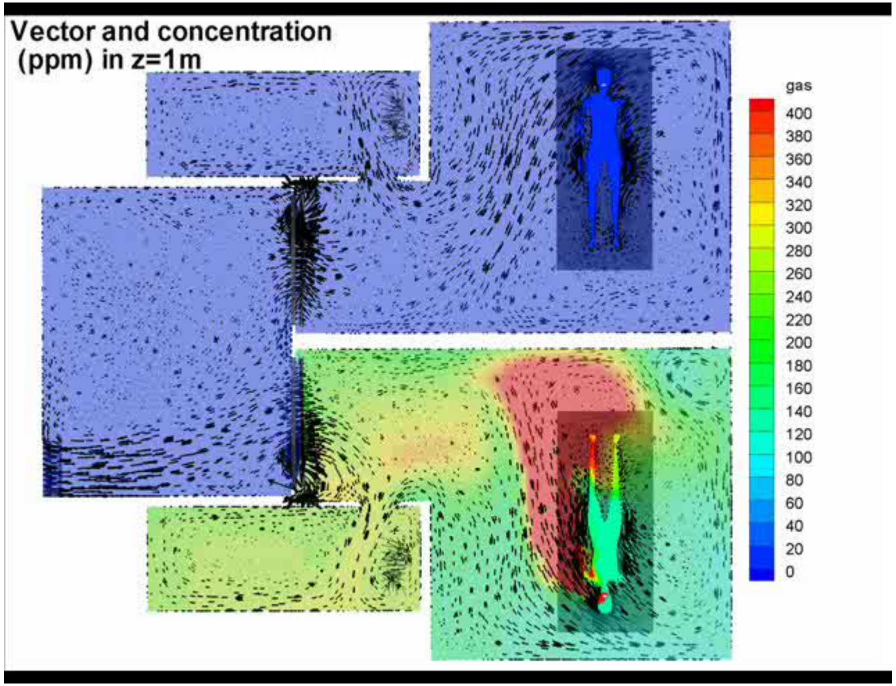


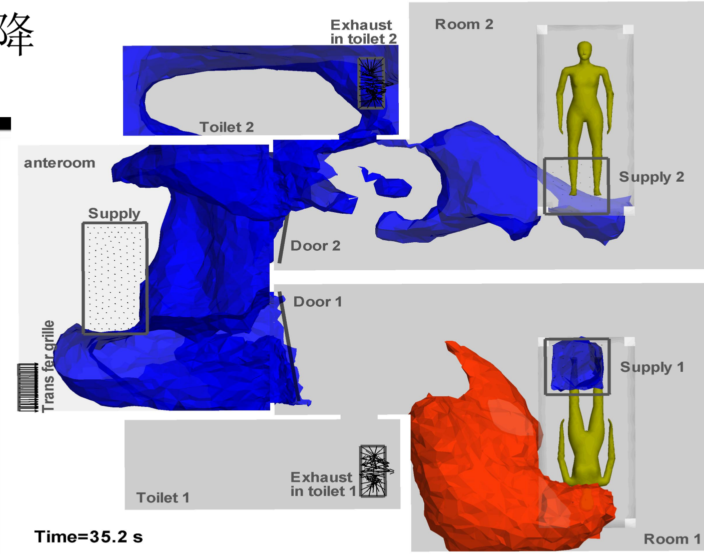
At P-anter in anteroom

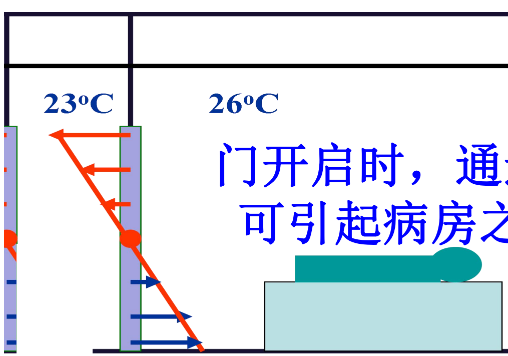


At P1 in Room 1

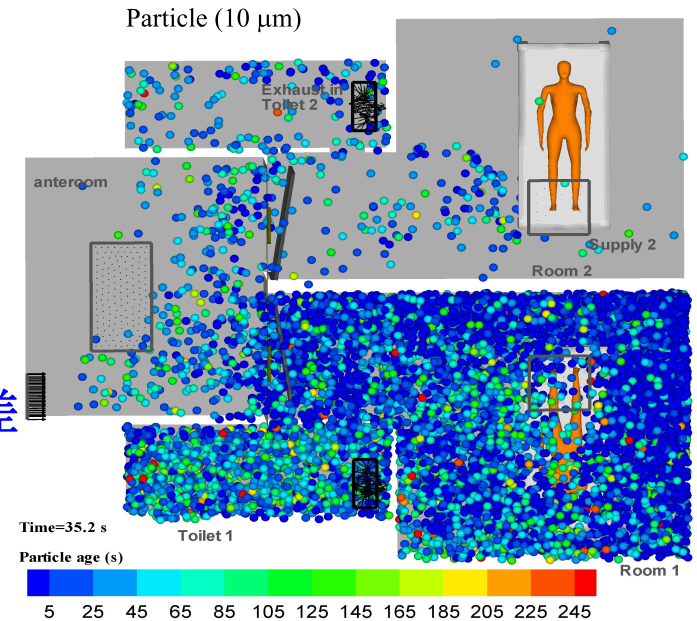
减小完全开启时间、增大换气次数或安装门帘可降低病房之间的暴露风险



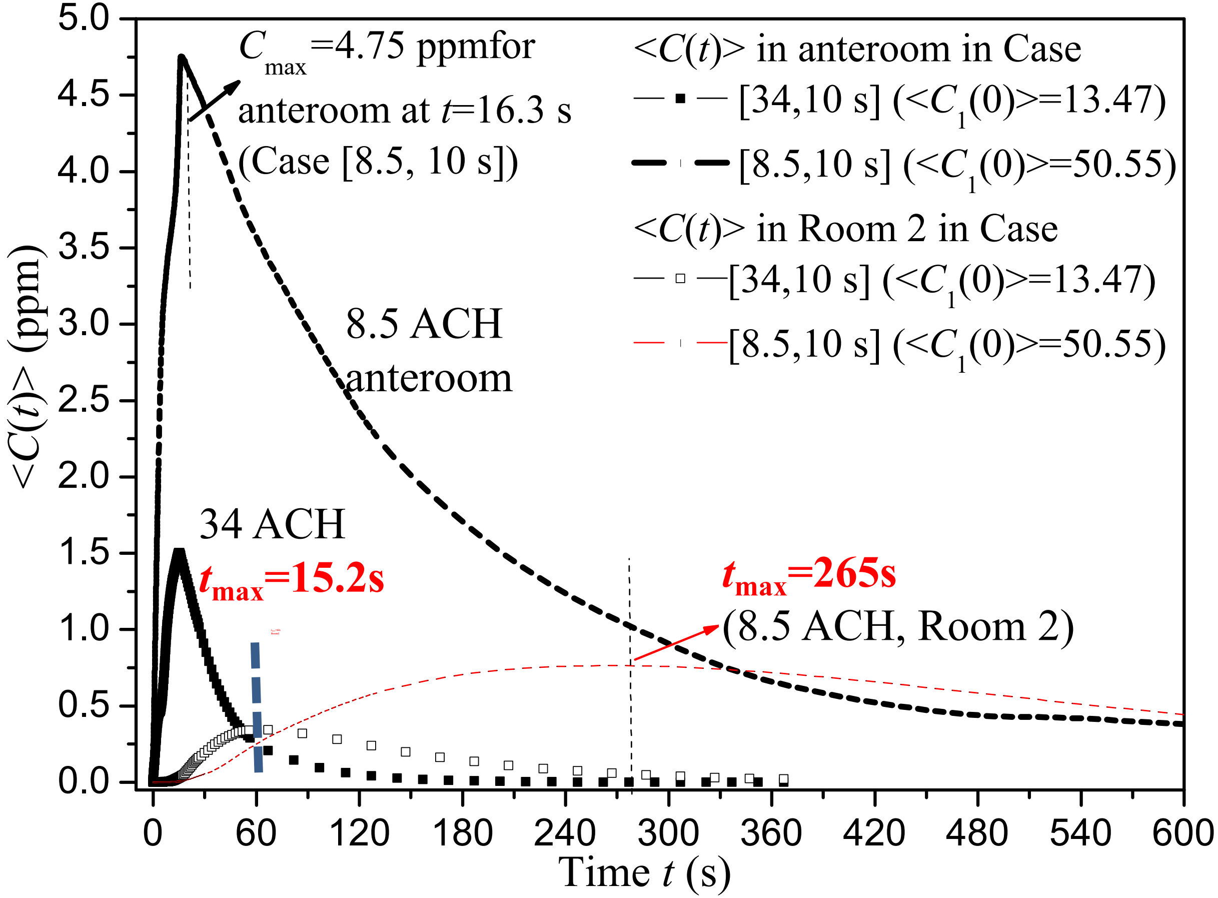


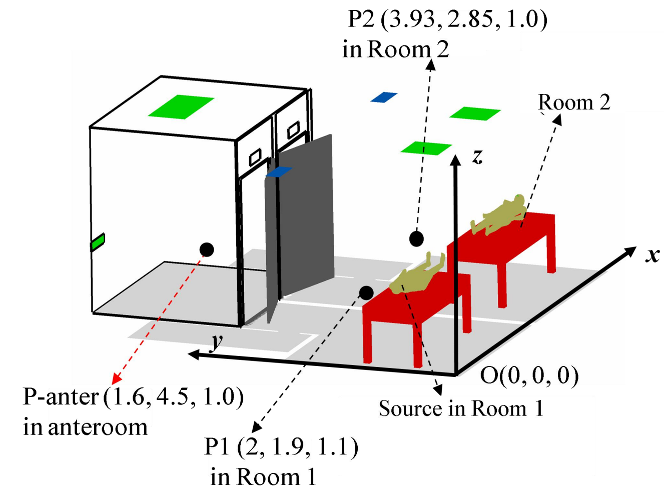


门开启时，通过门洞的温度差可引起病房之间的飞沫扩散

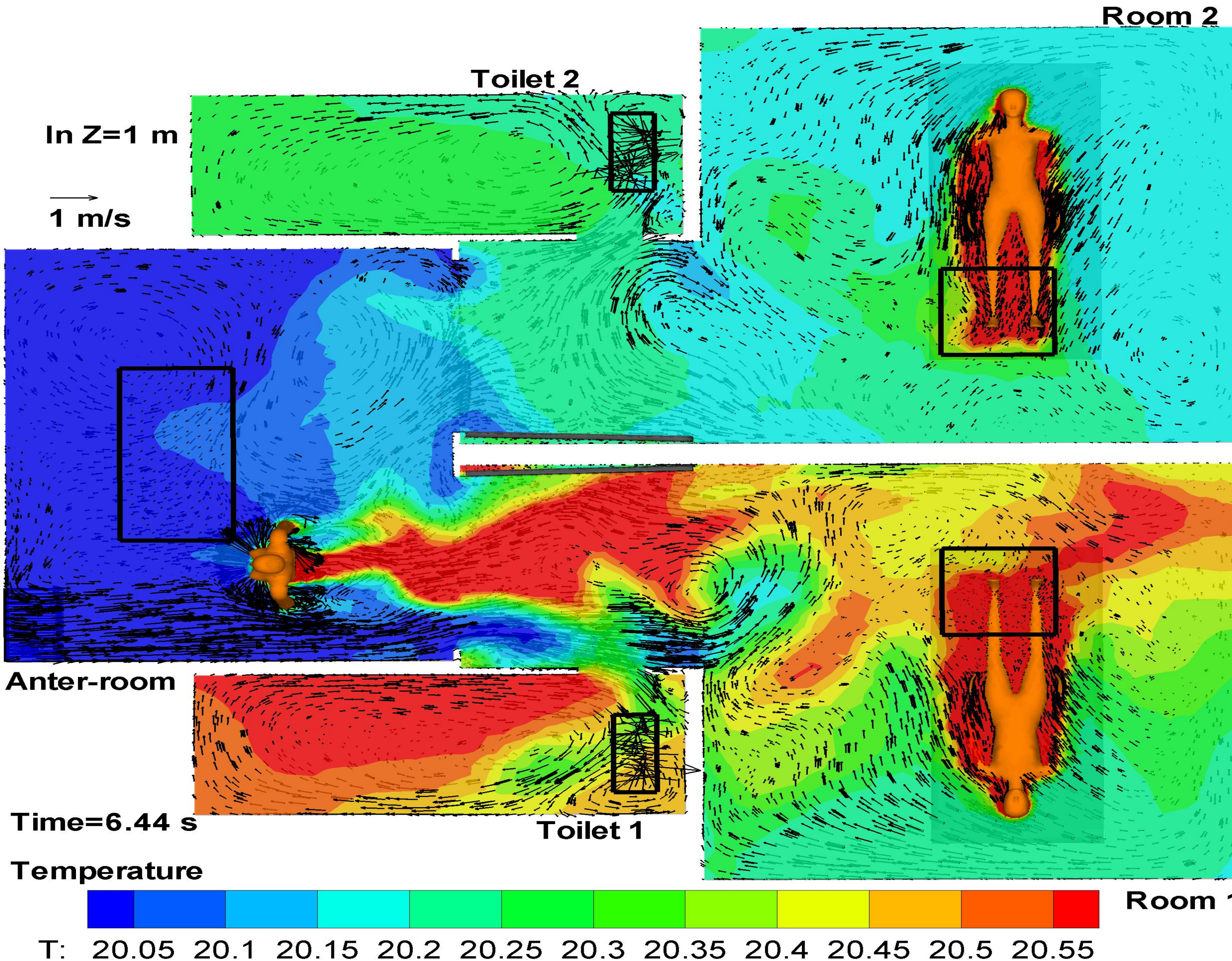


当门完全开启10s时，更大的通风量(34ACH)获得更小的病房之间飞沫泄露

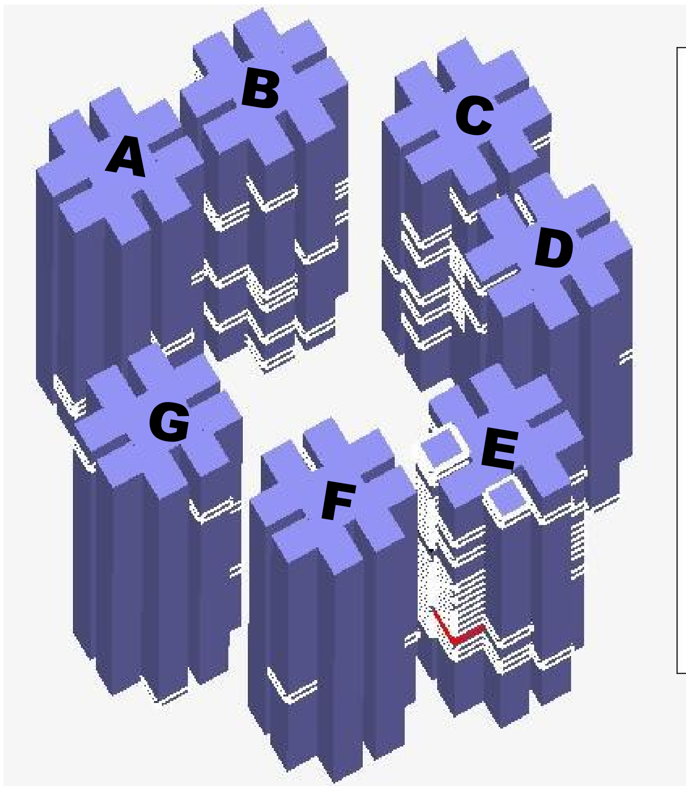


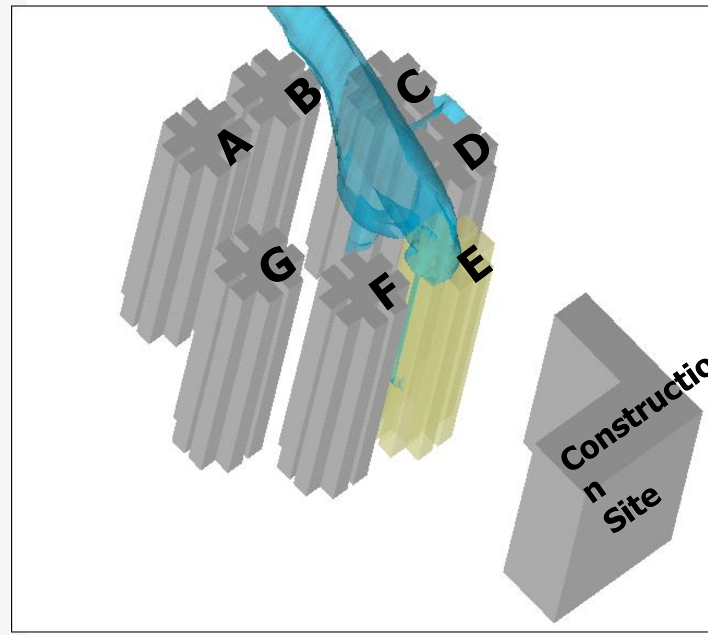


Hang J, Li YG*, et al. ***Building and Environment*** **2015**. 89, 264-278.


Room 2
Toilet 2
In Z=1 m
1 m/s
Anter-room
Time=6.44 s
Toilet 1
Temperature
Room 1
T: 20.05 20.1 20.15 20.2 20.25 20.3 20.35 20.4 20.45 20.5 20.55

Spread from Block E to other blocks in the Amoy Gardens Outbreak
淘大花园感染事件，从E座建筑到A、B、C、D座建筑的空气传播

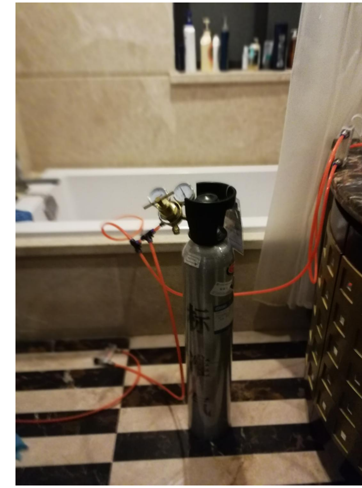




Li et al. Pop Dyn and Infect Dis in Asia 2006:305-327 (left)
Yu，Li et al. NEJM 2004;350:1731-39 (right)

研究二：新型肺炎疫情背景下的室内通风与飞沫扩散研究






与广东省疾控合作，进行广州、佛山两个居民楼楼层之间的疫情与飞沫扩散研究



广州某餐厅(仅 0.5-0.7 ACH)与湖南某会议室(仅 0.2-0.3 AC):通风差是疫情主要原因

风水学 VS 健康、节能的建筑环境和城市气候

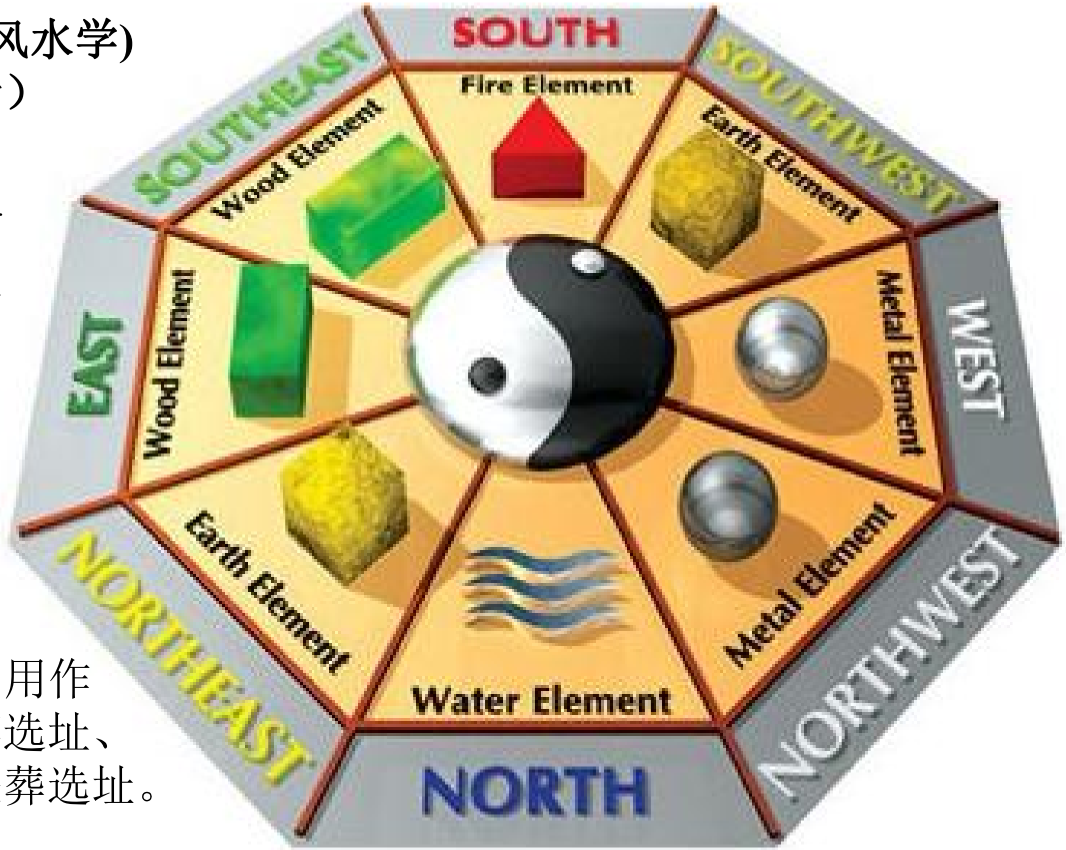
Wind and water PK Science of Built and urban environment

玄学 (堪舆风水学)
（阴阳五行）

选择能助人事业兴旺，环境适宜的地方或布局

天人合一
因地制宜
观形察势

古代风水：用作城镇及村落选址、宫殿建设丧葬选址。



现代自然科学
(风, 污染, 热湿)

因地制宜的建设健康, 舒适安全,节能的建筑环境和城市室外环境

定量化研究
参数化研究
细节化研究
多尺度结合

现代风水：建筑、家居、办公室等(加入天文学、地理学、建筑学等因素）

http://geography.airtofly.com/Files/BeyondPic/2007-5/17/20060608195359 0fb58.jpg

研究二：长途巴士通风与蒸发对飞沫扩散的影响

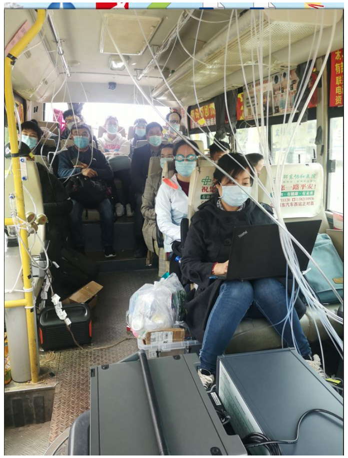
长途巴士是重要的城际交通工具之一，巴士内飞沫空气传播是重要的途径之一。

Xia Yang(杨霞，学生为第一作者), Cuiyun Ou, Hongyu Yang, Li Liu, Hualiang Lin, Tie Song, Min Kang, Jian Hang*(通讯作者). Transmission of pathogen-laden expiratory droplets in a coach bus. Accepted by **Journal of Hazardous Materials 2020 (中科院一区期刊，IF=7.7).**

急寻！5月26日与韩国MERS患者同行的9名巴士乘客！

央视财经 2015-06-03 11:51

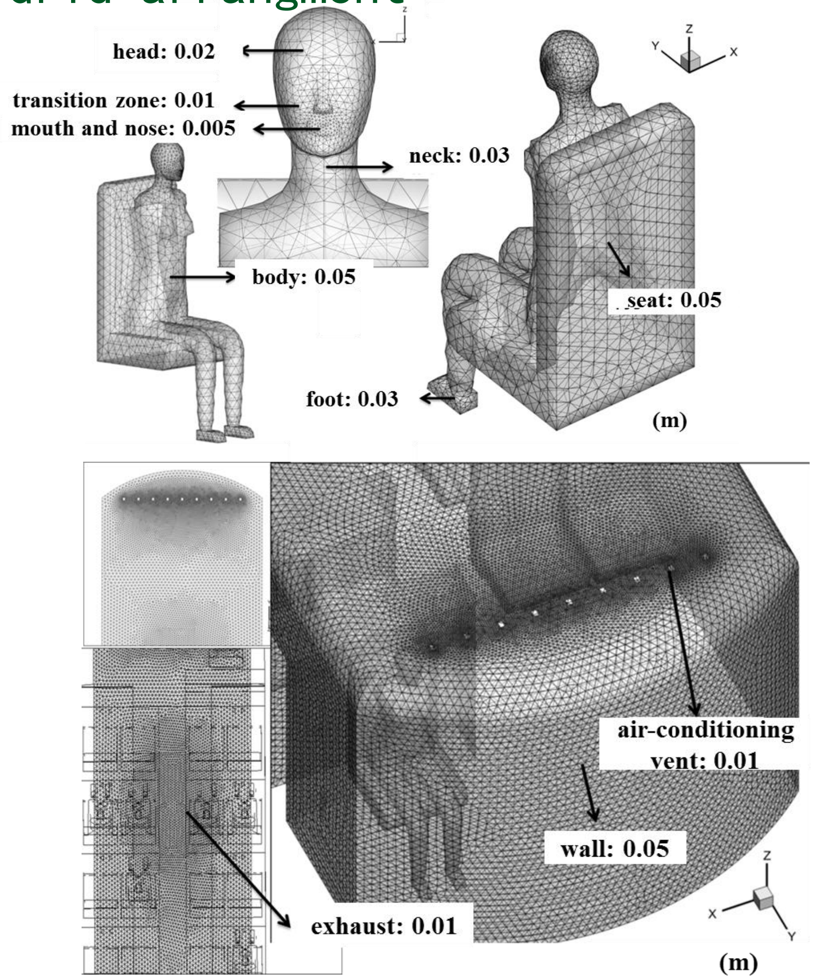
广东省卫生计生委2日通报，我国首例中东呼吸综合征确诊患者2日精神状态好转，仍有发热，体温38.2摄氏度，胸片显示双下肺仍有渗出，生命体征相对稳定。专家会诊认为，患者病情进展程度趋缓，病情谨慎乐观。

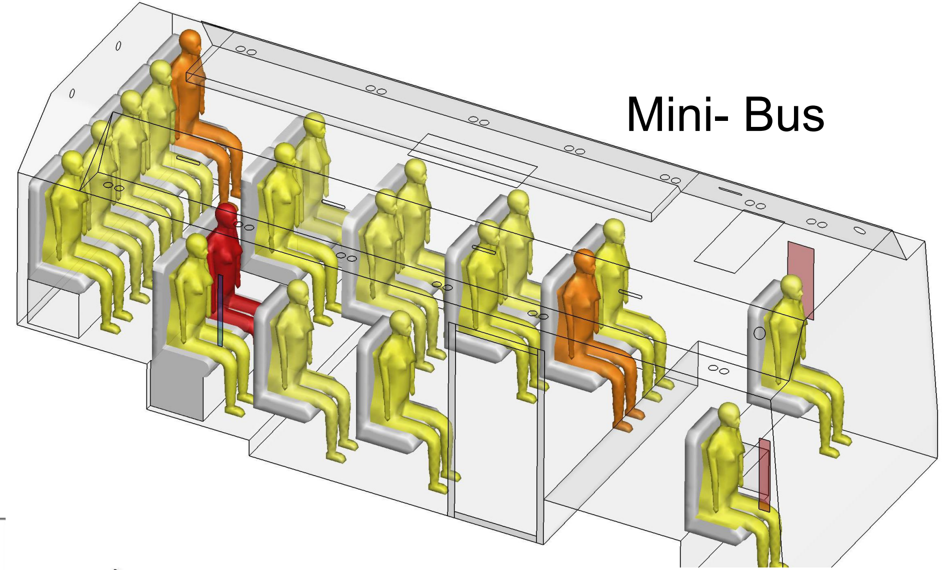


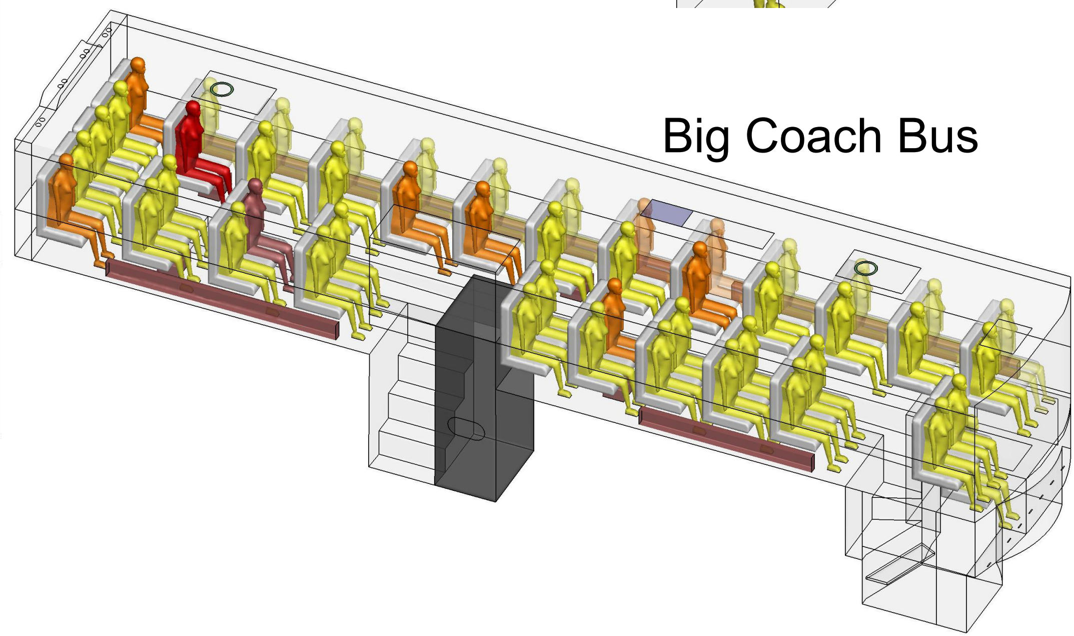
- 长途巴士由于<u>内置空调</u>，<u>封闭空间</u>，<u>乘客多而杂，</u>导致病毒性呼吸道传染病极易在这种情况下传播。
- 2015年5月韩国MERS患者所乘坐的广州至惠州的长途巴士。2020年1月，湖南某省长途巴士中，新型肺炎一传十。

《一起在公共交通工具内气溶胶传播的新型冠状病毒肺炎聚集性疫情流行病学调查》

Grid arrangment







网格大小参考：Zhang L, Li Y. Dispersion of coughed droplets in a fully-occupied high-speed rail cabin [J]. Building and Environment, 2012, 47:58-66.

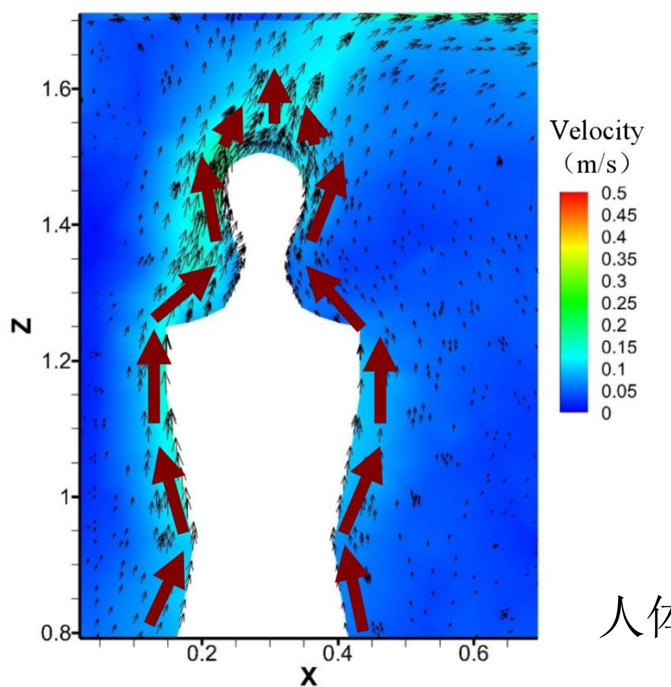
环境相对湿度对于飞沫粒径的影响

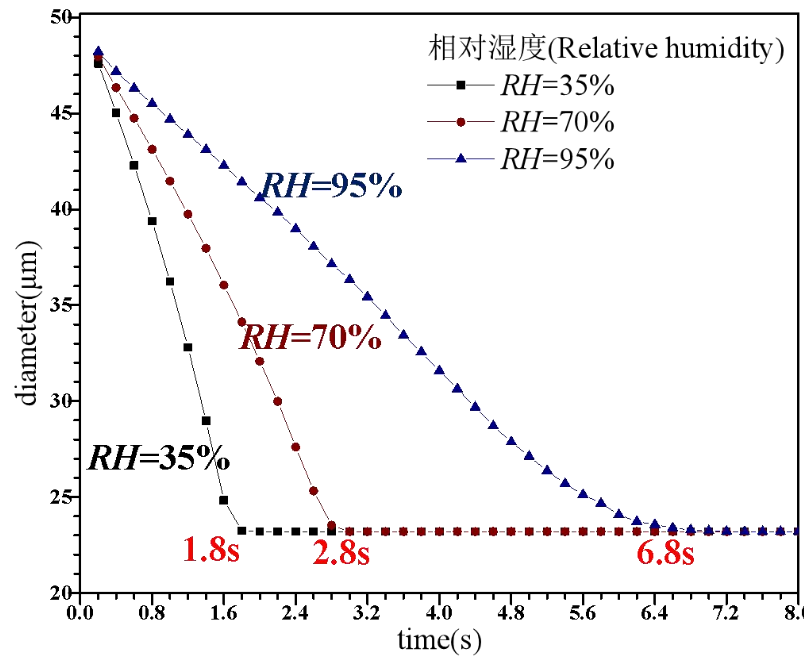
颗粒物完全蒸发后，粒径改变

10μm→4.64μm　　0.2s之内蒸发完毕

50μm→23.20μm

其体积变为原来的10%

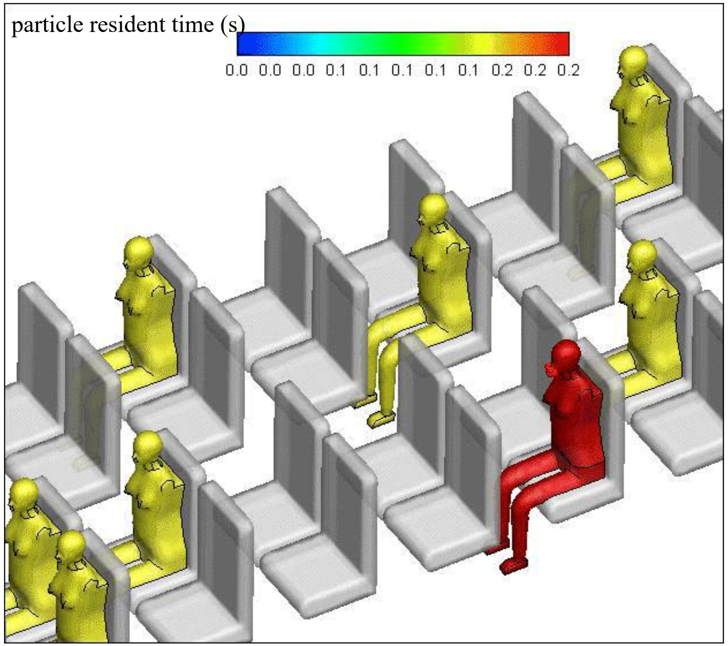




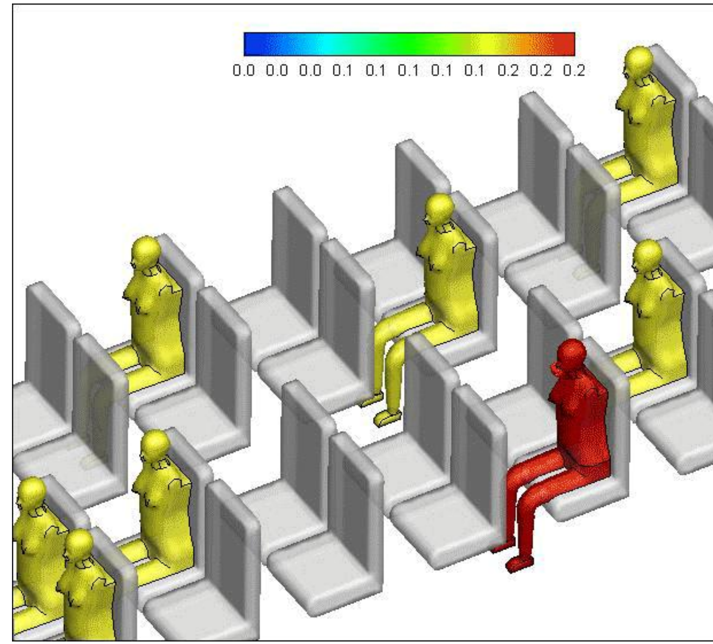
初始粒径为50μm时飞沫的粒径变化

人体热羽流对飞沫扩散有重要影响

高相对湿度95%条件下，飞沫蒸发更慢，更多飞沫沉降在物体表面；
干燥空气(RH=35%)飞沫蒸发、扩散更快



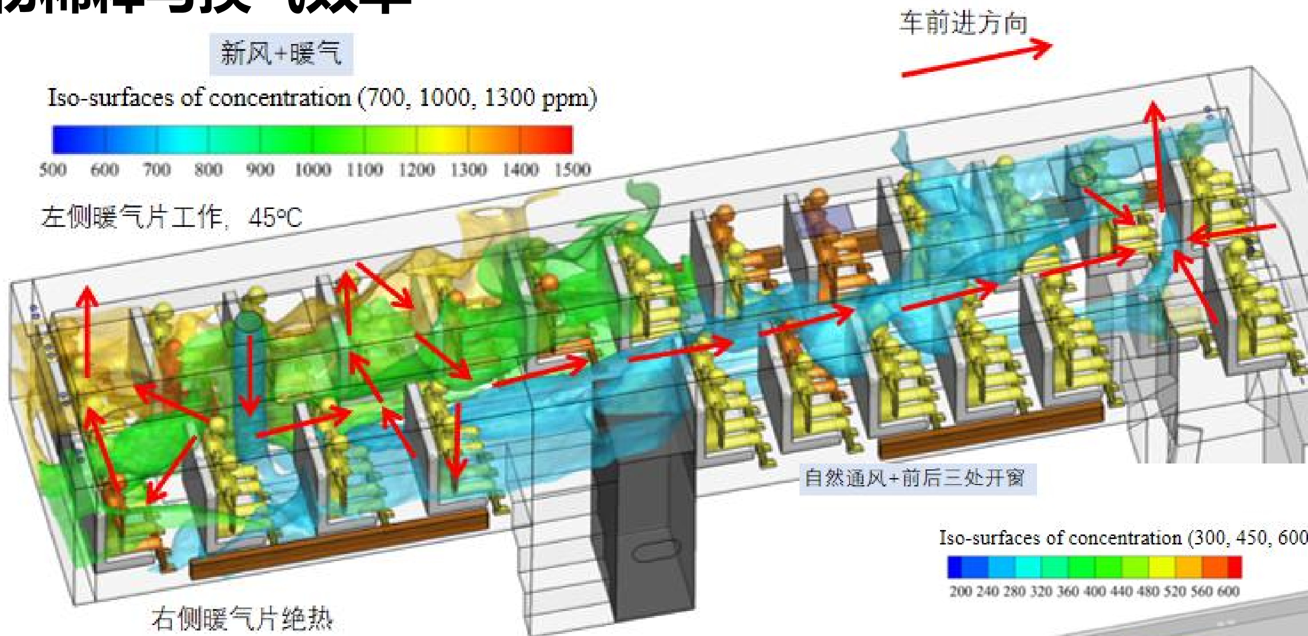
相对湿度 *RH=35%*



相对湿度*RH=95%*

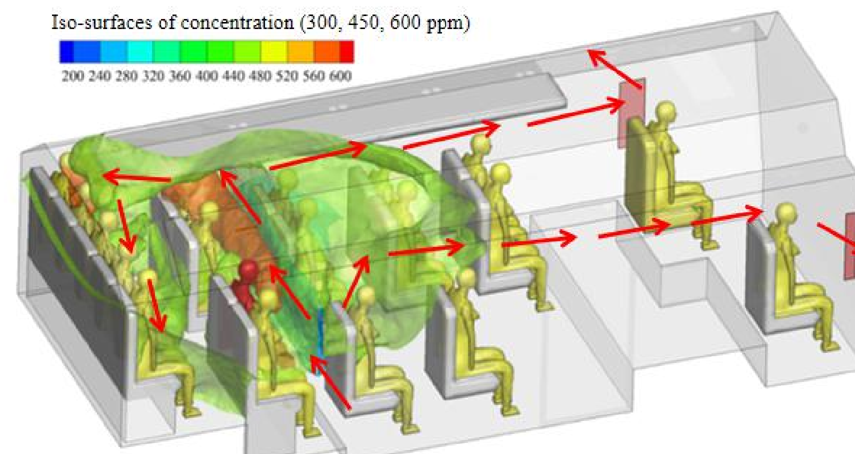
（其中飞沫的颜色代表其停留时间。蓝色表示刚释放的飞沫）

室内通风三项基本原则：增大通风量与换气次数、改进气流组织方式、提高污染物稀释与换气效率



通风越大，感染风险越小 (q为人均新风量)

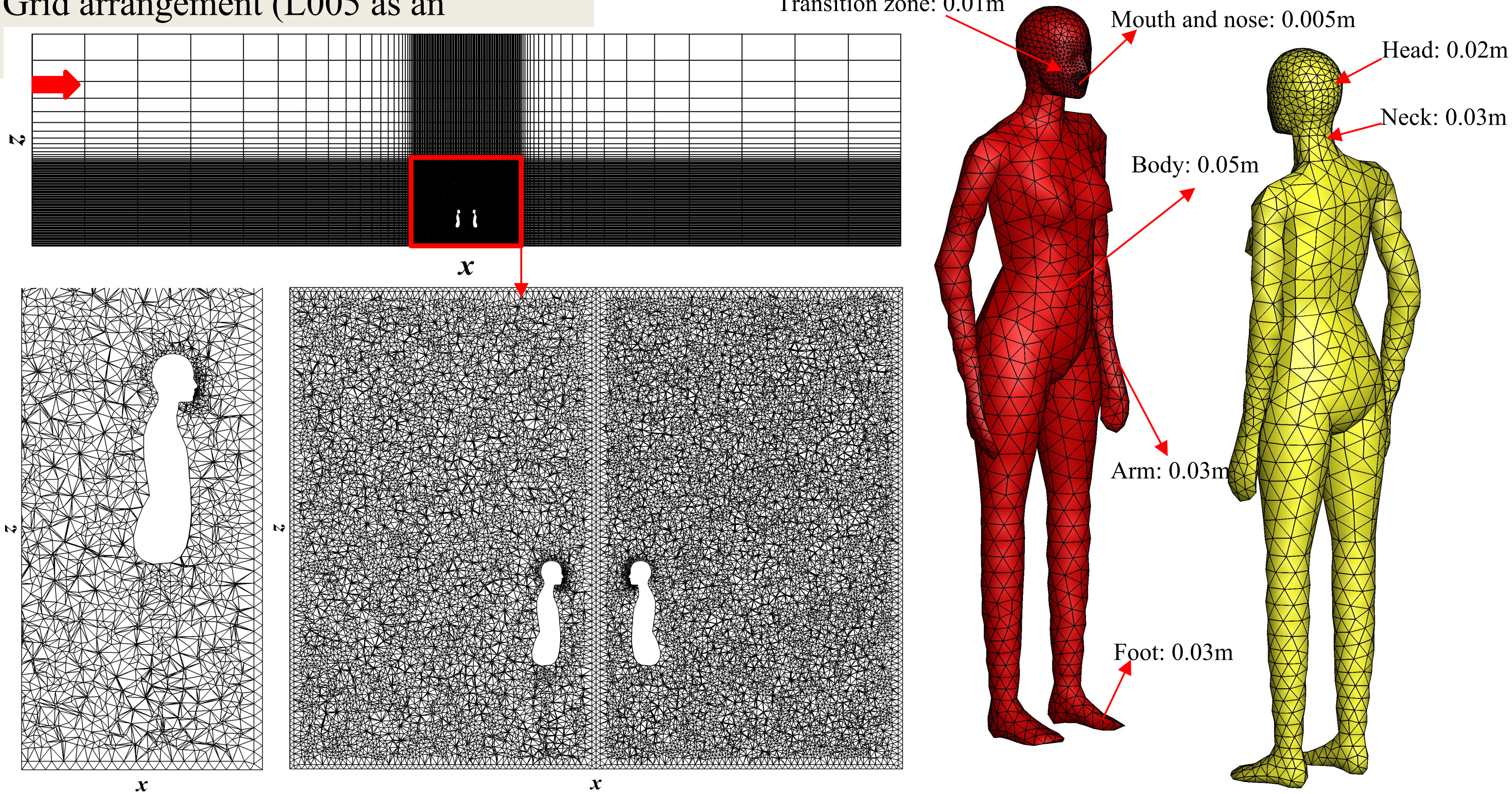
$$P = \frac{Case}{S} = 1 - e^{-Iqpt/Q}$$



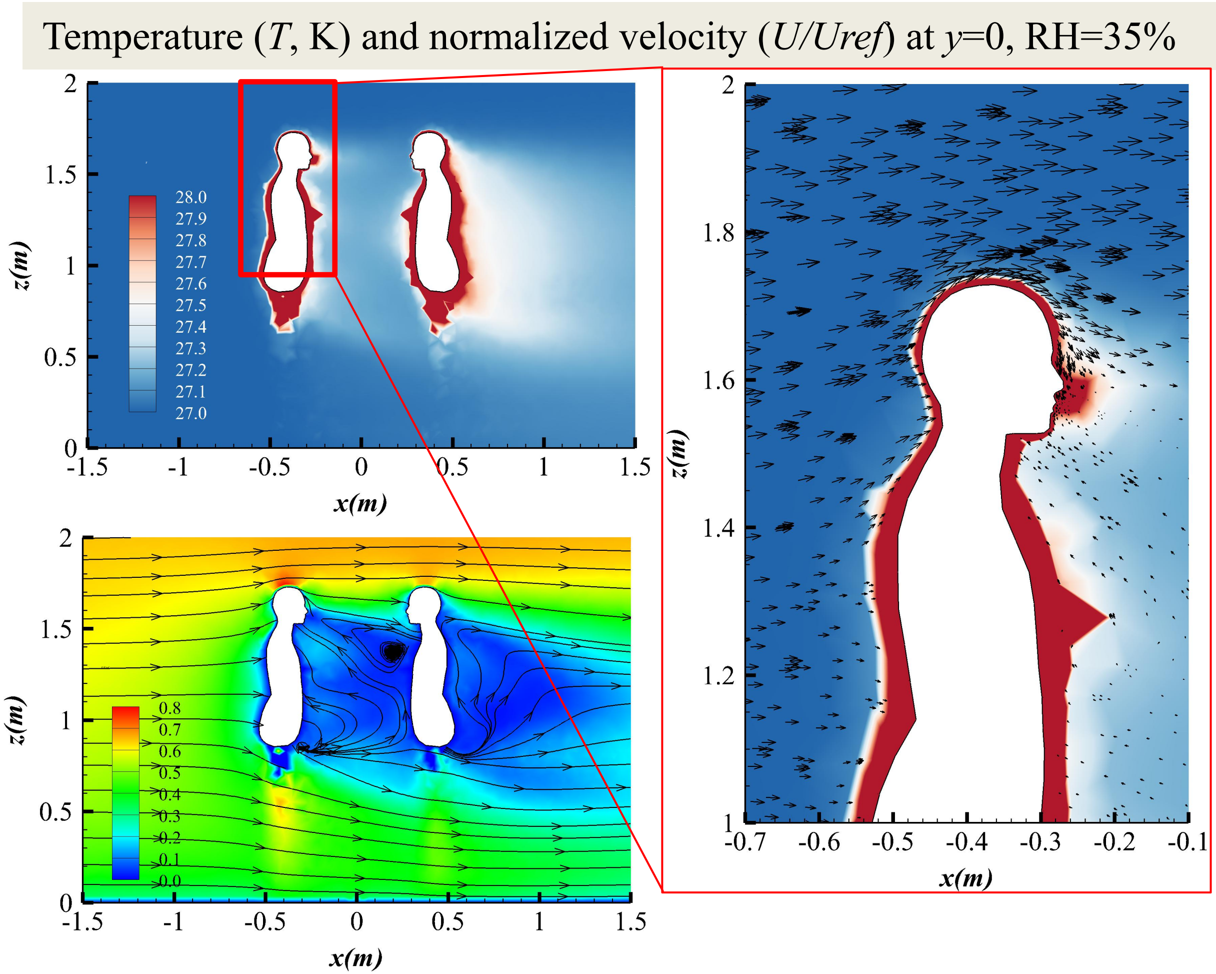
巴士通风量大小、气流的组织方式，决定了飞沫扩散及感染风险

室外飞沫蒸发与扩散研究

Grid arrangement (L005 as an

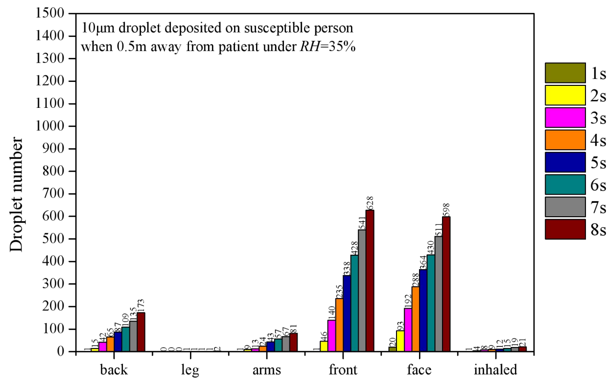


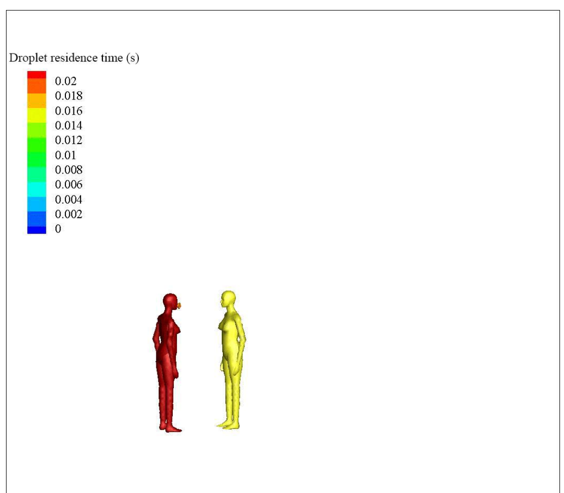
室外风速往往较大，可破坏人体热羽流



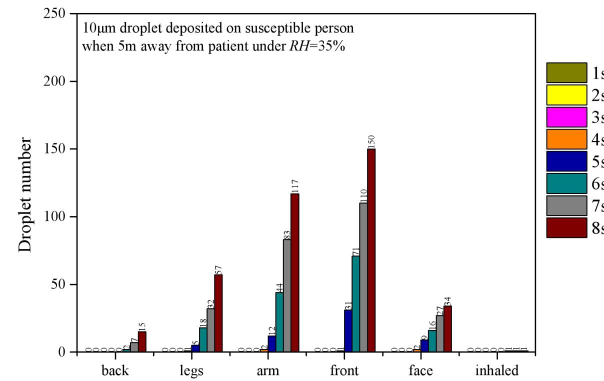
Droplet deposit on susceptible person under *RH*=35% (L=0.5m or 5m)
室外风险相对室内较小，和风向及站位有关；但面对面近距离谈话，最好戴口罩

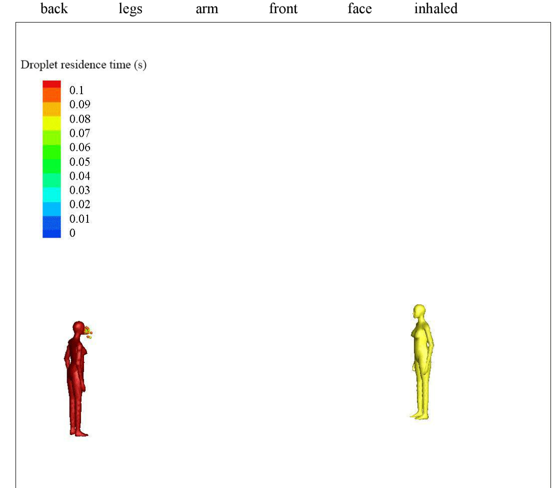
10μm droplet, L=0.5m





10μm droplet, L=5m



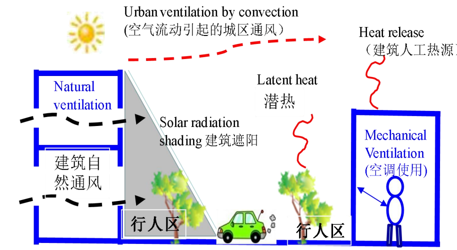


Research topic： Urban micro-climate and built environment

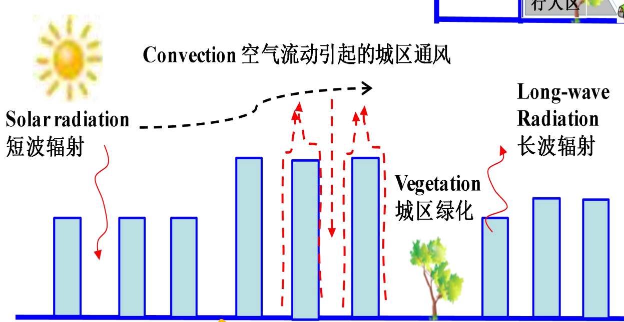
建筑环境 built environment(0.1m-10m)

城市微气候 Urban micro-climate (100m-10km)

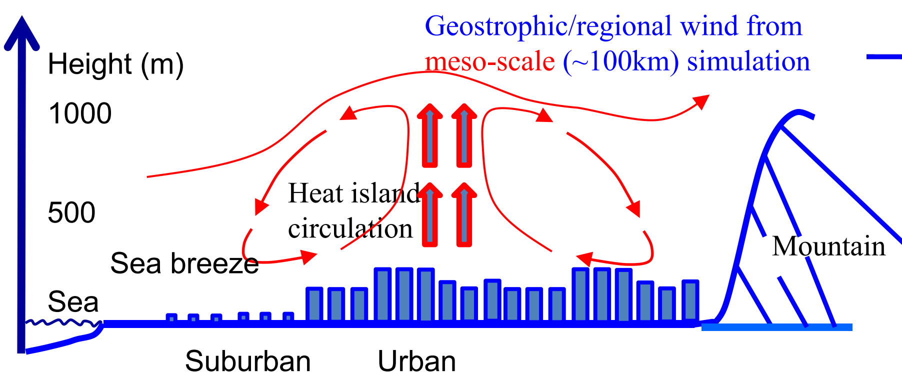
building-street scale(~10m-100m)



neighbor-hood scale (~1-2km)

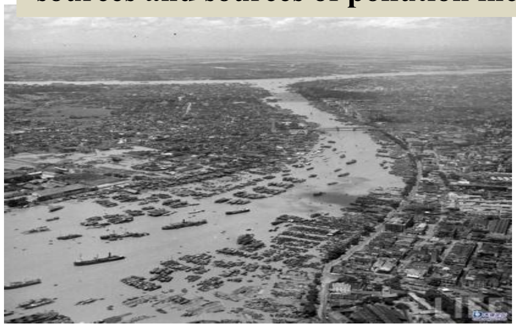


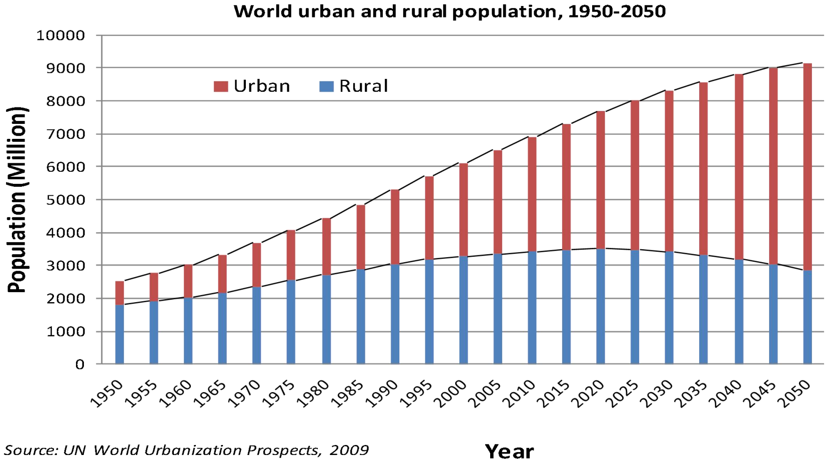
城市尺度 City-scale (~10km)



Rapid urbanization: More and more people are moving into cities

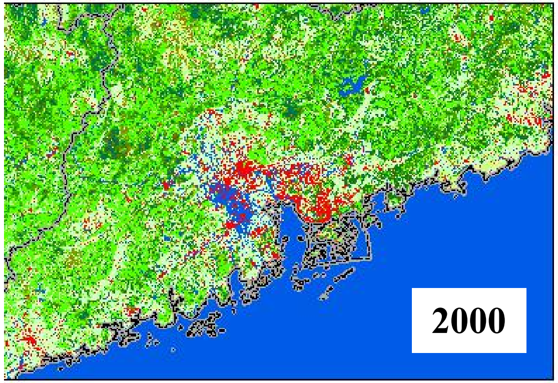
High-rise and high-dense urban construction, anthropogenic heat sources and sources of pollution increased

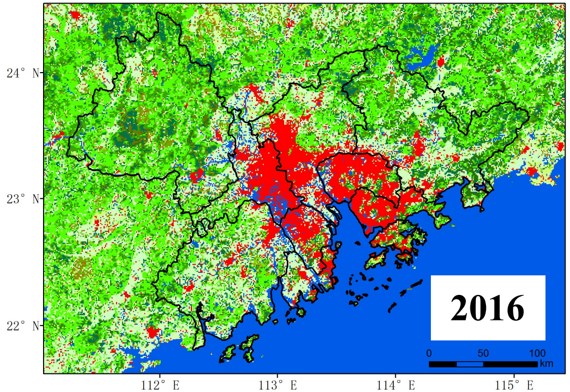




- 51% (i.e. 3.5 billion) of 6.9 billion by 2010; 60% (i.e. 5.0 billion) of 8.3 billion by 2030.
- Large cities worldwide (>1 million): 355, by 2000; 449 by 2010 , 668 by 2025.

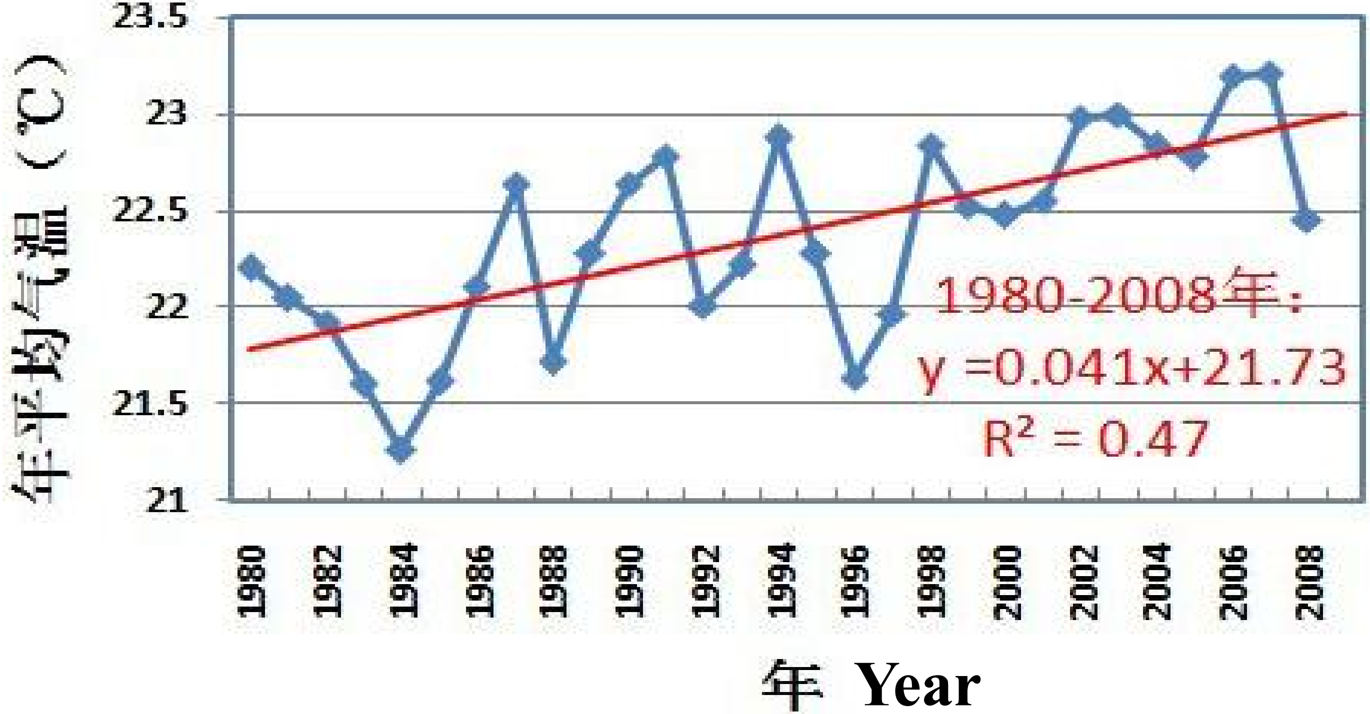
Land use in Pear River Delta region(2000→2016)





0.041 °C/year >> 0.019 °C/year by global warming

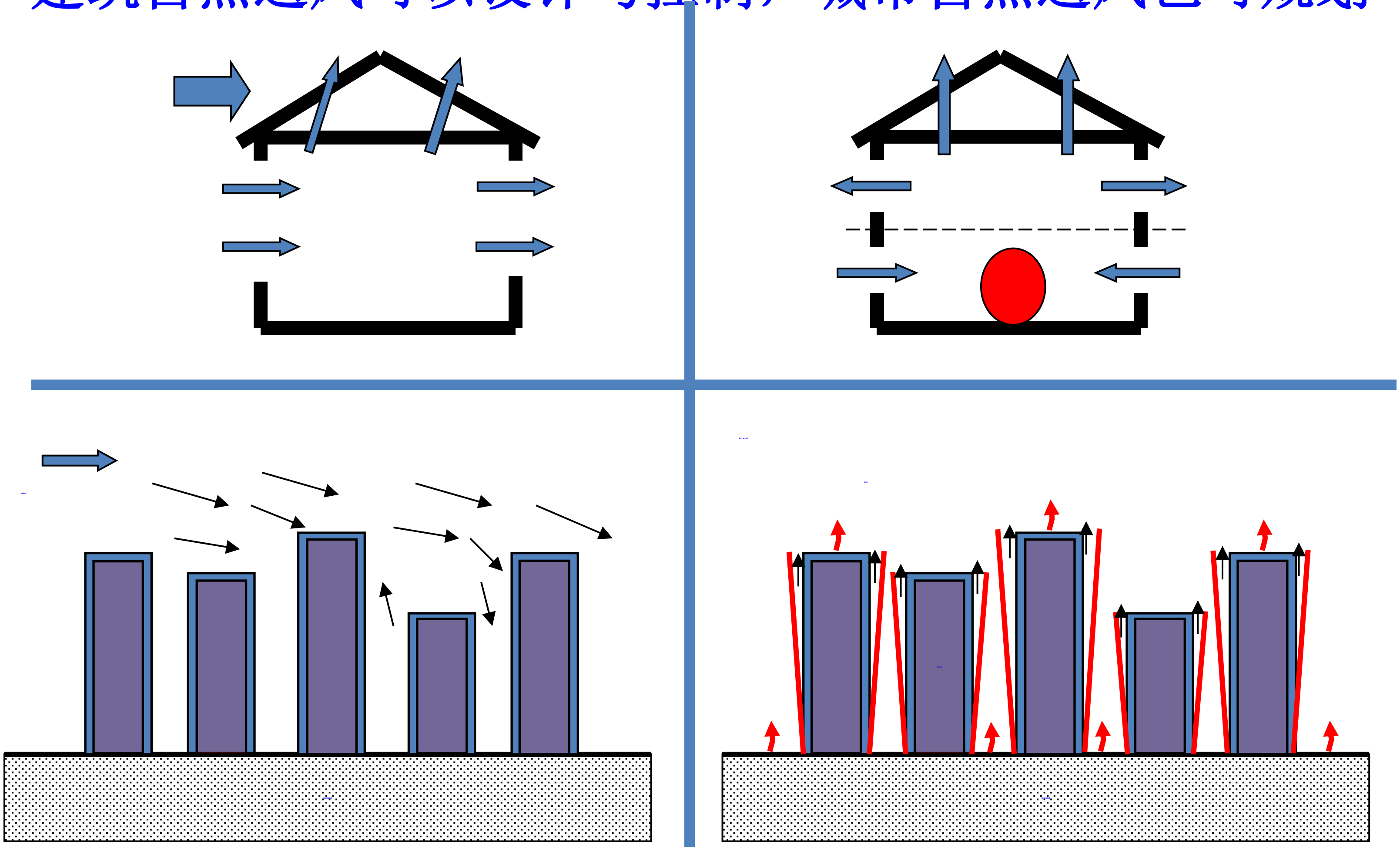
Annual
T (°C) in
Guangzhou



In the last five decades, *T* in Beijing/Shanghai/Guangzhou rises 2 to 2.5 °C, much greater than *T* rise due to global warming (0.76°C) in the last century. 过去 50 年北京和上海等大城市的平均气温上升了 2 至 2.5°C,远高于过去一百年的全球变暖温度升幅(0.76°C)。

Building ventilation and city ventilation

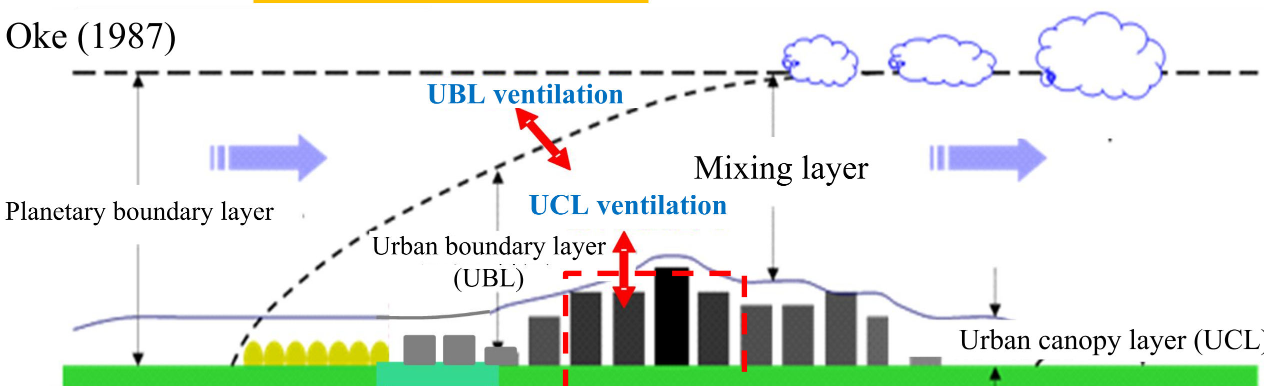
建筑自然通风可以设计与控制，城市自然通风也可规划

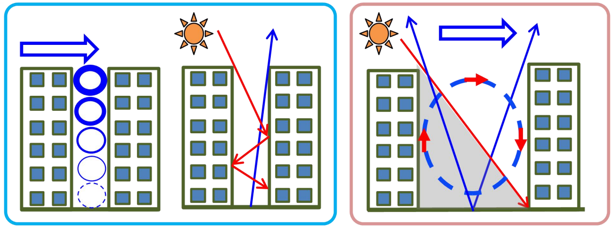


Source： Prof Yuguo Li in the University of Hong Kong

For indoor-outdoor ventilation: dynamic force and buoyancy force

Atmospheric conditions
Urban morphologies
→ Urban turbulence (UCL+UBL) → Urban ventilation/ pollutant exposure





$$F_r = \frac{U_{ref}^{2}}{\beta g H (T_w - T_{ref})} = \frac{U_{ref}^{2}}{g H \Delta T / T_{ref}}$$

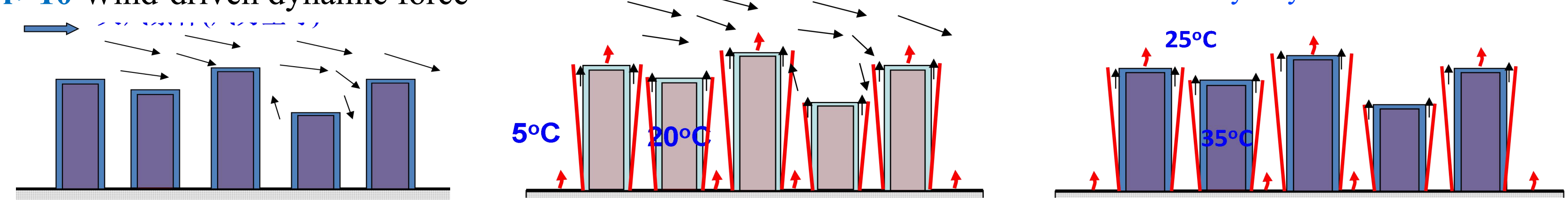
$$F_r = \frac{U_{ref}^{2}}{g H \Delta T / T_{ref}}$$

Urban ventilation depends on dynamic force and thermal buoyancy force.

Fr>10 Wind-driven dynamic force

0.1<Fr<10 both forces interacts

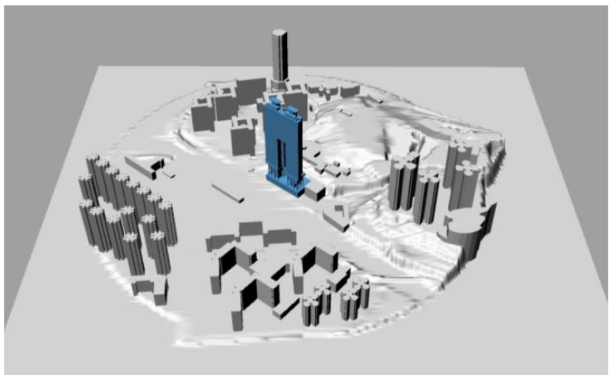
Fr<0.1 Buoyancy force dominates

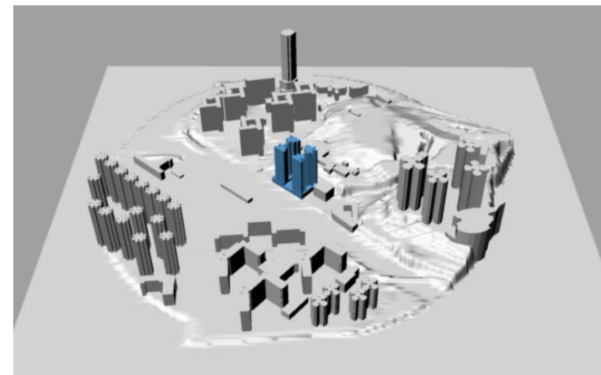


An example of urban wind environment simlation in Hong Kong

香港城区风环境模拟示例

-两种设计比较 Two design schemes



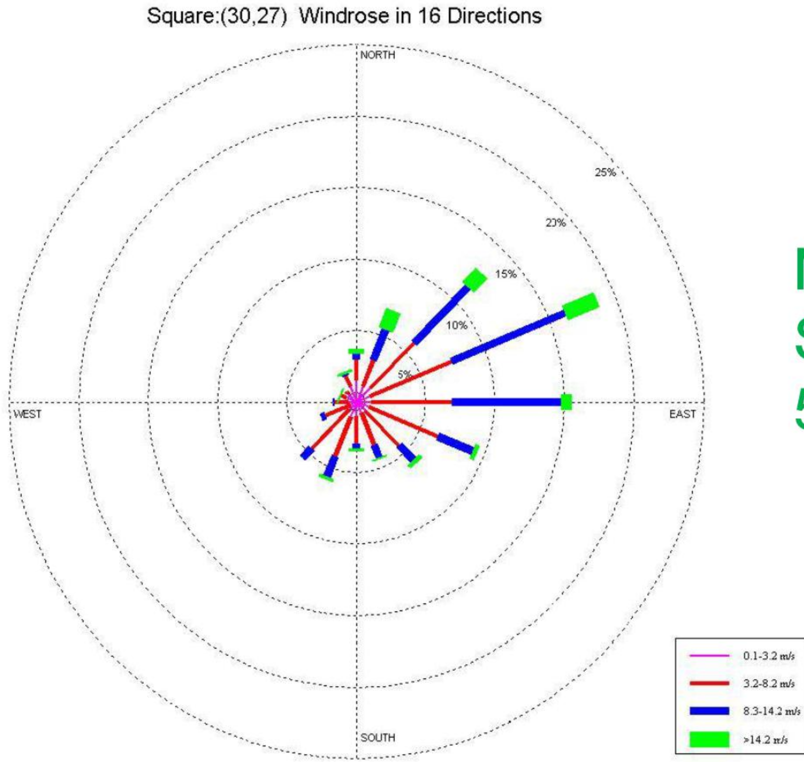


Proposed scheme
推荐设计：203m

Two-tower design
Fully open at the podium level>>20m
Varying gap from the podium level to the upper level
Height: +202.9mPD

Base scheme
一开始的设计：110米

Four-tower design
20m gap above the podium level
Height: +110mPD

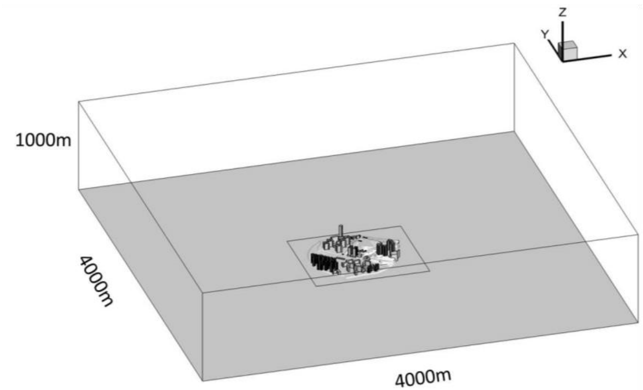


NNE+NE+ENE+E+ESE+SE+SSW+SW=79.4%>75%

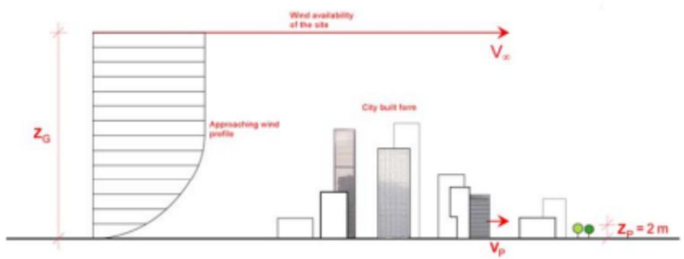
Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)
N	*3.6*	E	*15.3*	S	*3.4*	W	*1.7*
NNE	*6.8*	ESE	*9.2*	SSW	*5.8*	WNW	*1.3*
NE	*12.6*	SE	*6.0*	SW	*5.5*	NW	*1.0*
ENE	*18.5*	SSE	*4.2*	WSW	*2.7*	NNW	*2.2*

- *Numbers in green represent the selected prevailing wind directions for simulation*

Computational approach



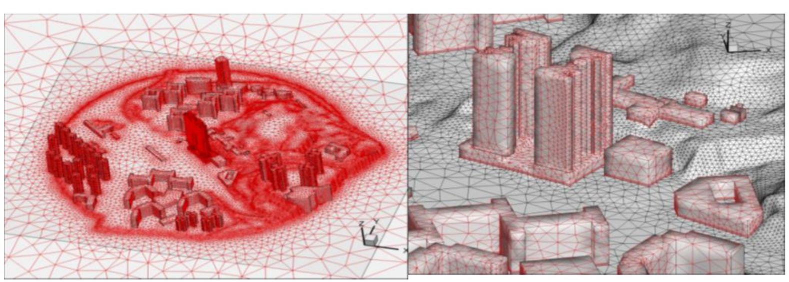
Computational domain:
4000mx4000mx1000m
CFD solver: Ansys 12.1 (Fluent 6.3)
Turbulence model: RNG K-ε model
(*AIJ guideline-Yoshie et al, 2007; COST2004*)



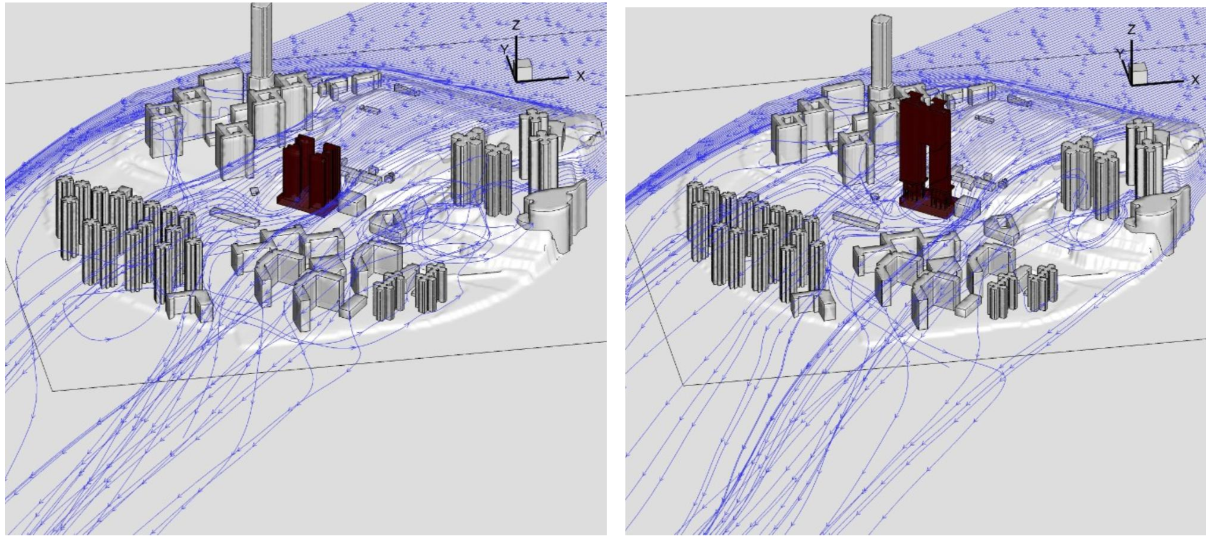
Boundary conditions:
Inflow---power-law profile, n=0.35

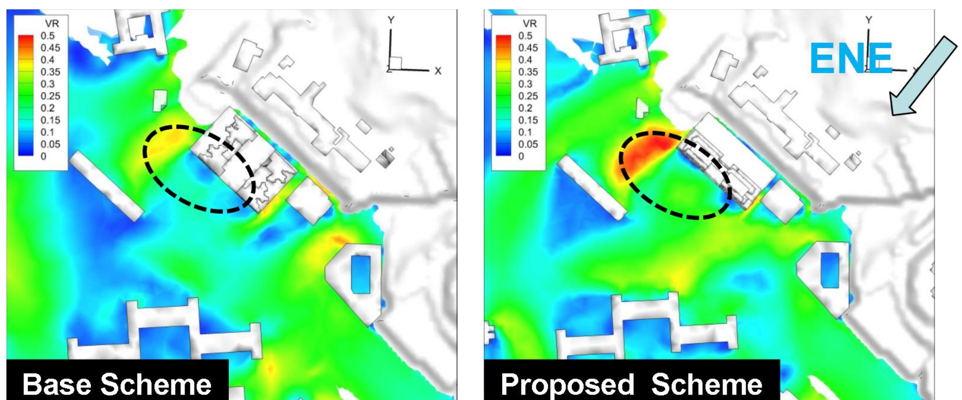
$$U_z = U_r\left(\frac{Z}{H_r}\right)^n$$

Outflow---Zero gradient, fully developed
Lateral, top boundary---Symmetry



城市风环境模拟，往往主要关注行人区风速比





2m above the street level

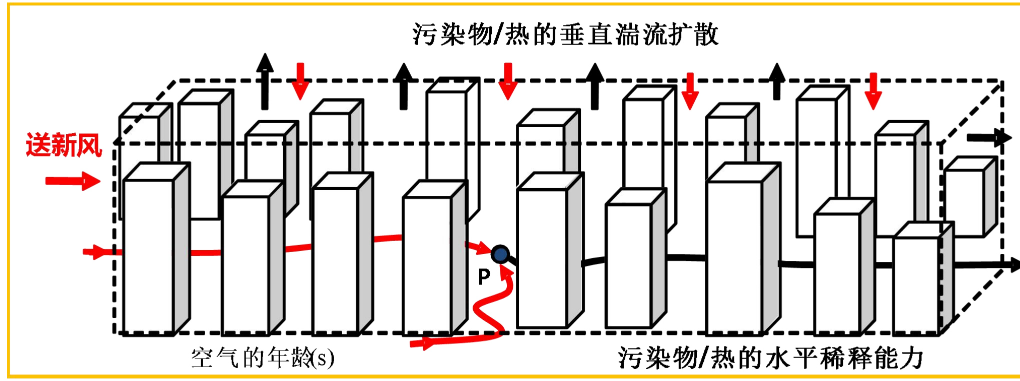
城市通风-呼吸性 ~ 城市形态urban morphologies

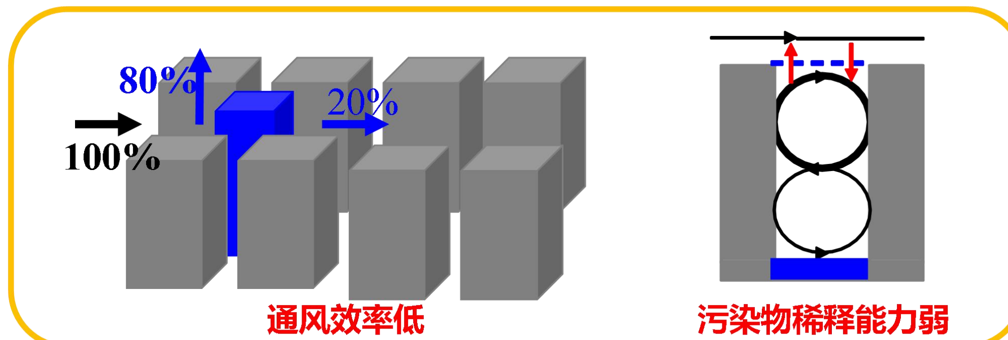
三项基本原则：增大通风量与换气次数、改进气流组织方式、提高污染物稀释与换气效率

Air change rate per hour (ACH)
Air exchange efficiency
Exchange velocity and In-canopy velocity

空气的年龄
Age of air

污染物逃逸速度Net escape velocity
污染物稀释流率 Purging flow rate

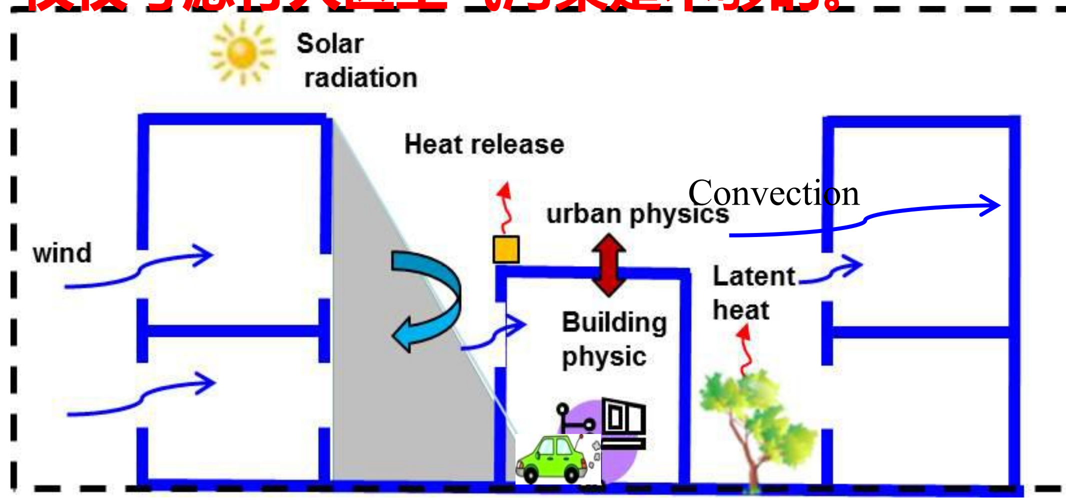




Hang J, et al., *Atmospheric Environment* 2009. 43(4): 869-878.
Hang J, Li YG, *Atmospheric Environment* 2011. 45(31): 5572-5585.
Hang J, et al. *Building and Environment* **2012**. 56, 346-360.（引用118次、高被引）
Hang J, et al. *Building and Environment* **2013**. 70:318-333.
Hang J, et al. *Building and Environment*, **2015**. 94:166-182.

People spend 90% of their time indoor. The human exposure of outdoor pollutants mainly occurs after pollutants enter indoor.

人平均90%的时间是在室内度过的，城市主干道汽车尾气对行人和临街建筑室内人群暴露的危害，需要更多关注。仅仅考虑行人区空气污染是不够的。



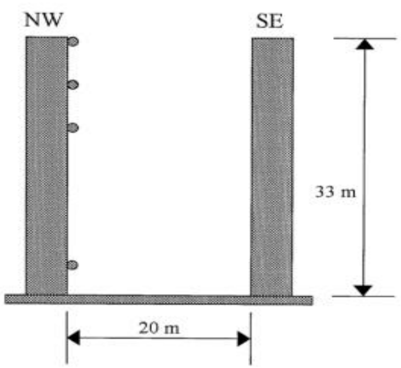
Room/Building/Street scale (~10m to 100m)

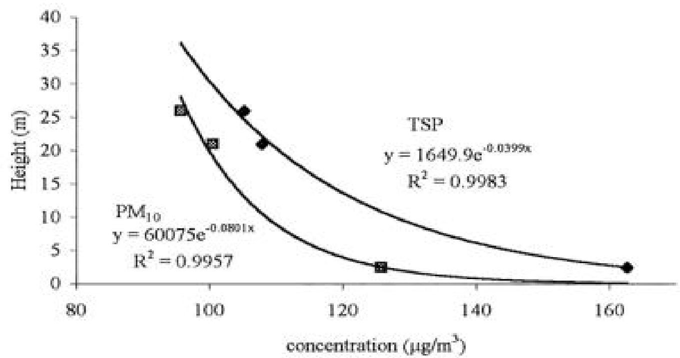
- **Vehicular human exposure in near-road buildings requires special more concern; 临街建筑形态对空气污染的影响需更多关注**
- Urban layouts and atmospheric conditions influence both urban ventilation and building natural ventilation.

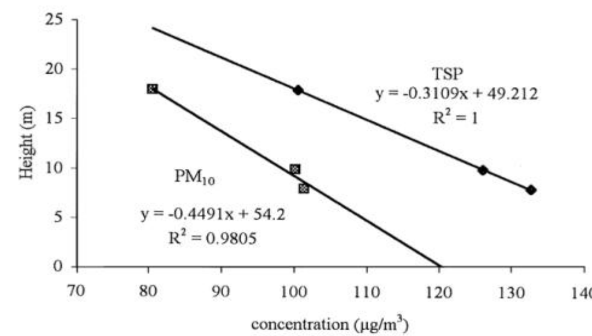
Sustainable urban morphologies can help reducing overall pollutant exposure in near-raod buildings .

城市建筑形态对临街建筑人群污染暴露的影响需要定量分析和设计

Most studies found leeward-side concentration is higher than windward side. But vertical profiles are reported differently , e.g. from the ground to high levels, concentration decreases exponentially, or linearly or keep nearly constant (*Chan et al., 2000; Kalaiarasan et al., 2009; Ouang et al., 2012*)







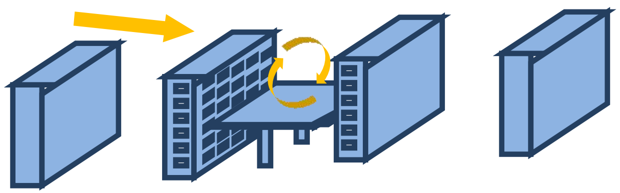
Chen, C., **Zhao, B**., Zhou, W.T., Jiang, X.Y., Tan, Z.C., 2012. Build. Environ. 47, 339-348
A methodology for predicting particle penetration factor through cracks of windows and doors for actual engineering application..

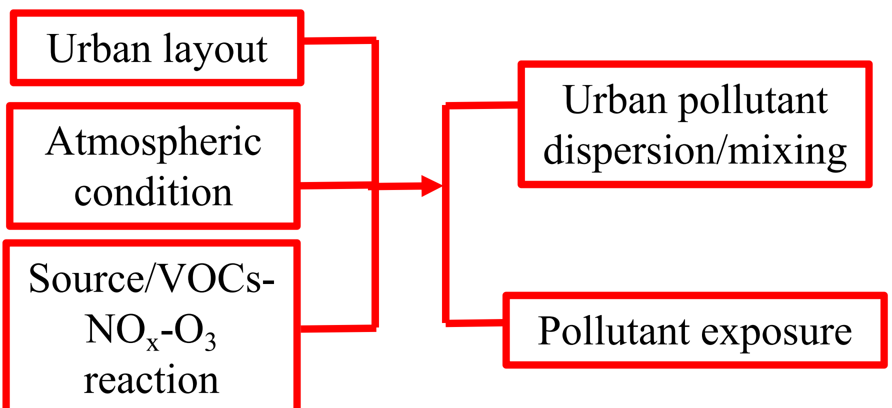
Ji, W.J**., Zhao, B**., 2015. Estimating mortality derived from indoor exposure to particles of outdoor origin. PLOS. ONE. 10, e0124238.

Urban layout ~ vehicular pollutant exposure

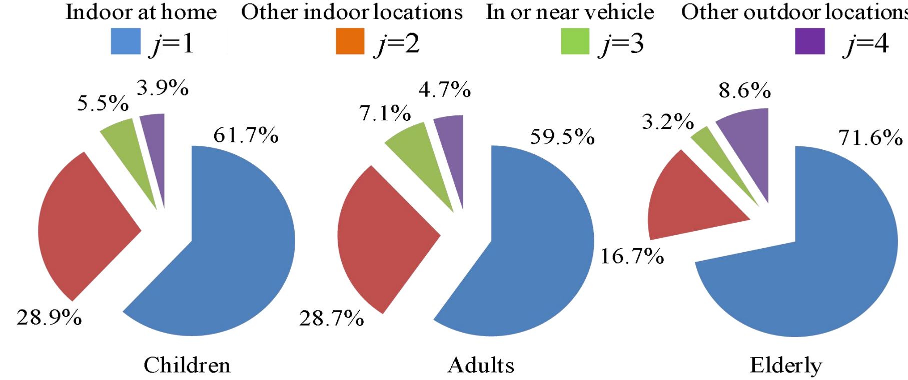
Daily Pollutant Exposure (mg/m^3-day) **日暴露量**: the extent of human beings' contact with different air pollutants within one day

Intake fraction (IF) 污染物吸入比: 1ppm=10^{-6} represents 1g of air pollutants is inhaled by an exposed population from one ton of pollutants emitted from the source

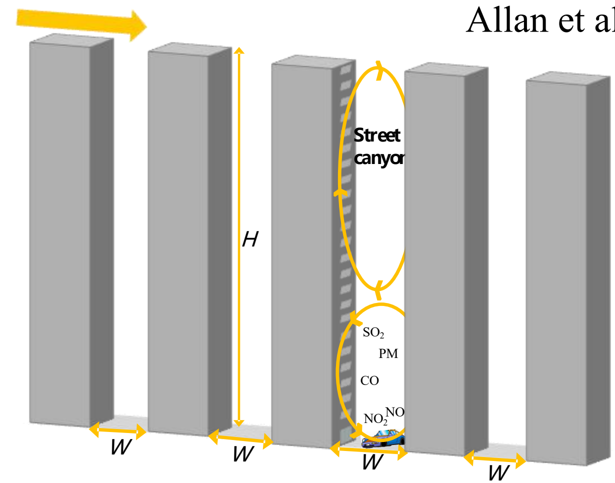




Time fraction for four activity patterns



Allan et al. (2008)

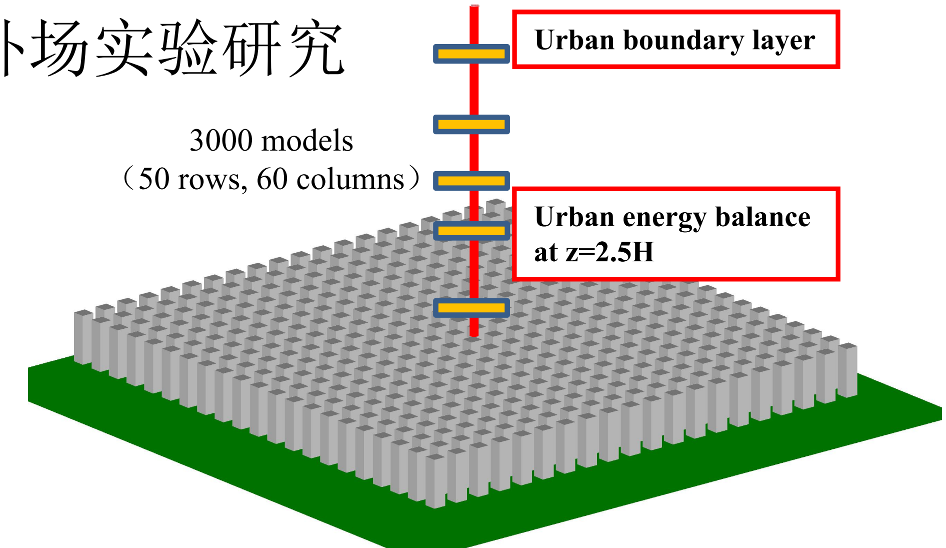


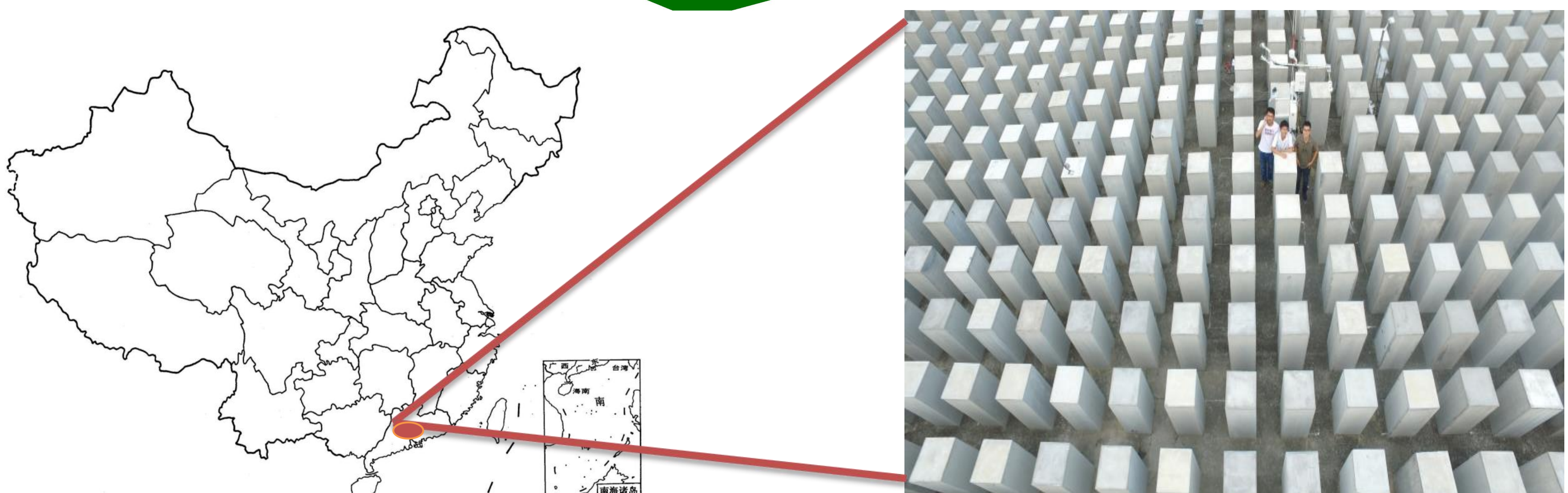
VOCs-NOx-O_3 chemical reactions

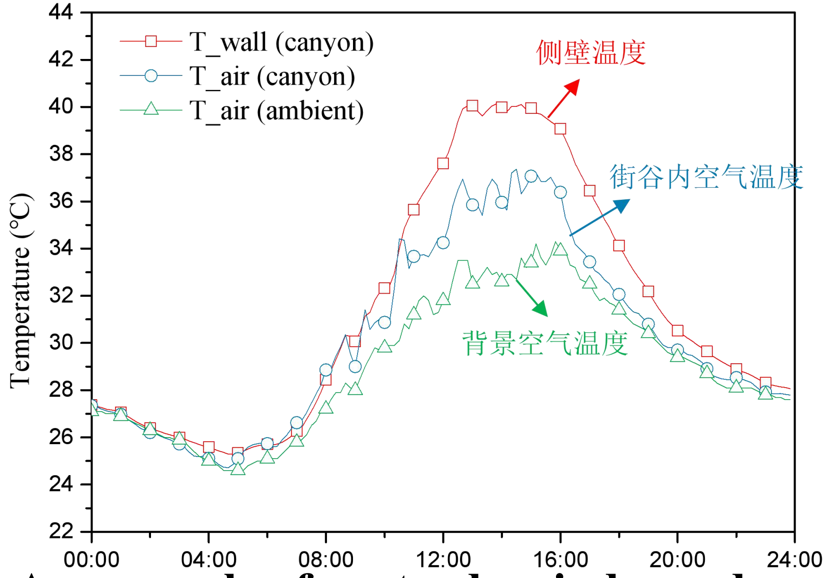
Hang J, Luo Z*, et al., Environmental Pollution 2017, 220:72-86.
He L, Hang J*, et al., Science of the Total Environment, 2017, 584–585: 189–206
Zhang KE, et al., Science of the Total Environment, 2019, 653: 968–994

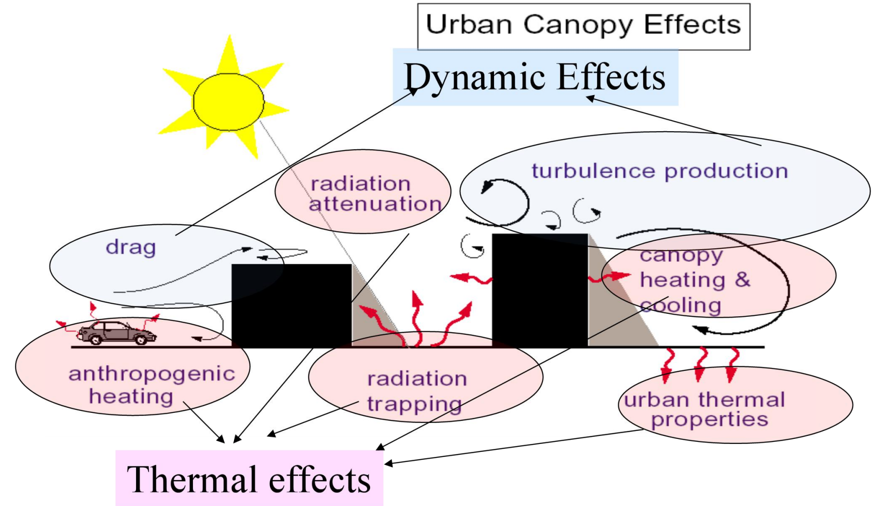
Scale-model outdoor measurement of urban climate and health: SOMUCH

城市缩尺尺度外场实验研究

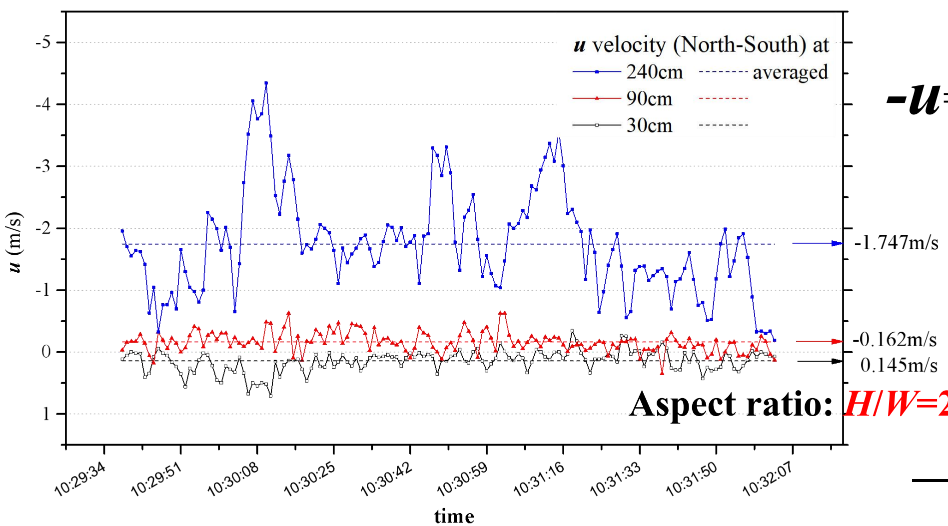


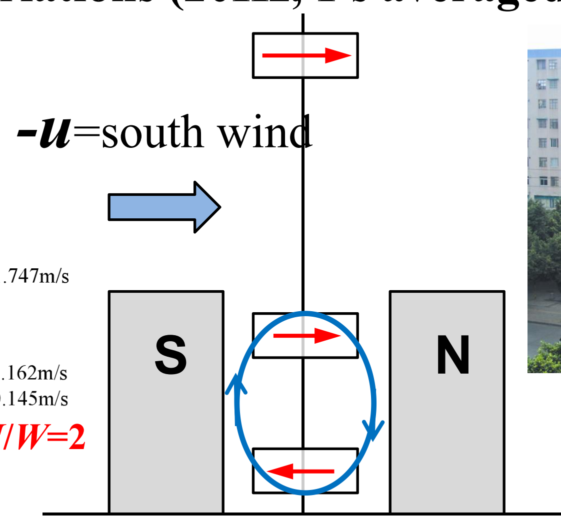






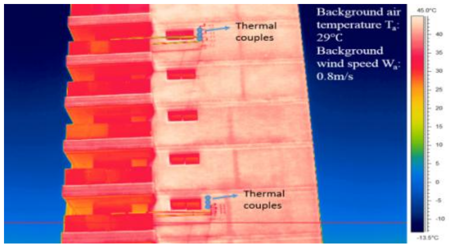
- An example of unsteady wind speed variations (20Hz, 1 s averaged data)



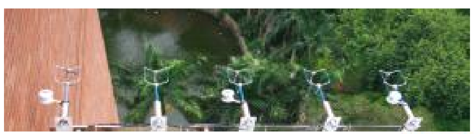


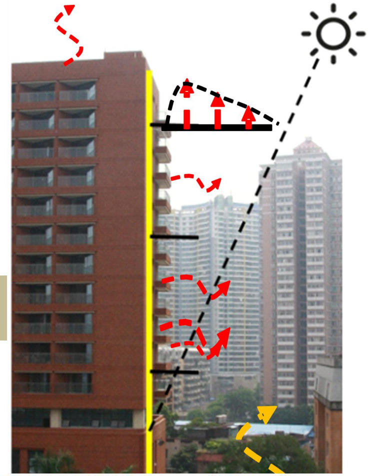
Realistic cities are complicated. High-quality measurements/CFD simulations have big challenges as thermal effects are important.

Thermal boundary conditions are complicated, and vertical profiles are not easy to measure.



Devices setup is difficult





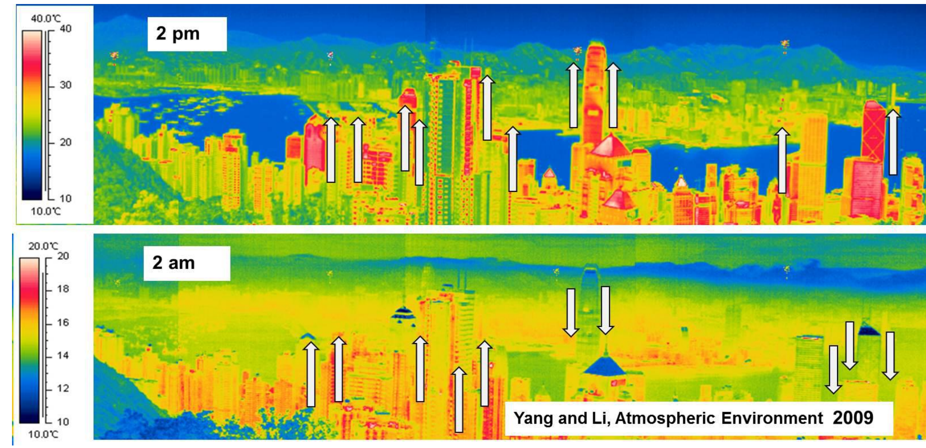


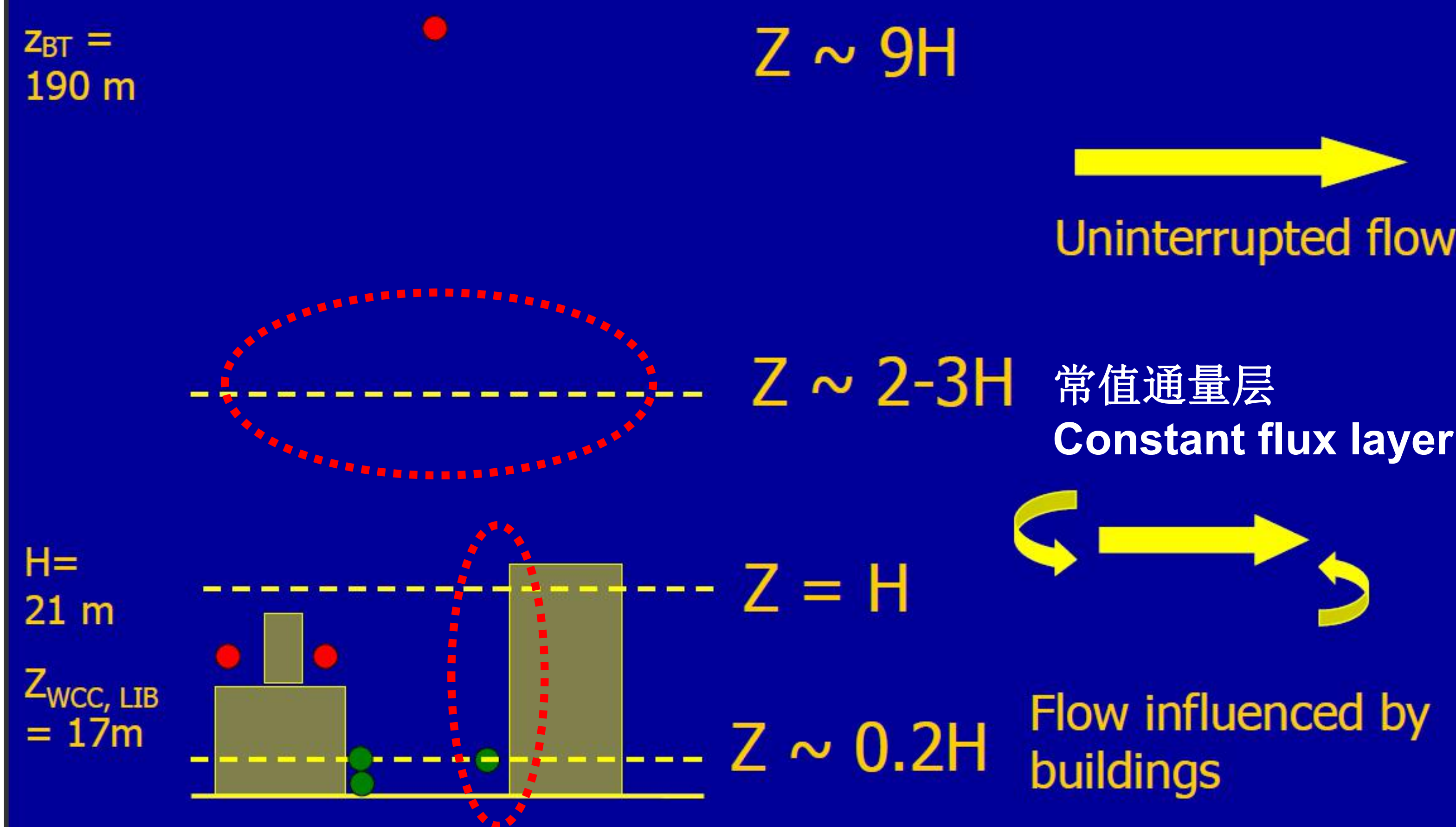
Table IV. Values of parameters relevant to the surface energy budget.

Land use classification adopted for the present study	Buildings	Asphalt	Grassland	Water	Trees
Albedo [−] (Ichinose *et al.*, 1999)	0.18	0.18	0.16	0.08	0.16
Surface emissivity [−] (Ihara *et al.*, 2003)	0.96	0.91	0.95	0.93	0.95
Evaporation efficiency [−] (Ichinose *et al.*, 1999)	0.05	0.05	0.30	1.00	0.30
Density [kg m^{-3}] (Ichinose *et al.*, 1999)	2.4×10^3	2.1×10^3	1.8×10^3	1.0×10^3	1.8×10^3
Specific heat [J kg^{-1} K^{-1}] (Ichinose *et al.*, 1999)	882	882	1176	4200	1176

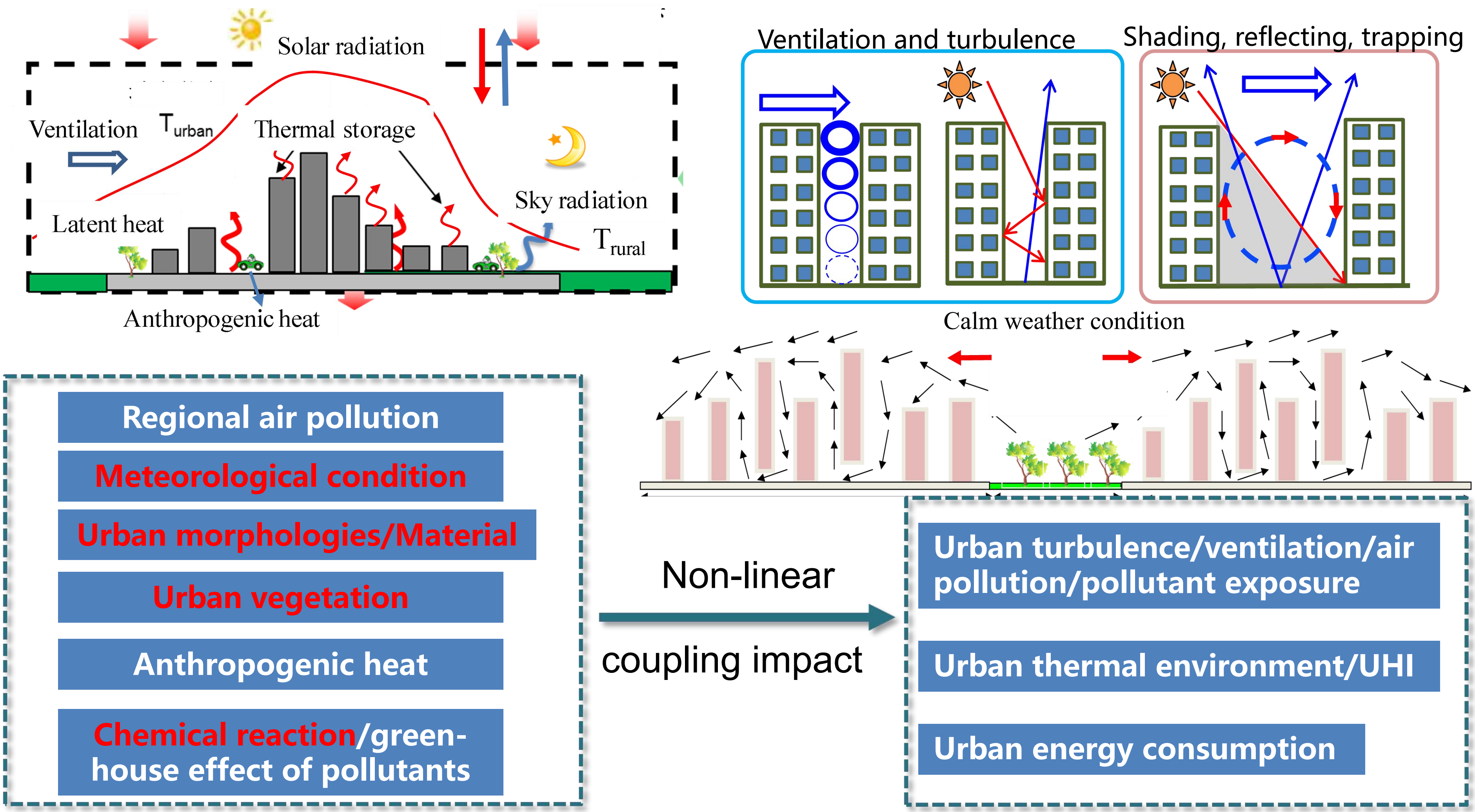
Can we use one constant for all building???

Heights of measurement

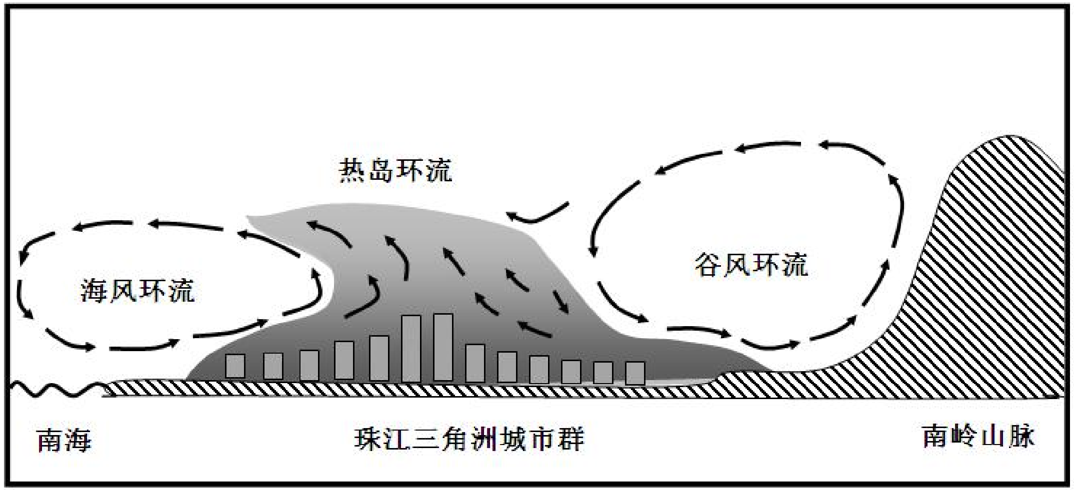
城市气象 观测， 主要关注近地面与屋顶高度

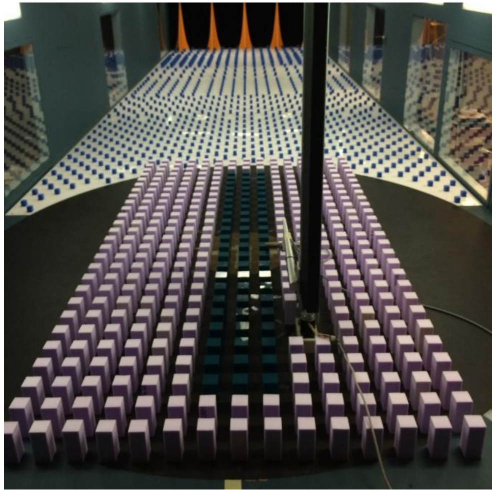


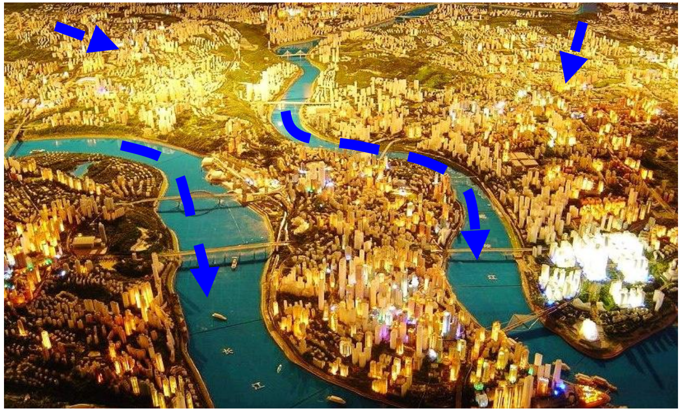
The impacts of each factor have not been clearly known



每个真实城市都有各自的个性。除了城市本身因素与气象条件外，还需要考虑周边地形地貌、河流湖泊等。例如珠三角模型，存在主导风、海陆风、热岛环流、山谷风等。**但也可以研究其共性、理想城市模型。**





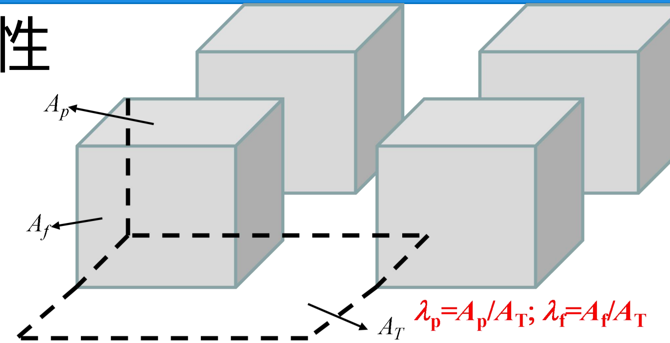


缩尺尺度外场实验可控性好、能满足热力学相似要求

- 缩尺尺度城市气候实验，可满足热力学相似性
- 可为数值模拟提供较好的实验验证数据

λ_P :Buidling area density 0.25

λ_f :Frontal area density 0.25



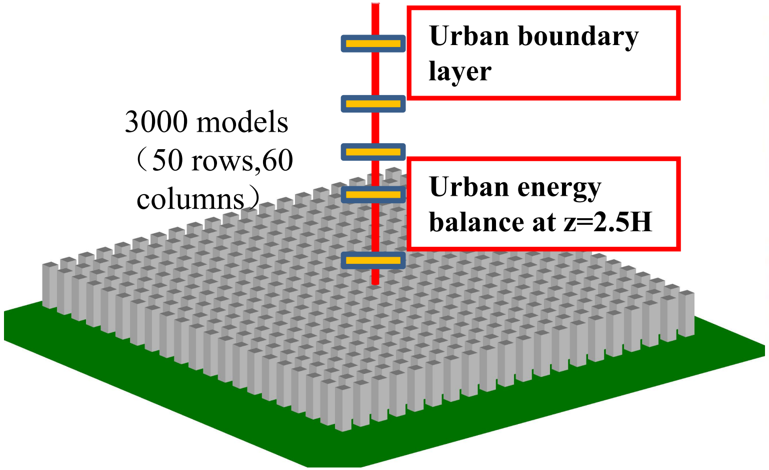
国外会议时的实验梦想

柏林犹太人纪念碑_百度图片

城市气候与健康缩尺尺度外场实验研究（SOMUCH研究-国家优青项目）
Scaled Outdoor Measurement of Urban Climate and Health

➢构建**热惯性足够大、建筑储热项易测、建筑形态与绿化可控**的中、高密度缩尺尺度模型，**建筑热力边界可测**，可提供高质量实验数据，明确物理机制，为数值模拟与城市冠层模型(UCM)提供验证

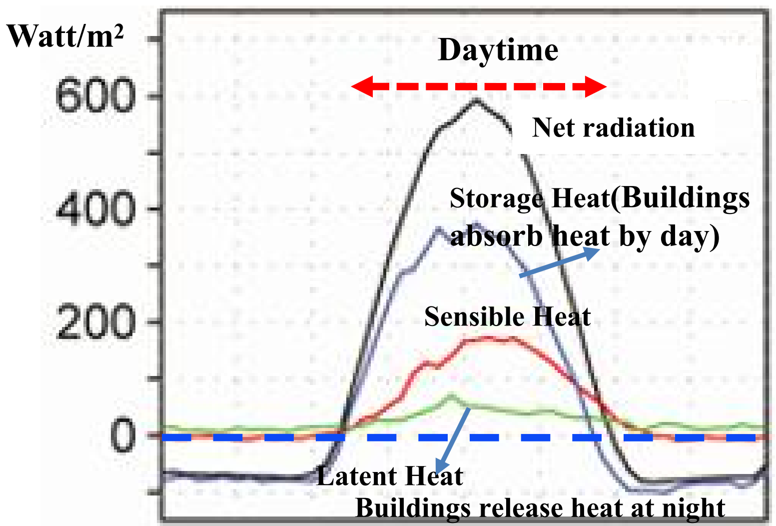
建筑形态与气象条件的影响：
- ➢ 城市湍流特征
- ➢ 城市污染物扩散特征
- ➢ 城市热岛与能量平衡



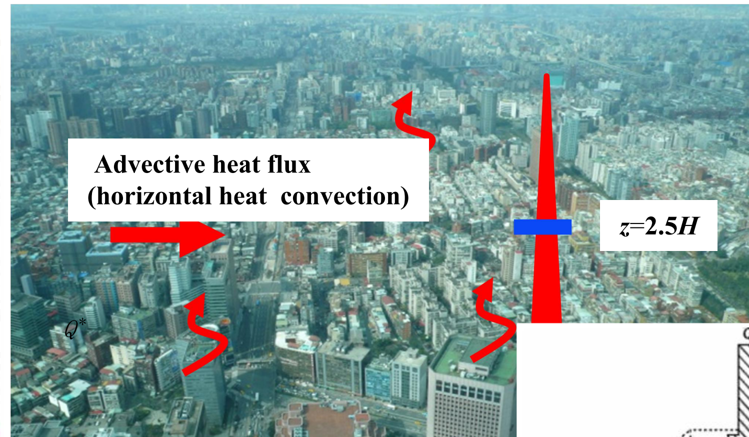
真实城市能量平衡：

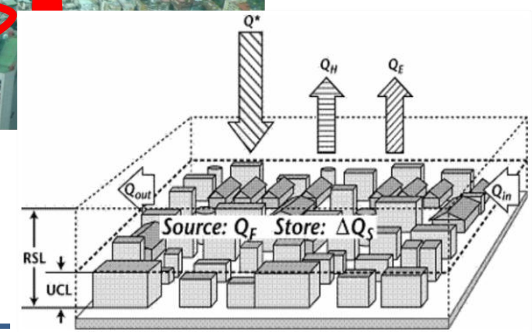
建筑储热难直接测量，假设下垫面均匀、数据不确定性较大

In real cities, urban thermal storage can not be measured directly



Urban energy balance at a height of 140m in spring, Beijing(Shiguang Miao et al,2012)





Real city: Q^* + Q_F = ΔQ_S + Q_H + Q_E + ΔQ_A

Net radiation + Anthrop logic heat = Building thermal storage + Sensible heat + Latent heat + Adve tive heat flux

Four components of long and short waves

accurately)

(Unable to measure directly)

Vertical turbulence

Vapour evaporation

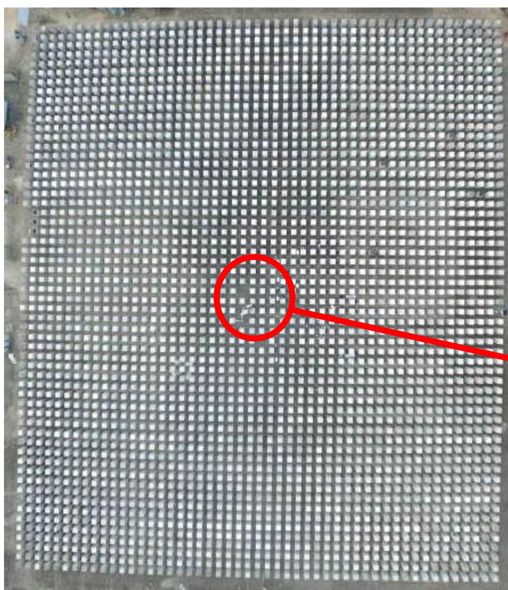
Homogeneous underlying surface

Scale-model outdoor field measurement
缩尺尺度外场实验：储热可测、均匀性可保证

Scale-model city：

Q^* + Q_F = ΔQ_S + Q_H + Q_E + ΔQ_A

- Q^*: **Net radiation** — Measurable
- Q_F: **Anthropologic heat** — (Controllable and knowable)
- ΔQ_S: **Building thermal storage** — (measurable directly)
- Q_H: **Sensible heat** — Measurable
- Q_E: **Latent heat** — Measurable
- ΔQ_A: **Advective heat flux** — Inhomogeneous underlying surface is also computable

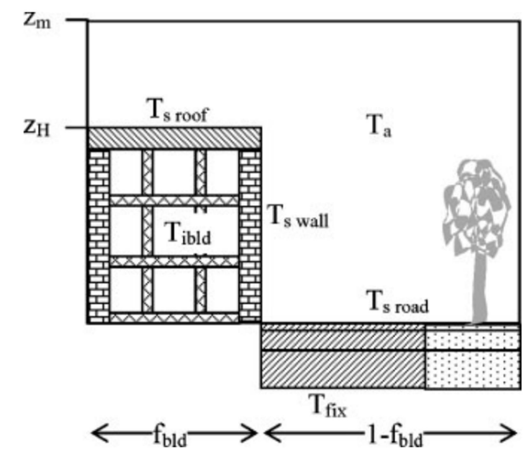


ESTM 估算储热通量

$$\Delta Q_S = \sum_i \frac{\Delta T_i}{\Delta t}(\rho C)_i \Delta x_i \lambda_{pi}$$

λ_P =0.25

λ_f = 0.6



城市单元：屋顶、壁面、地面、建筑内部，建筑外部

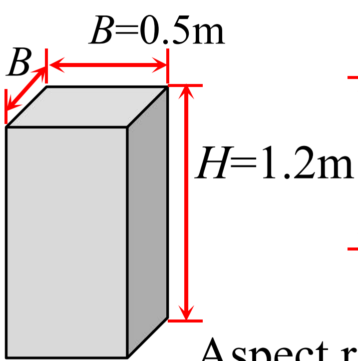
广州真实城市能量平衡 观测研究，依然缺乏，急需博士或博士后

缩尺尺度城市气候实验与健康研究（SOMUCH）

Scale-model Outdoor Measurement of Urban Climate & Health（SOMUCH）

- **Building model unit:**

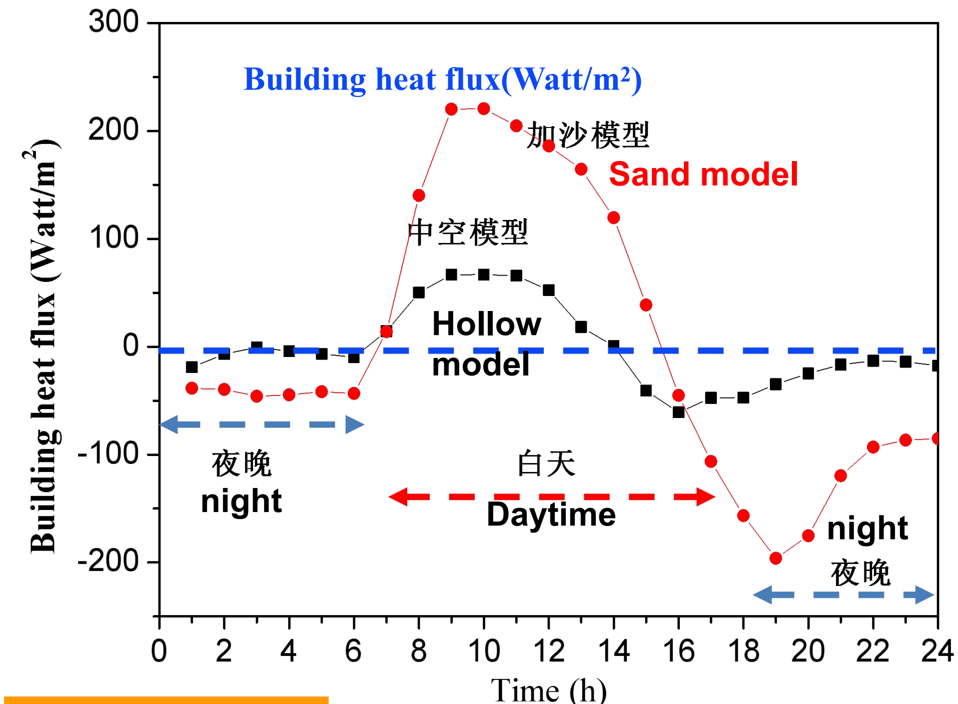
Hollow concrete models;
thickness=1.5cm;
2000 models in total.

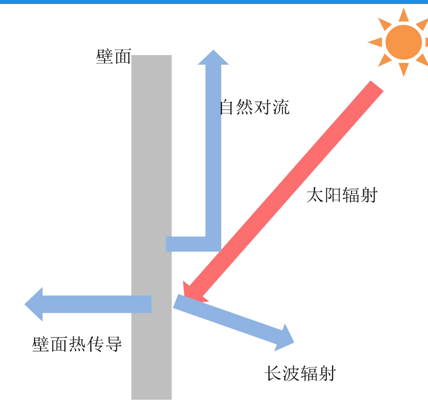


W=0.4m | W=0.6m | W=1.2m

Aspect ratio: H/W=3 | H/W=2 | H/W=1

Novelty: Considering impacts of building thermal storage, focusing on medium-high building density





$Re=\rho UL/\mu$>>11000 full turbulence(10^6)

$$F_r=\frac{U_{ref}^{\ 2}}{\beta gH(T_w-T_{ref})}=\frac{U_{ref}^{\ 2}}{gH\Delta T/T_{ref}}$$

$$\tau=m_b c_b/(\rho_{air}c_{p-air}q)$$

Heat storage/convection heat transfer

τ describe the city thermal inertia and thermal storage capacity

Scale-model city(H=1.2m) : τ=87s (empty)、1224s(sand)

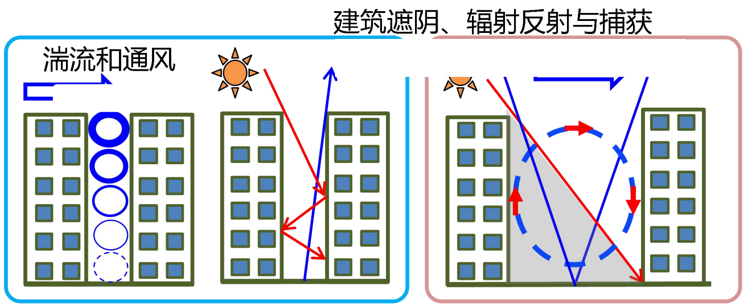
- **Actual city : τ=2500s (1:10 ratio, H=12m)**

Reynolds and Froude numbers (T_{wall}-T_{air}=10K)

Aspect ratio $AR=H/W$	U_{ref}	Re	Fr
H/W =3, 2, 1 H=1.2m	2.0m/s	152964	10.2
	0.5m/s	38241	0.625

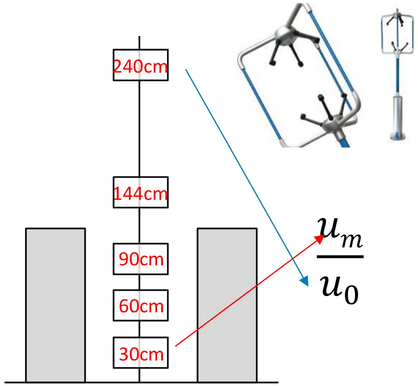
Satisfy Reynolds independence

Objectives: To quantify the effects of aspect ratio (H/W=1,2,3) and building thermal storage on the spatial-temporal features of turbulence and temperature in the street canyon



Narrow street canyon

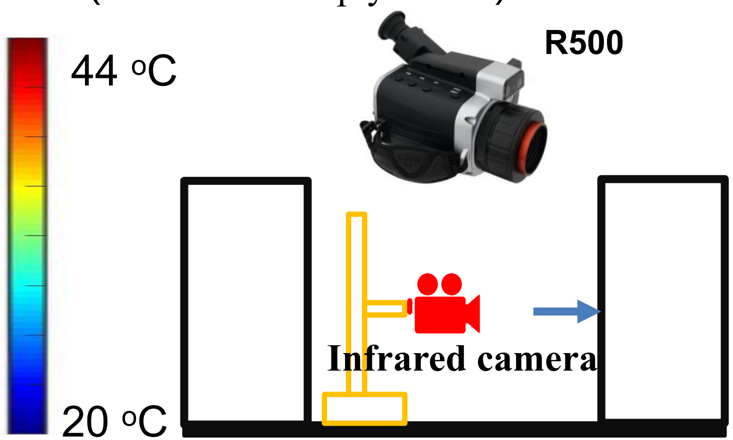
Wider street canyon



Three-dimensional sonic anemometer

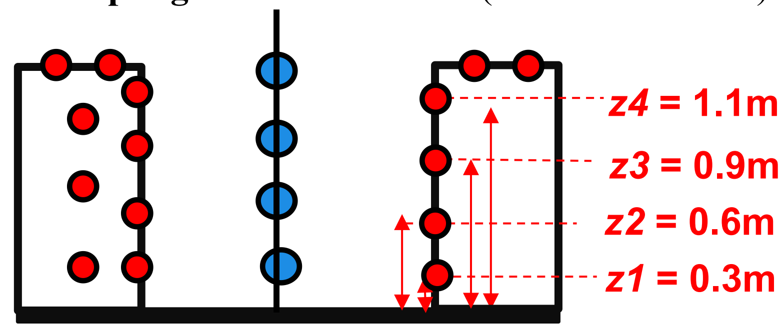
thermocouples

Different building thermal capacity (sand model\empty model)



300 thermocouples Sampling rate: 1 Hz

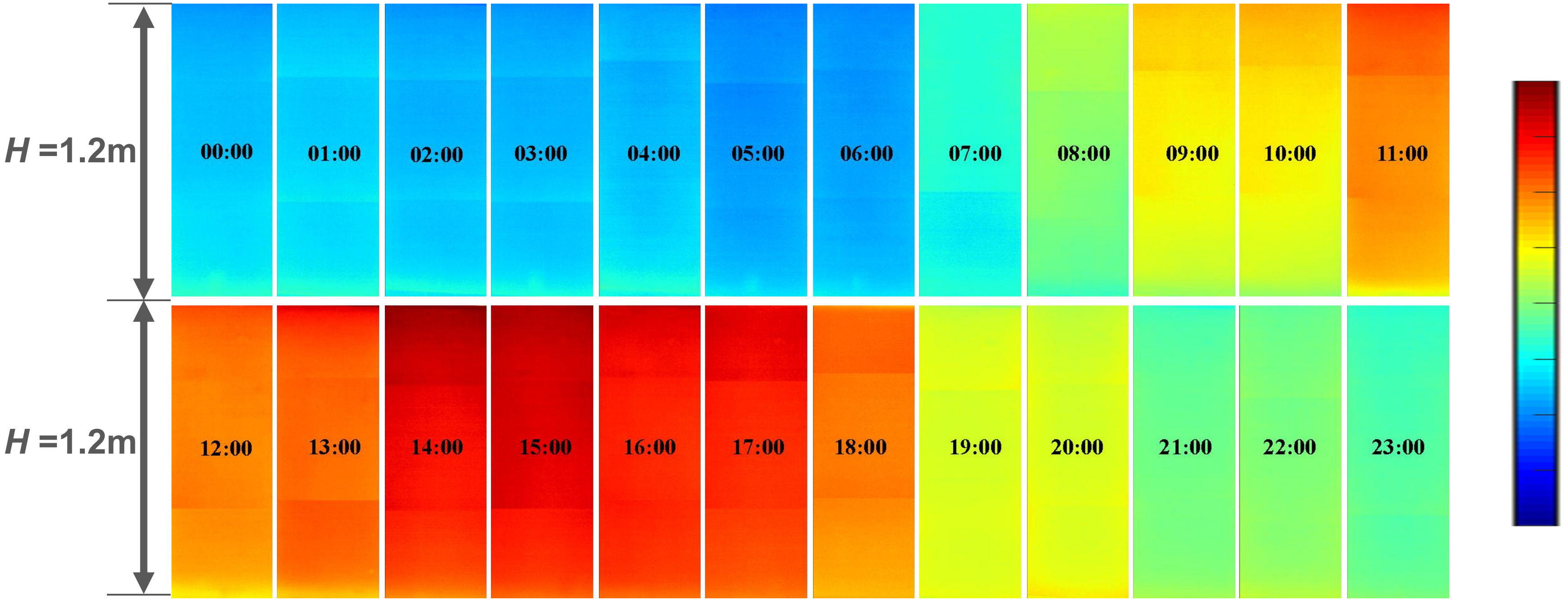
40 ibutton T/RH sensors (1record 10minute)



Due to solar radiation capture / heat storage and release, the wall temperature has 24-hour daily cycle characteristics

Analysis object： 0:00-23:00， June 26， 2017， hollow model facing north (*H*/*W*=1)， sunny day

Daily cycle

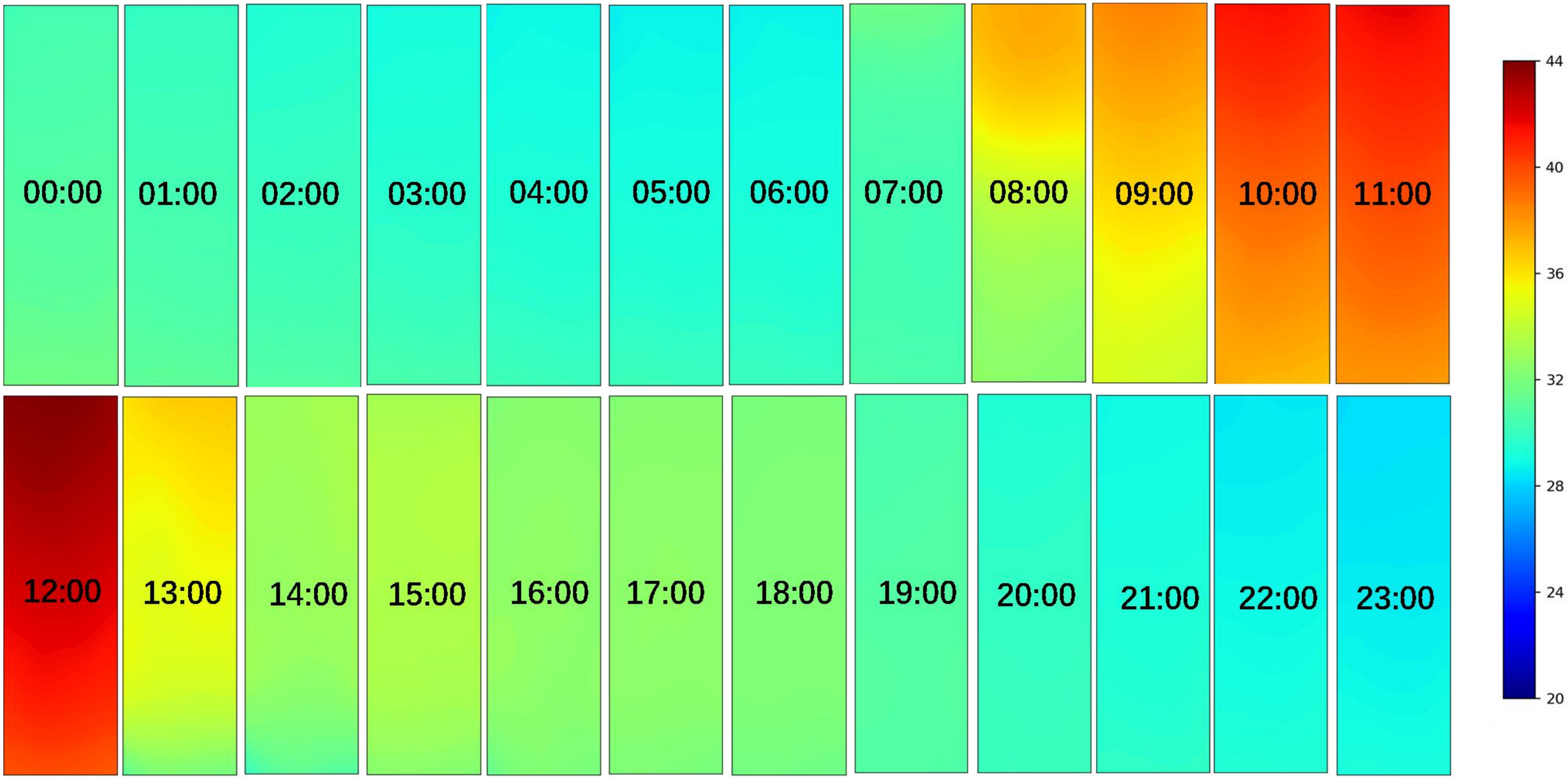


Effect of street orientation

东西朝向

H/W = 1, west wall, 20190728

Diurnal characteristic of wall temperature

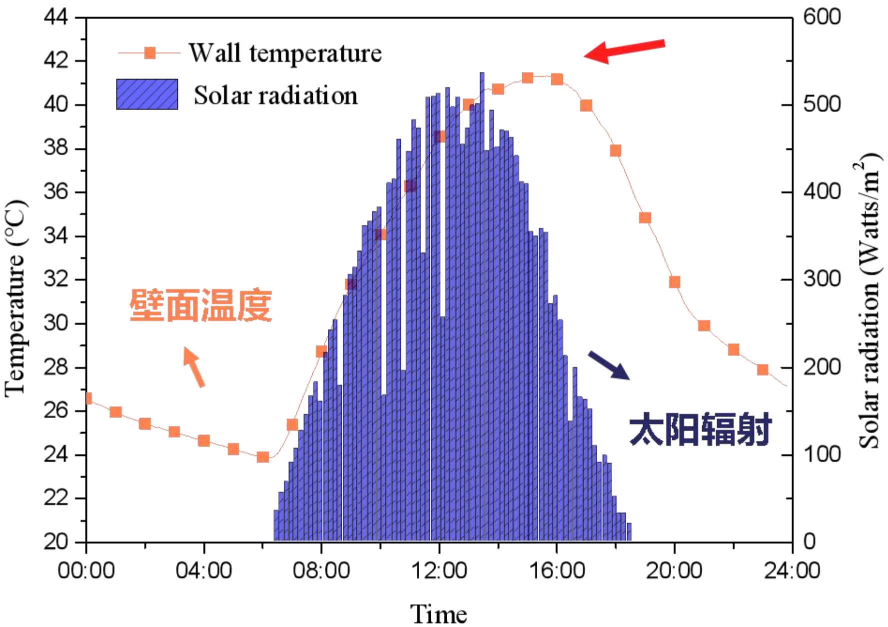


日循环　太阳辐射对温度日循环特征有重要影响（考虑不同天气条件）

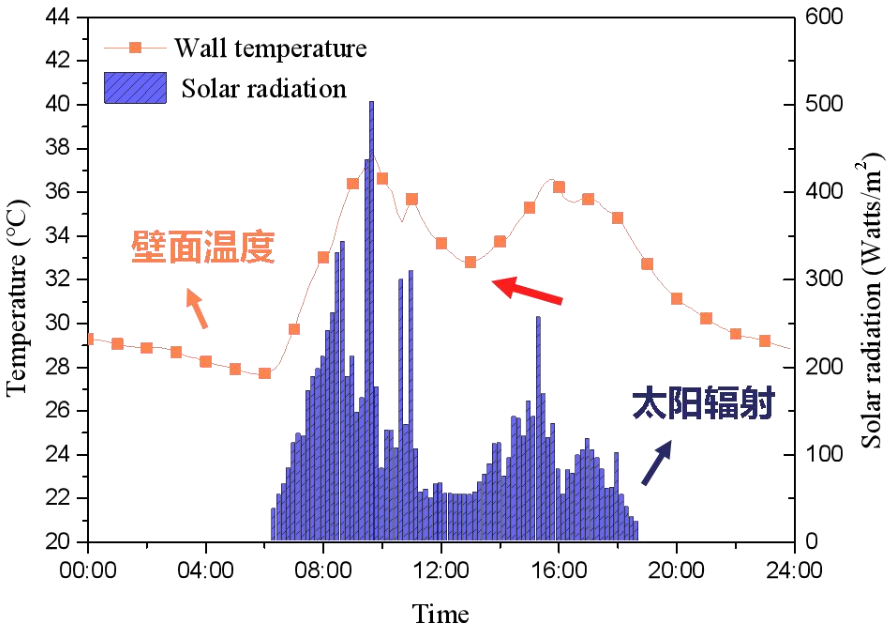
分析对象：2017年05月28日0时-23时，中空模型侧壁（H/W=1），晴朗天气

2017年06月09日0时-23时，中空模型侧壁（H/W=1），多云天气

晴朗天气

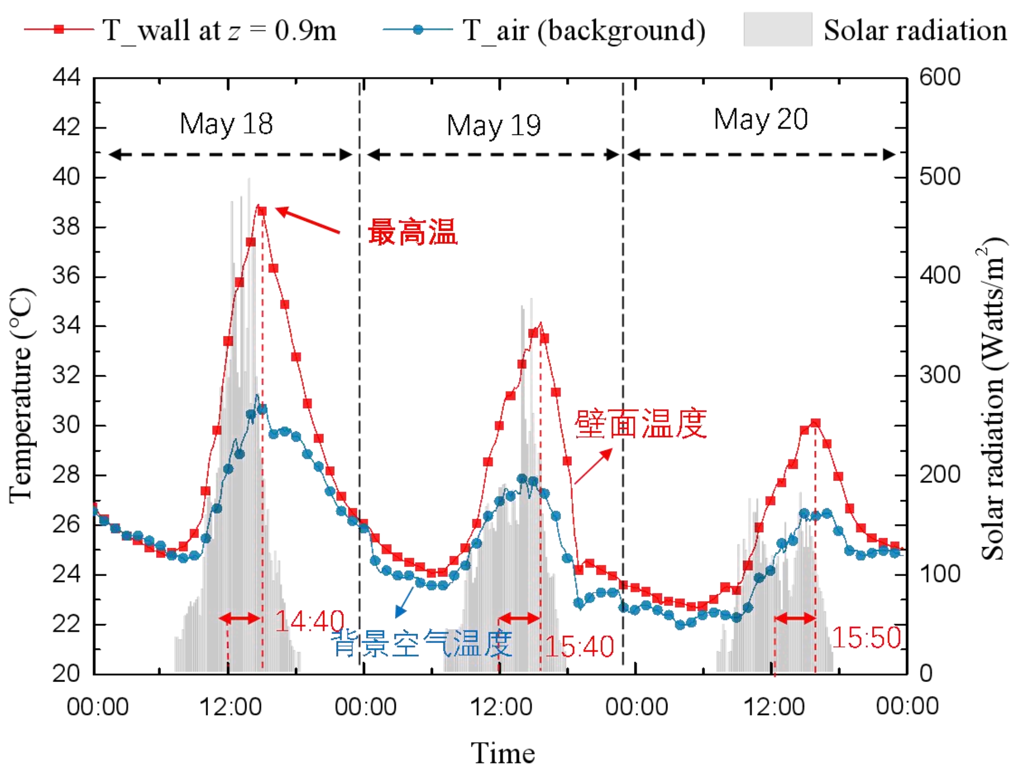


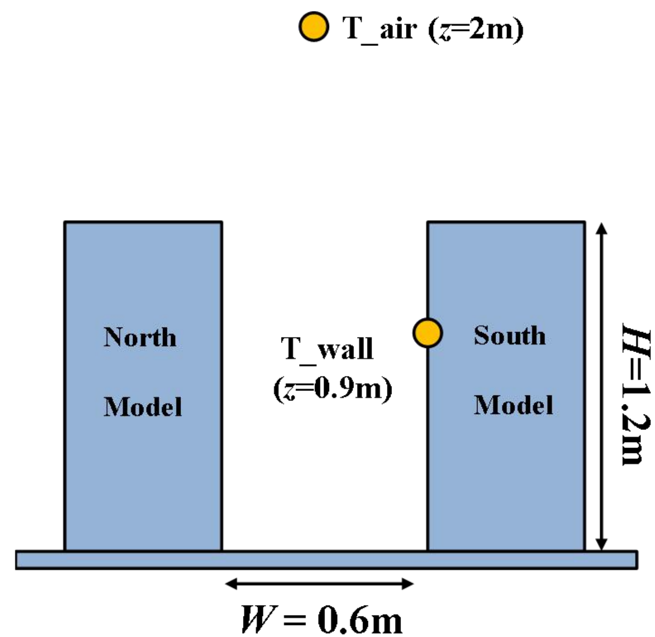
多云天气



日循环　最高温出现时间晚于正午12点，即出现能量滞后现象

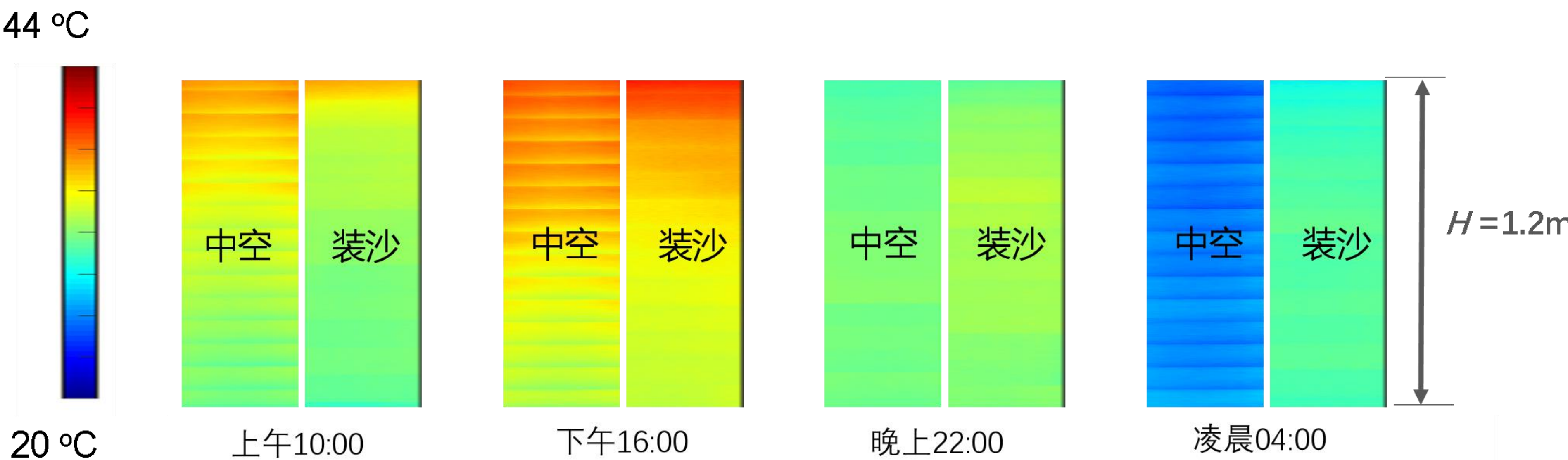
分析对象：2017年05月18~20日，中空模型高宽比2：1的朝北侧壁，晴朗天气，热电偶数据





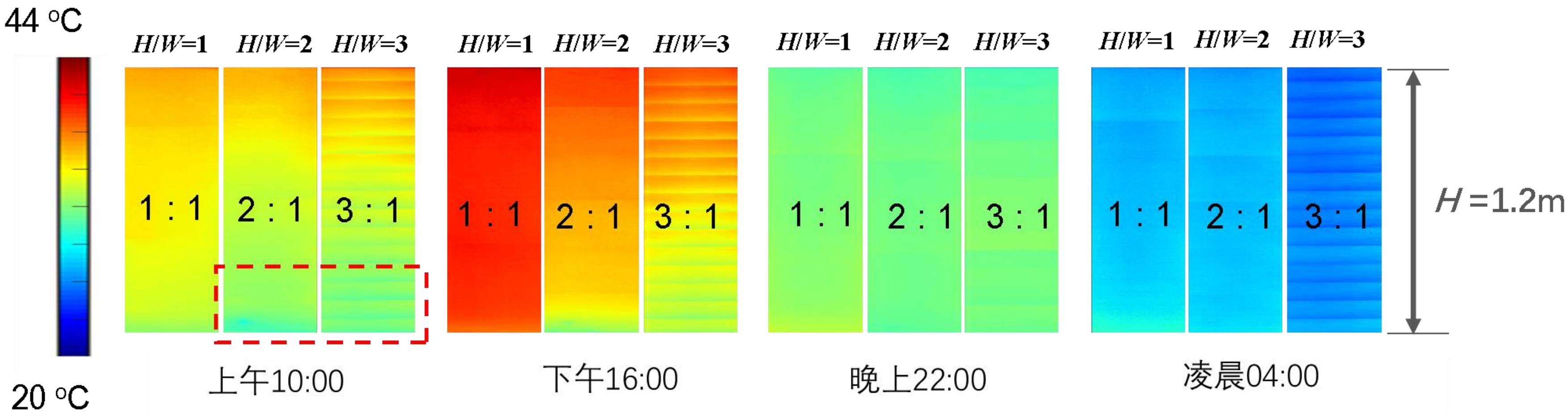
建筑储热能力 白天装沙模型温度更低、夜晚更高，建筑储热效应明显

分析对象：2017年06月26日0时-23时，**中空和装沙**模型朝北侧壁（H/W =3），晴朗天气



高宽比　街谷越宽，白天遮荫越差、升温越快、夜晚降温也更快

分析对象：2017年06月26日0时-23时，中空模型不同高宽比（*H/W* =1,2,3）朝北侧壁, 晴朗天气



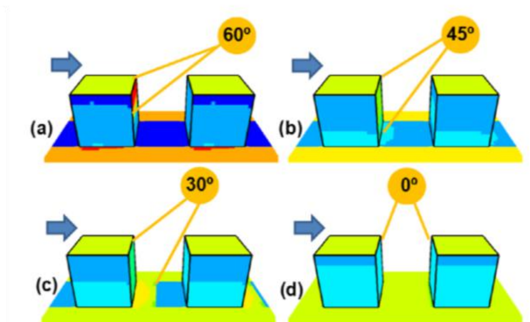
原因分析：

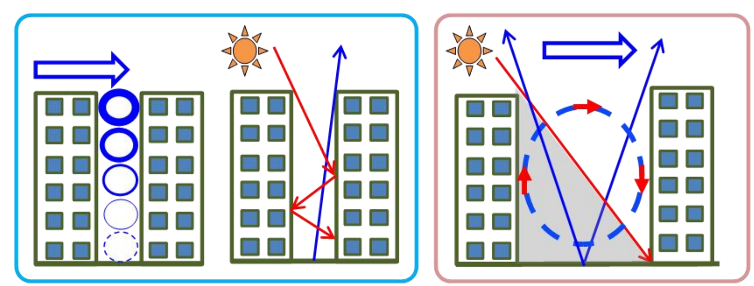
对流通风

长短波辐射

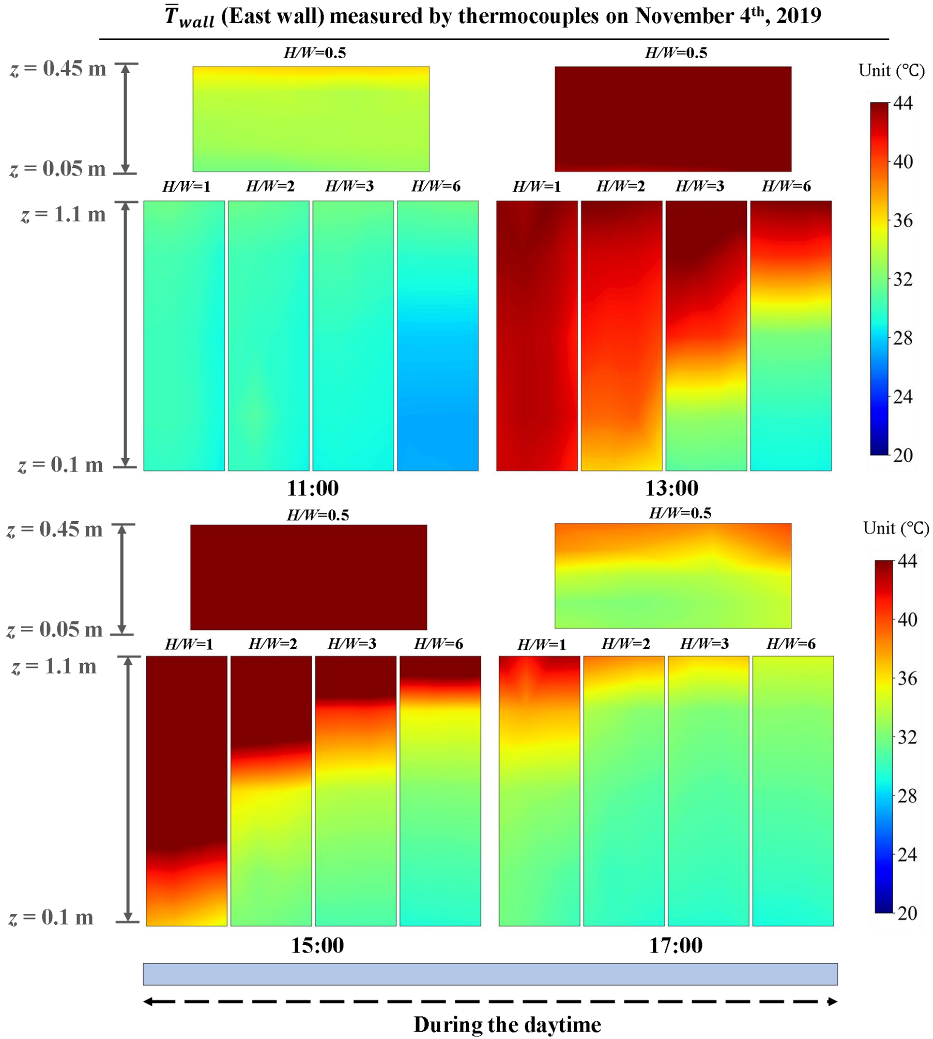
遮阴效果

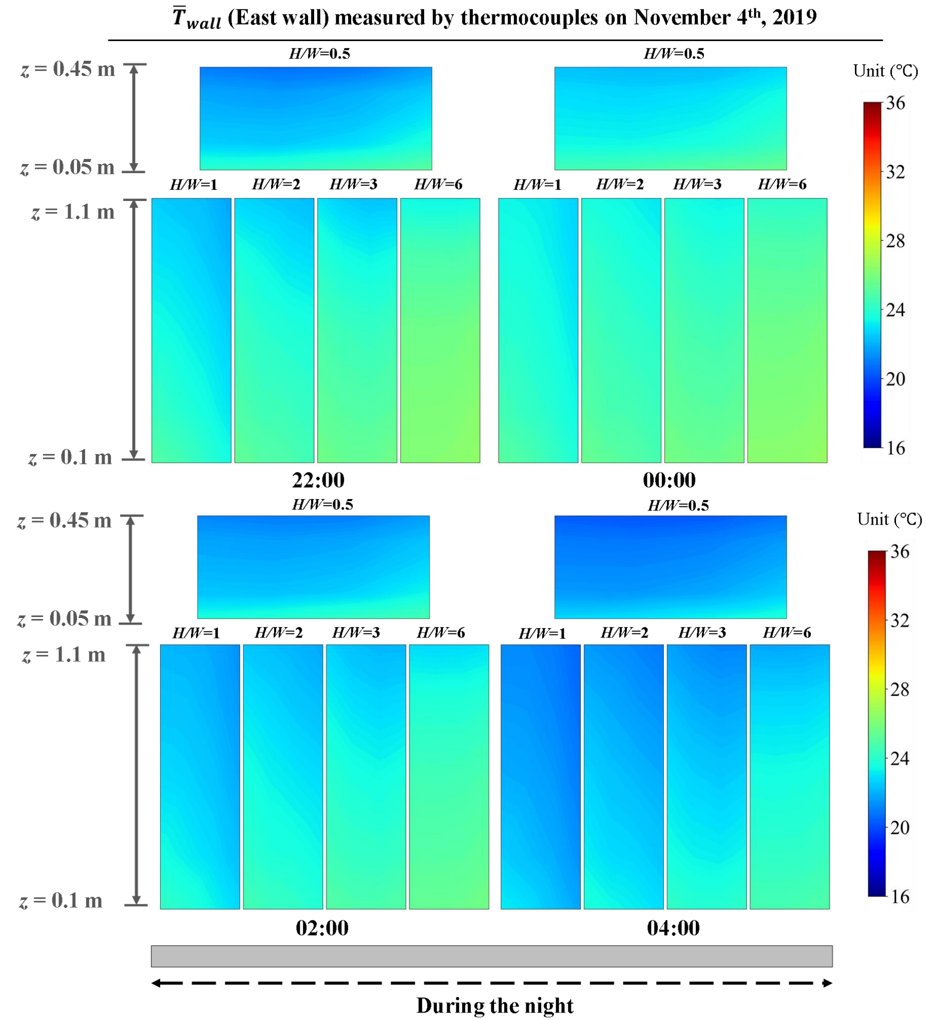
角度范围



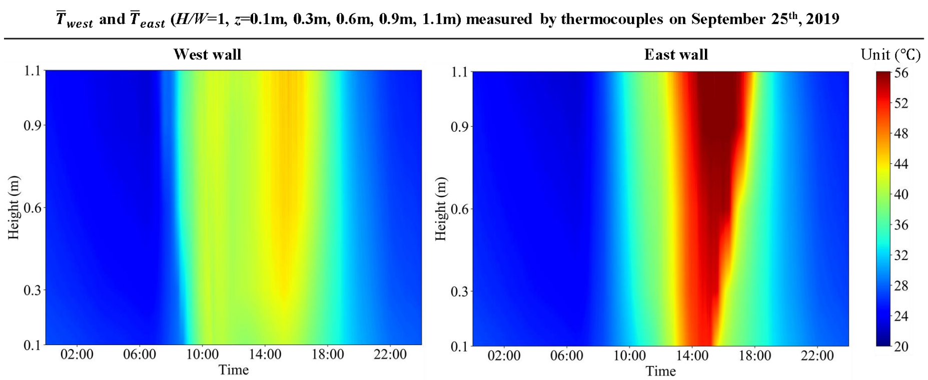


网格化热电偶布点测量建筑壁面温度分布

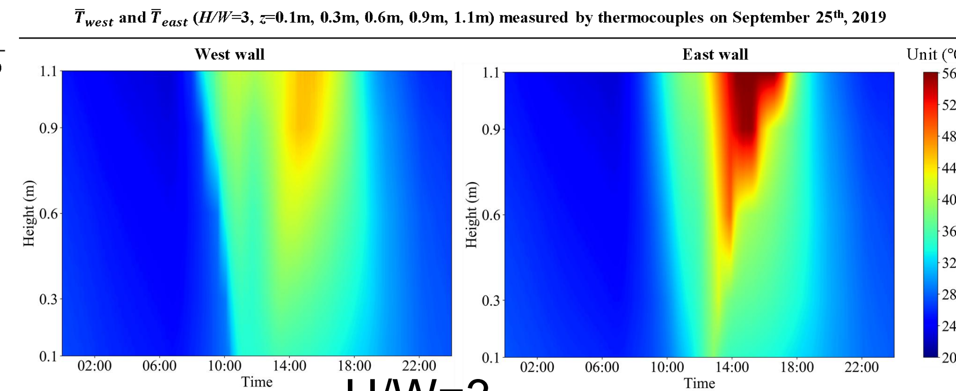




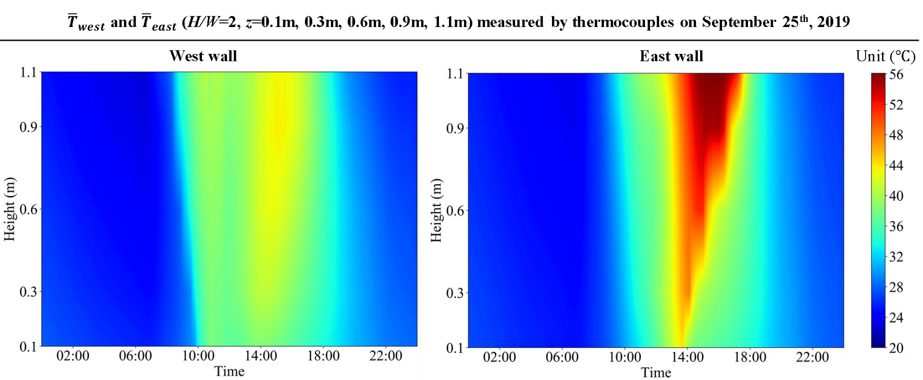
网格化热电偶布点测量建筑壁面温度分布



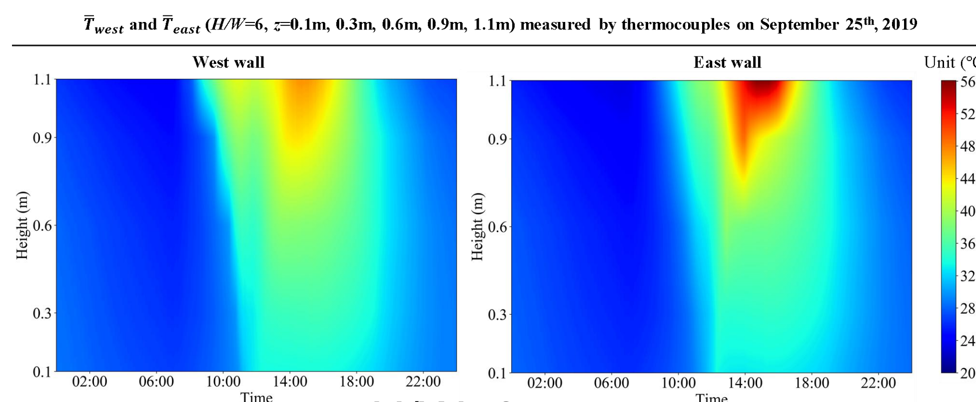
H/W=1



H/W=3

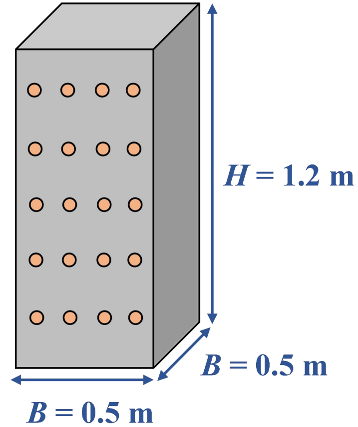


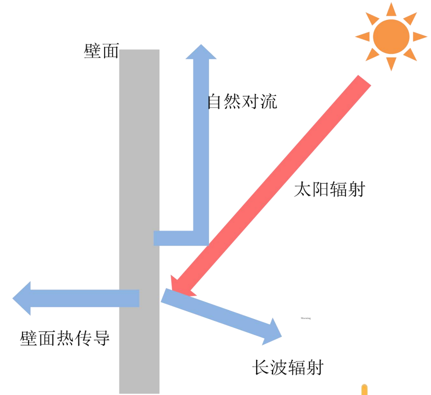
H/W=2

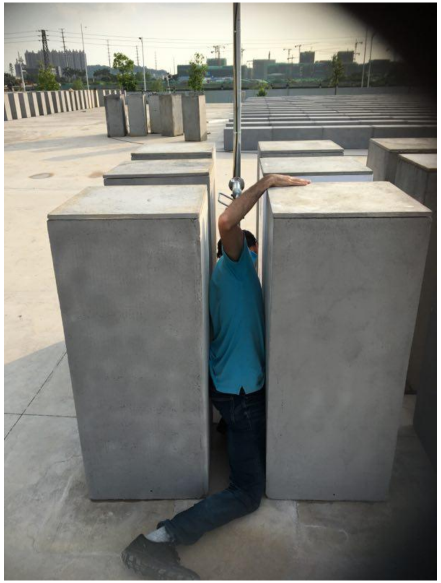


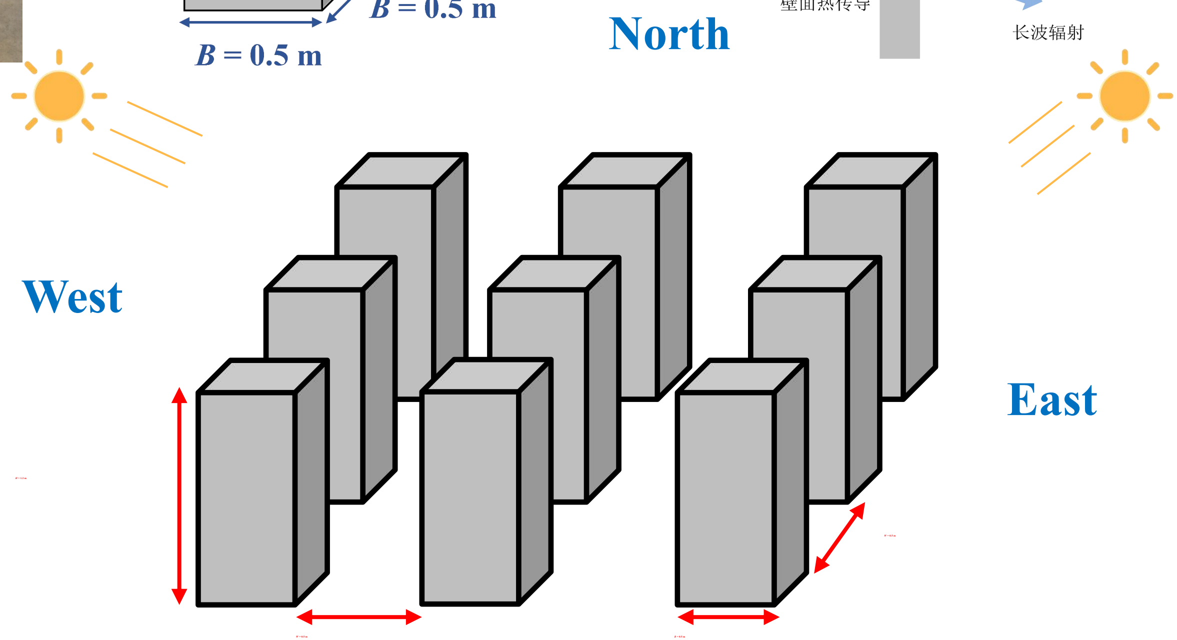
H/W=6

实验+CFD：建筑朝向 与建筑密度的影响

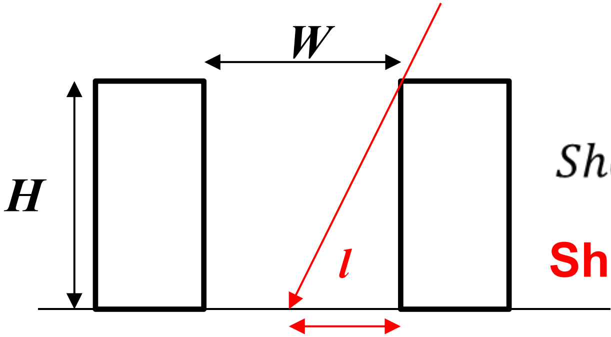






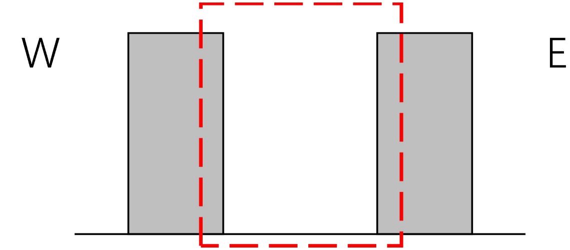


Shading index （两侧壁面+地面）

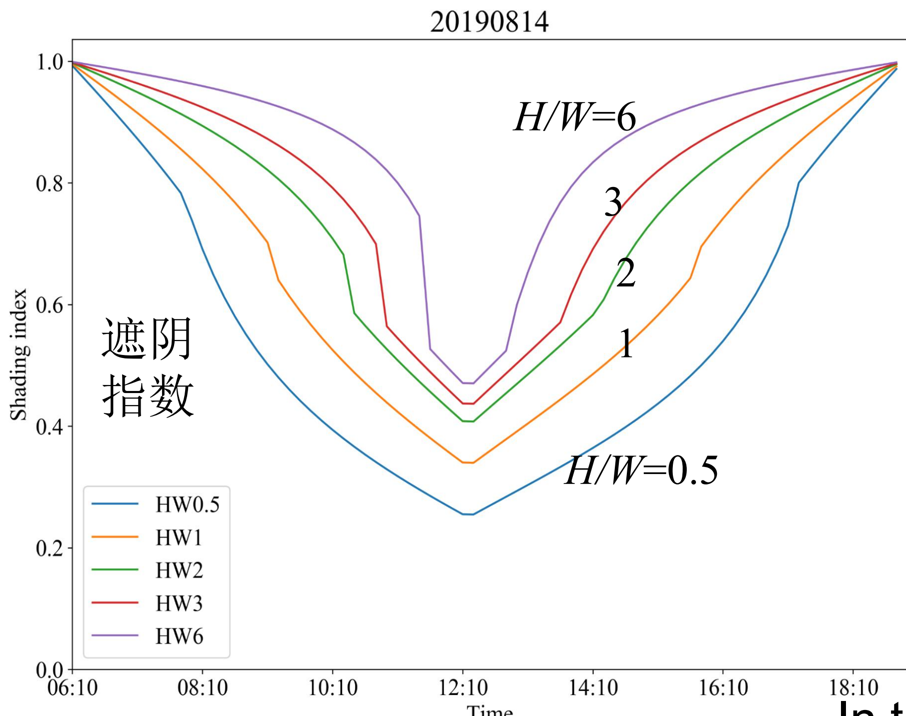


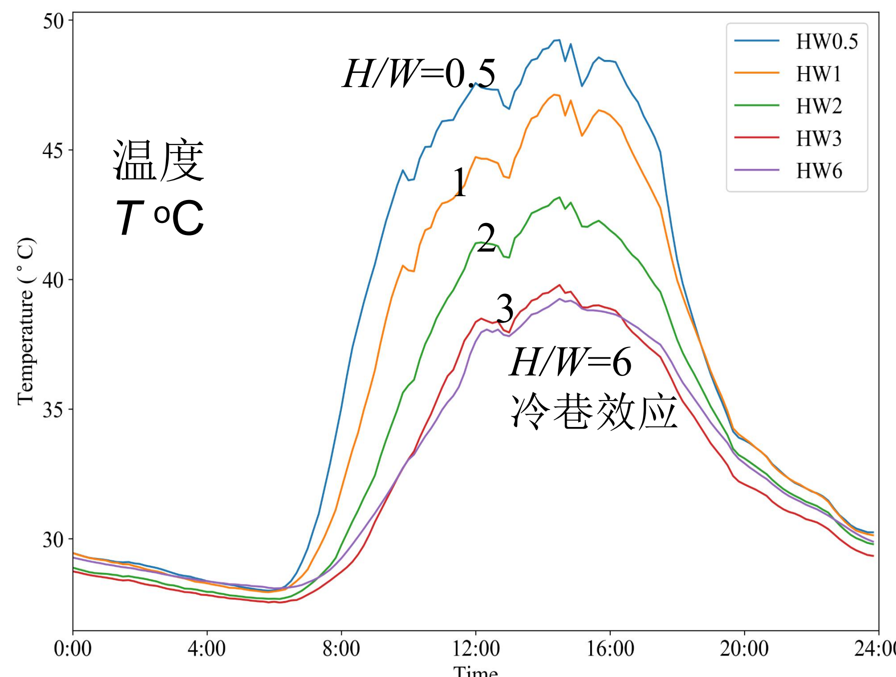
$$Shading\ index = \frac{l + H}{2H + W}$$

Shading index 越大，遮阴越好



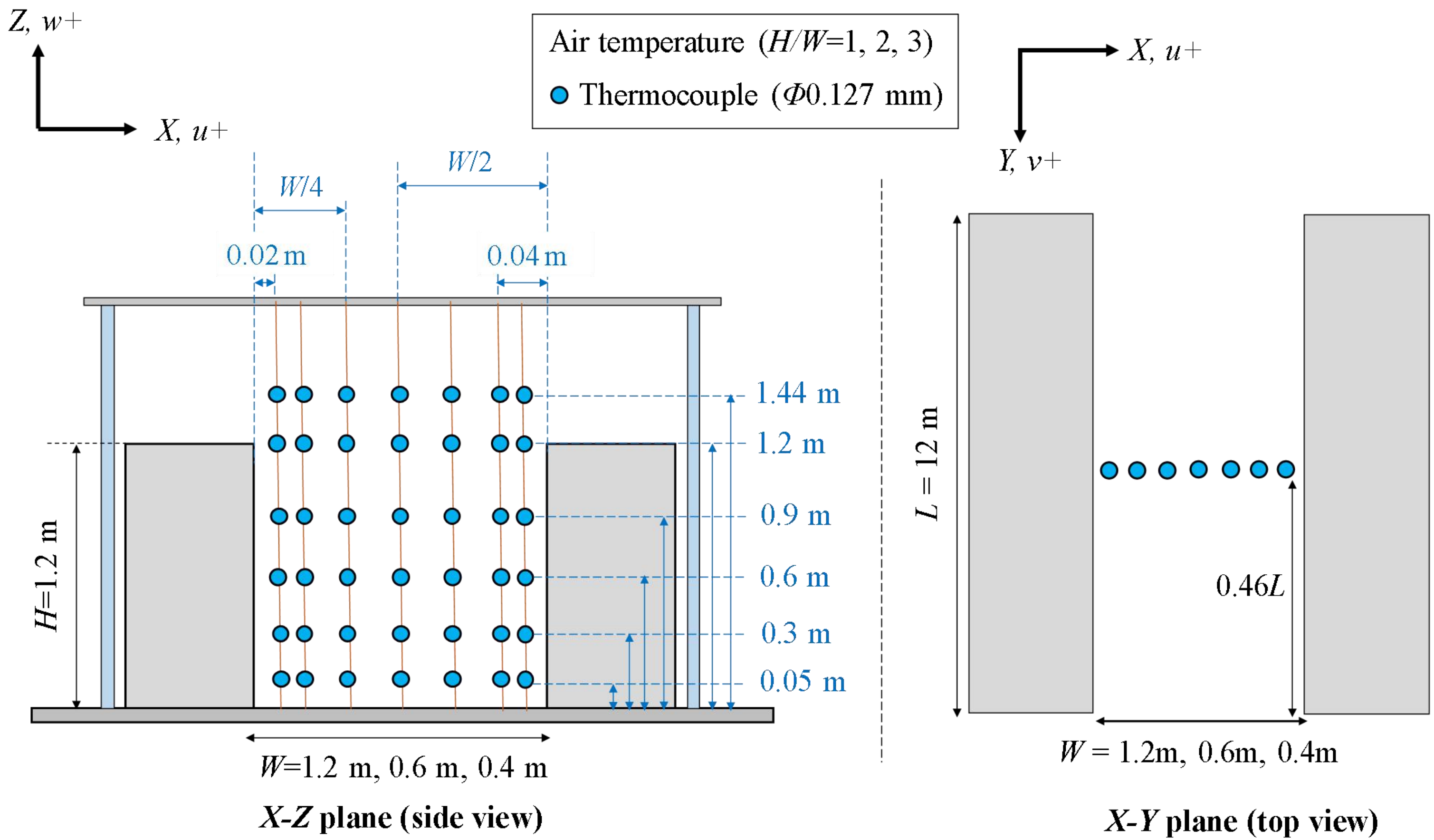
分析对象：两侧壁面+地面





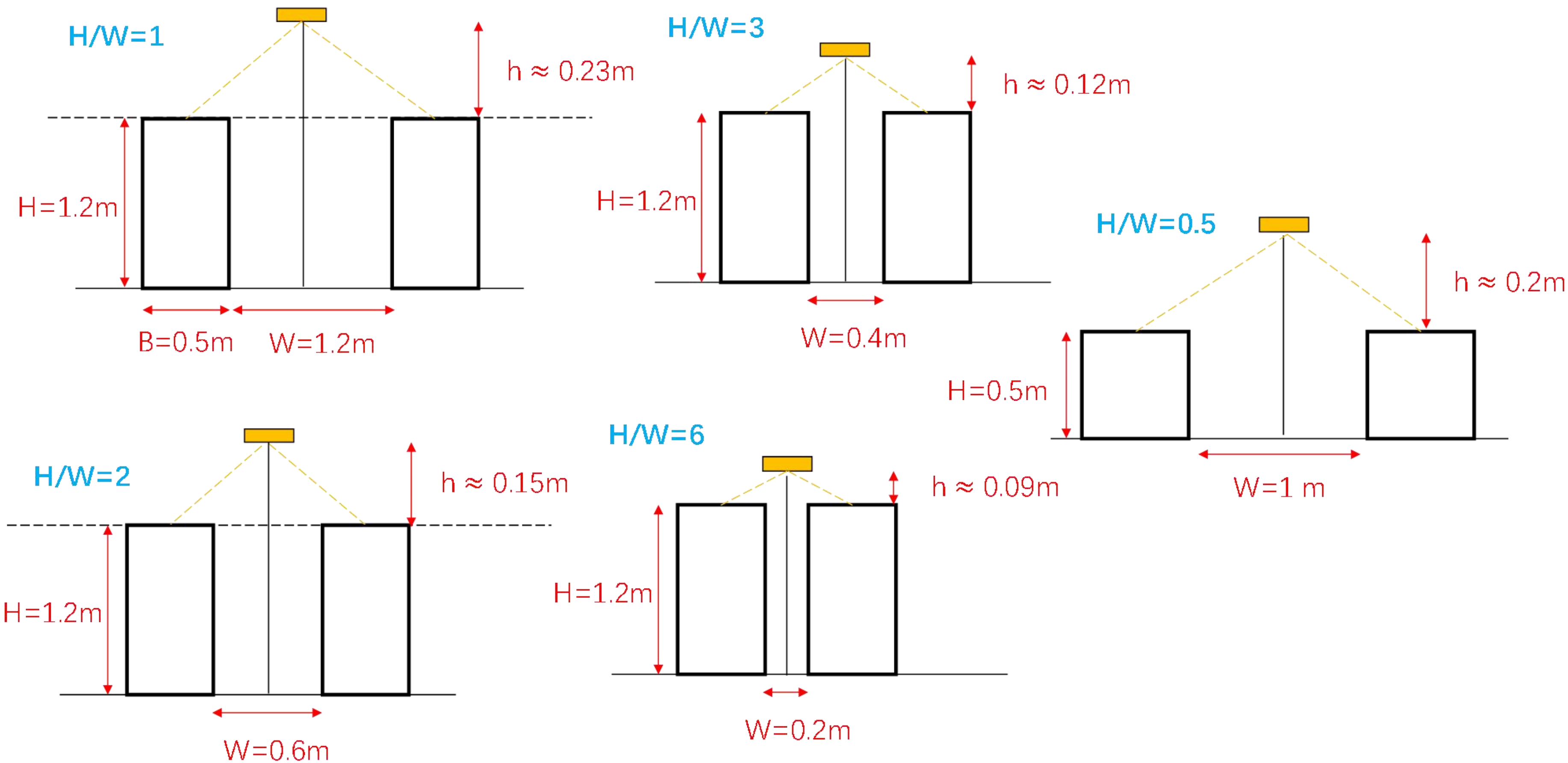
In the daytime

网格化热电偶测量街谷空气温度分布

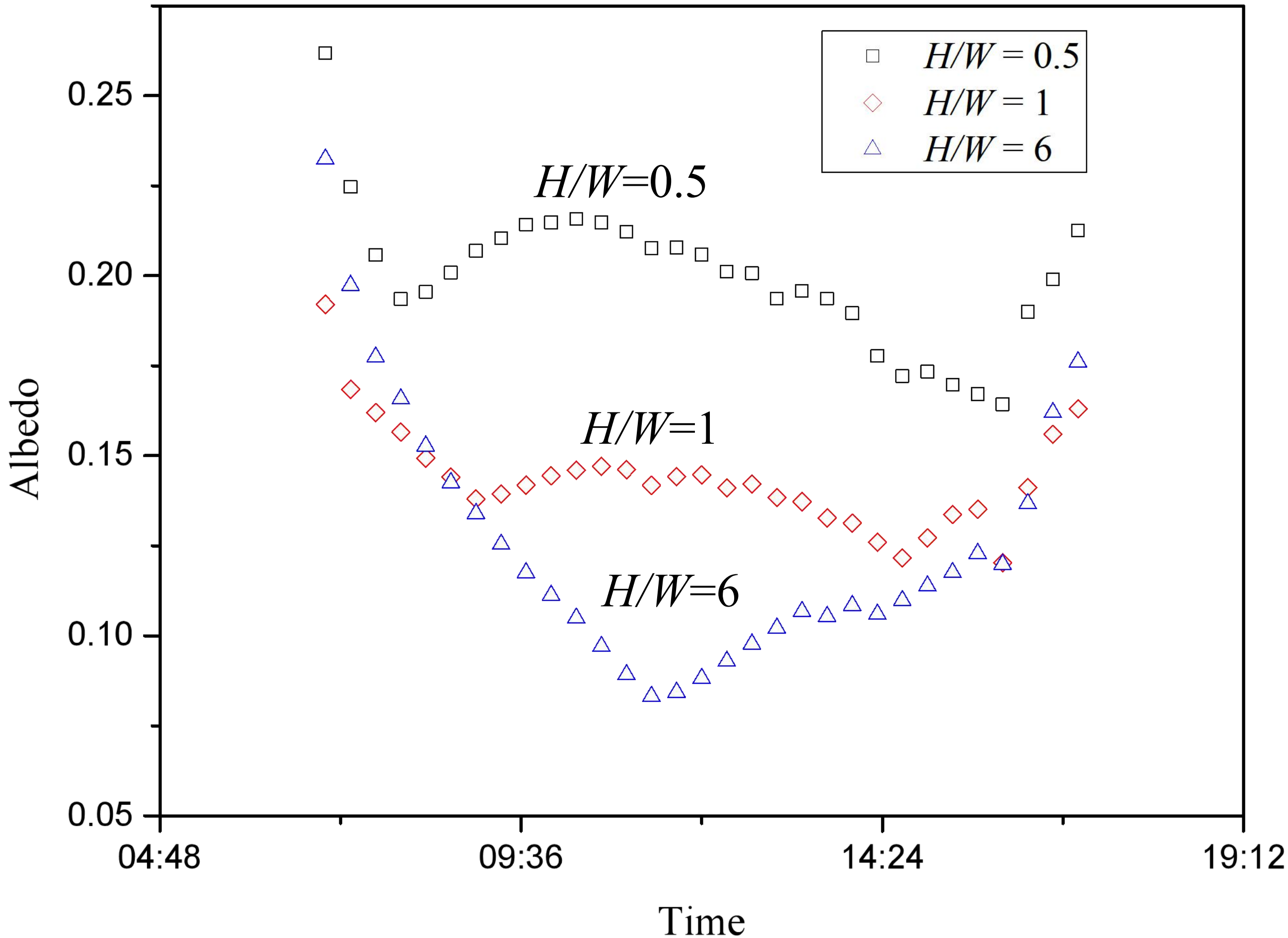


街区反照率的观测 （荷兰CRN4）

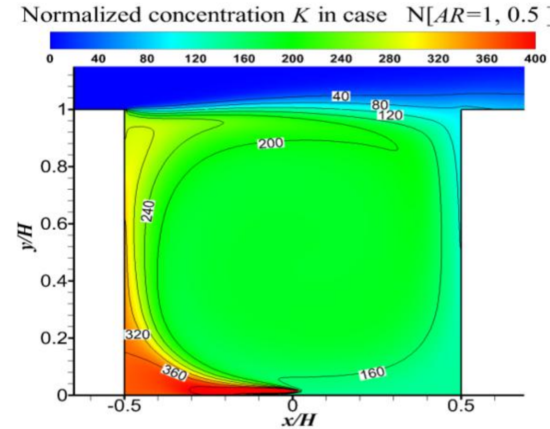
测量方案(若以屋顶高度作为基准点），测一个街谷 屋顶以上高度 h = (B + W / 2) / tan75°

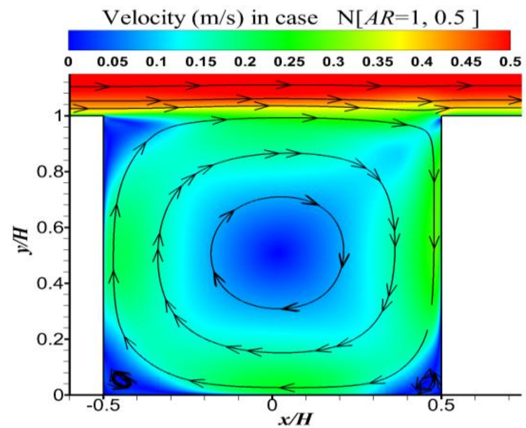


街谷高宽比对反照率的影响：街道变窄，使反照率减小



定量分析不同的能量过程(储热，长短波辐射，感热等)对其风热分布的相对贡献

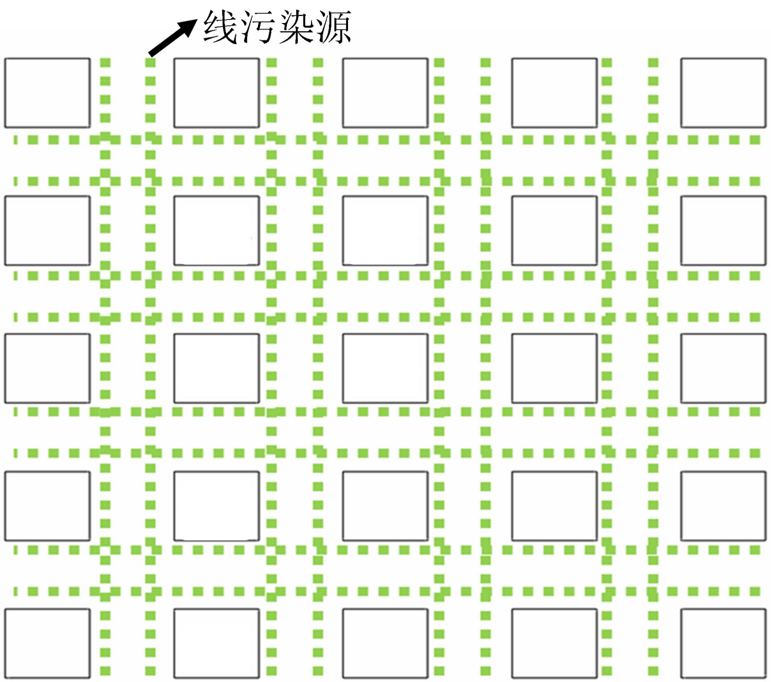


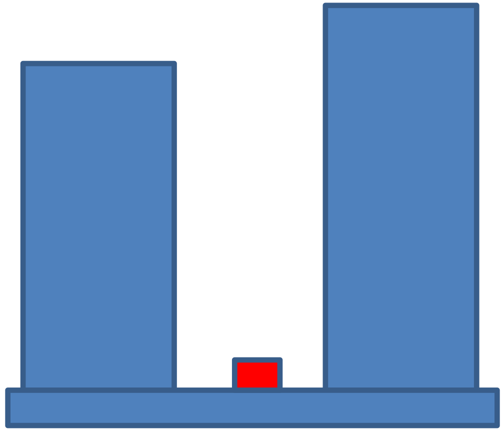


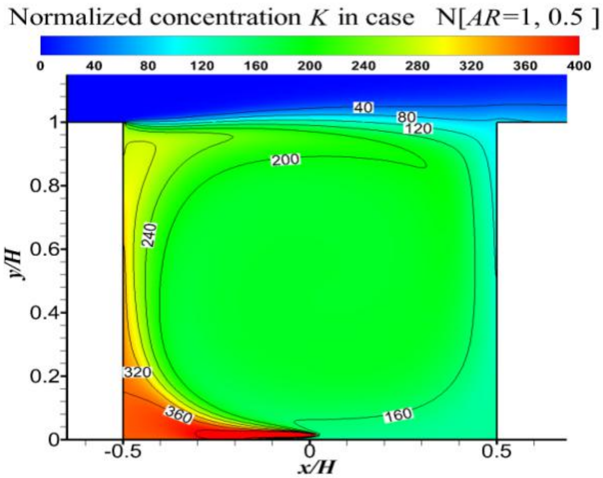
AR=1， U_{ref}=0.5m/s

H/W=1, tracer gas and CFD simulation show consistent result with the literature (one main vortex)

线污染源、颗粒物点源的可控性、均匀性





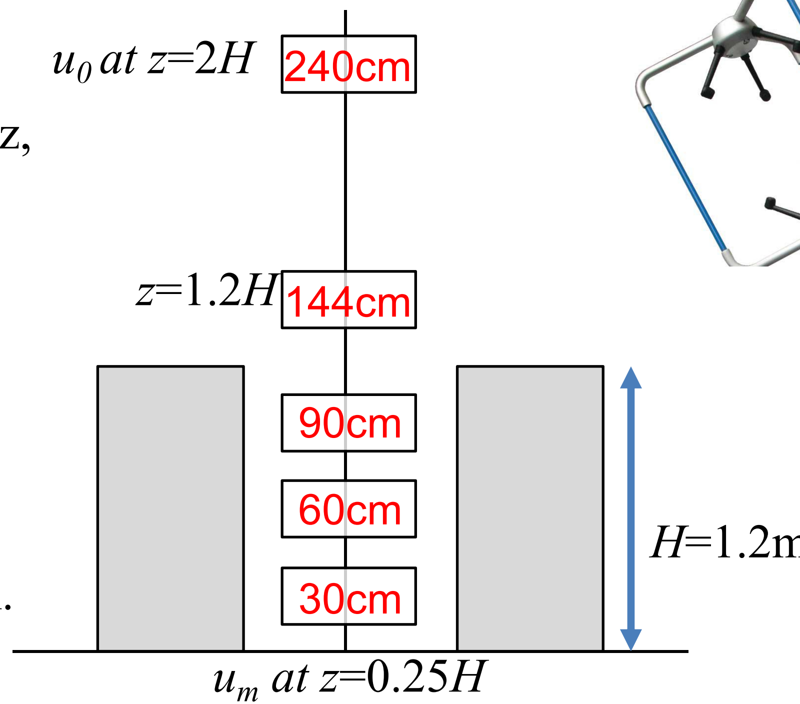


- **Wind velocity & turbulent characteristics:**

Sonic Anemometer
(Windmaster PK-020, 20Hz, GILL instruments Ltd.)

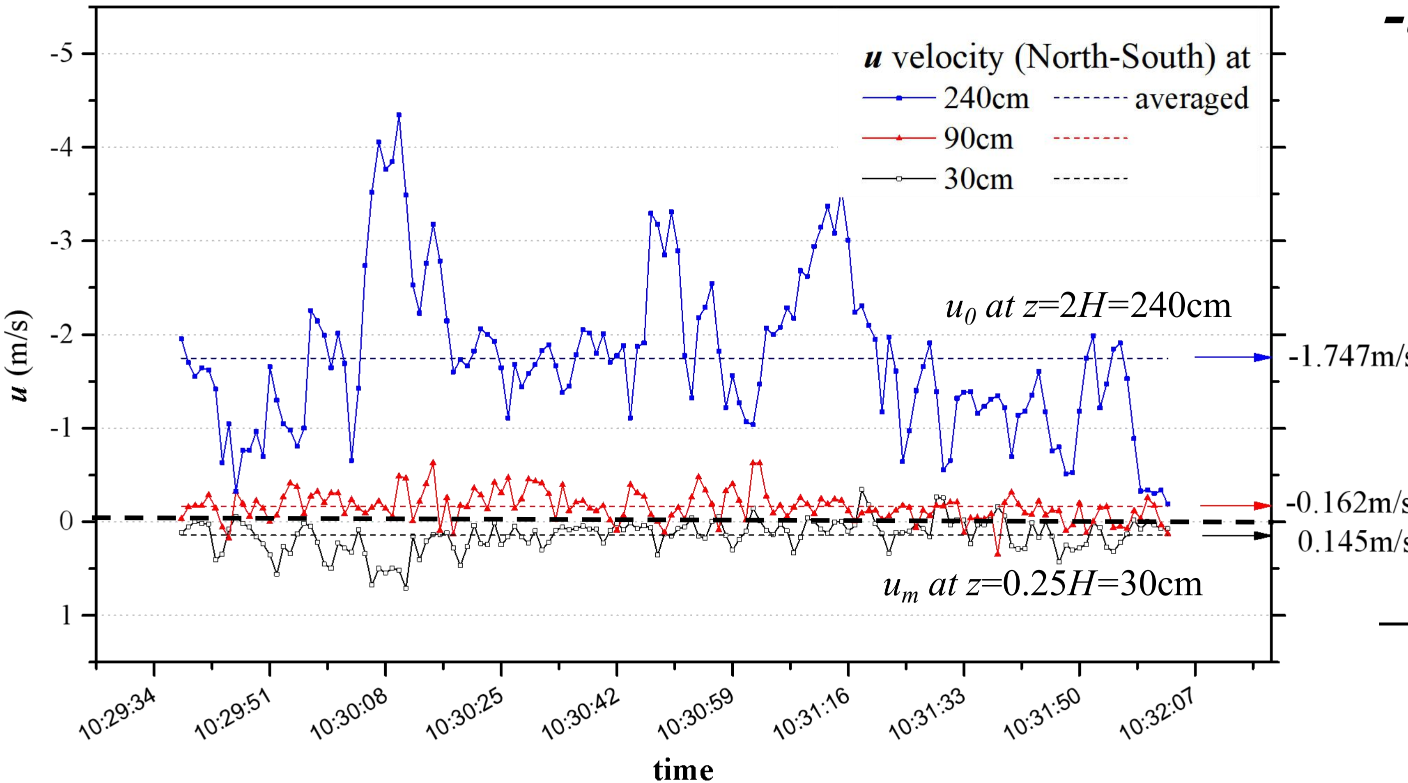
Sampling rate: 20Hz

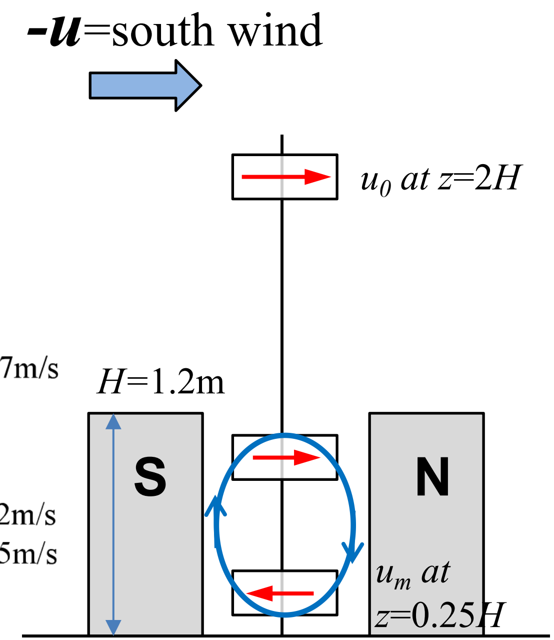
5 anemometers placed in each street canyon at different heights along the center line of street canyon.



Discussion Flow pattern with high wind speed in SOMUCH tests:

- Aspect ratio: $H/W=2$





湍流特征观测与分析

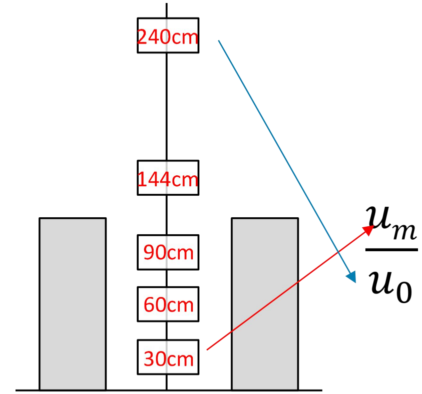
Discussion

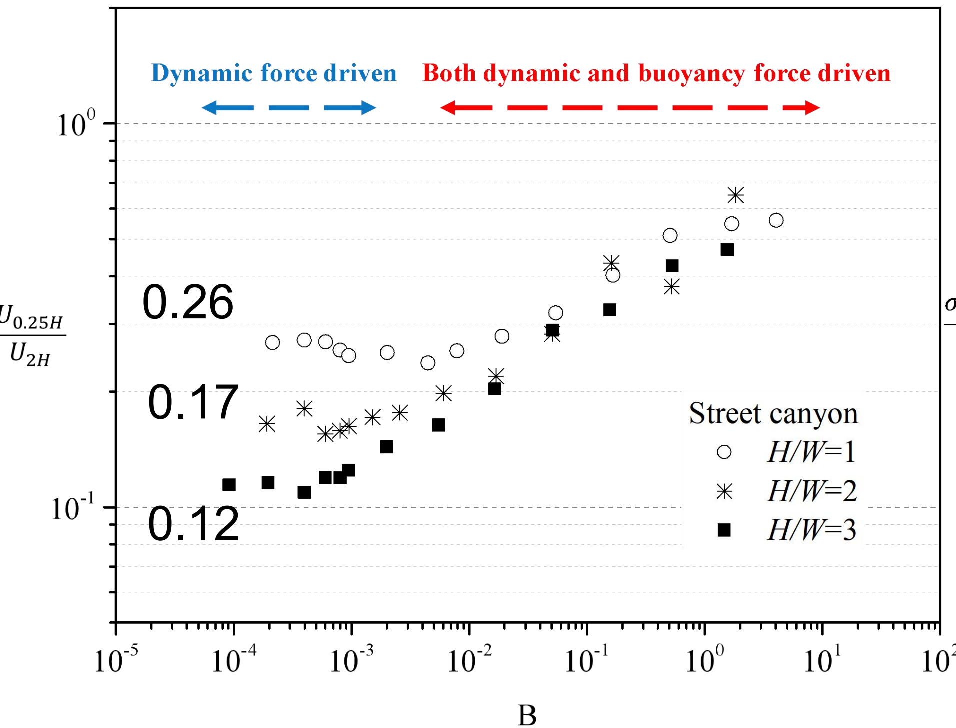
风速比 u_m/u_0 vs. B

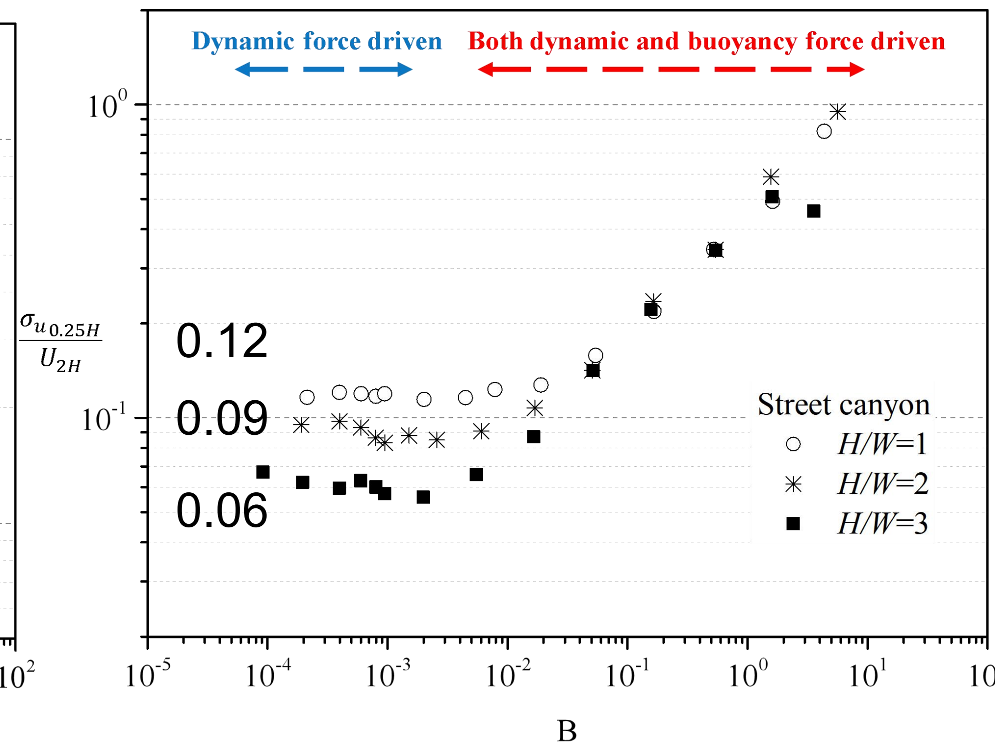
热浮力因子 $B = \dfrac{g \cdot \alpha \cdot \Delta T \cdot H}{u_0^2\left[1+\left(H/L\right)^2\right]}$ ⇒ $\dfrac{u_m}{u_0} = \begin{cases} \dfrac{u_m}{u_0} \approx \gamma_1 & B < B_C \\ \dfrac{u_m}{u_0} \approx \gamma_3 + \gamma_4 B^{\frac{1}{2}} & B \geq B_C \end{cases}$

$B_c \approx 0.05$

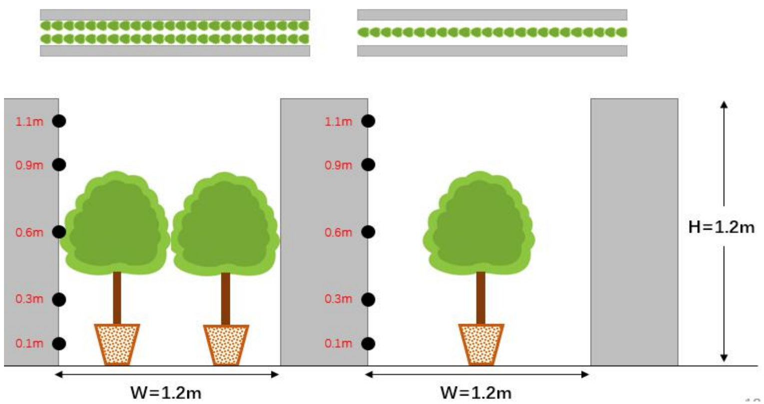
- **Aspect ratio: *H/W*=1**

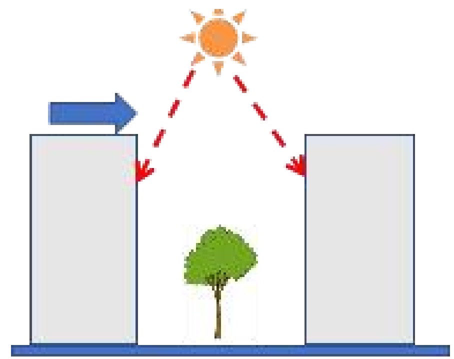


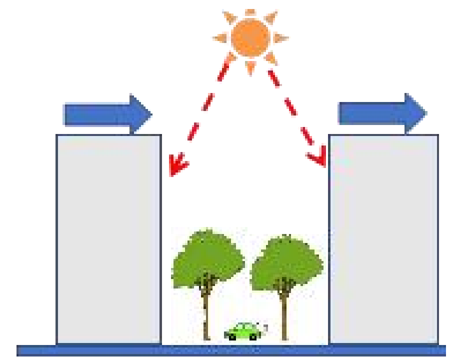




实验+CFD：街道绿化提供遮荫降温，但会降低风速、弱化通风



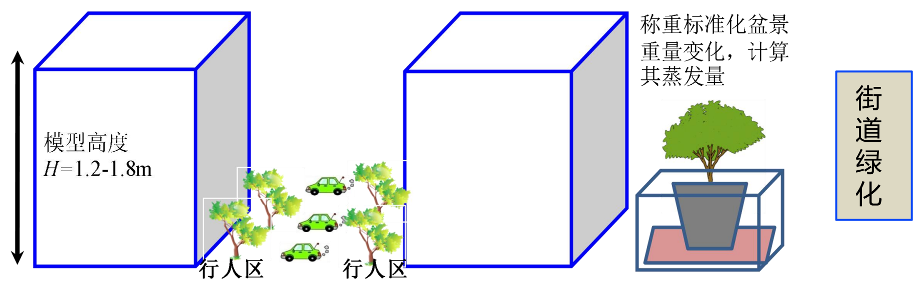


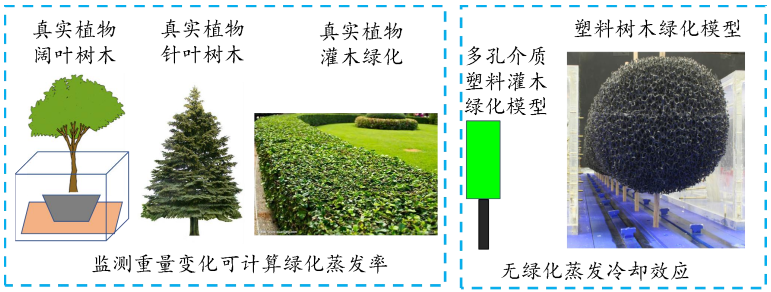


Present research

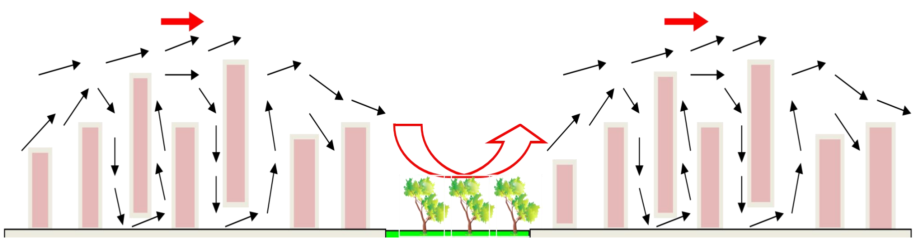
Urban vegetation impacts 遮阴与蒸发的相对重要性
Shading Vs Evaporation

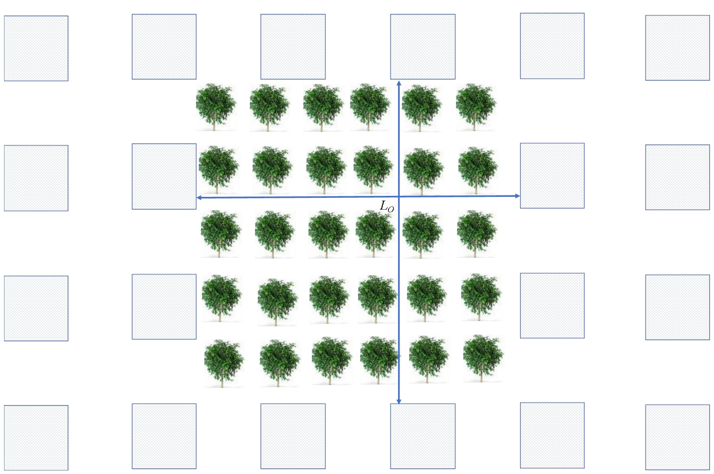
Urban vegetation effects in streets



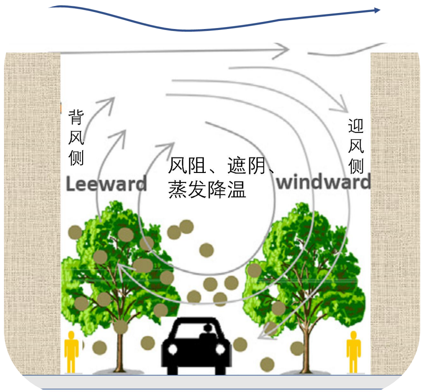


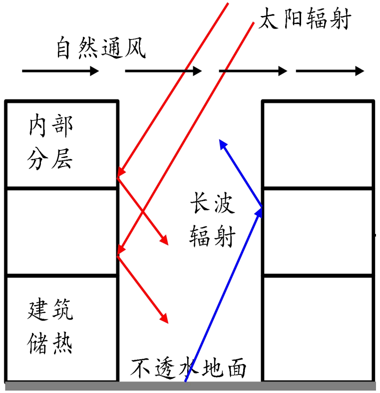
Urban vegetation effects in urban parks

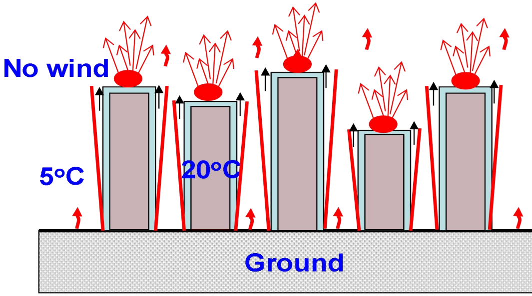




近期正开展的研究：Vegetation/cooling roof etc
城市绿化、建筑表面辐射特性与人为热的影响







表面材质、屋顶颜色

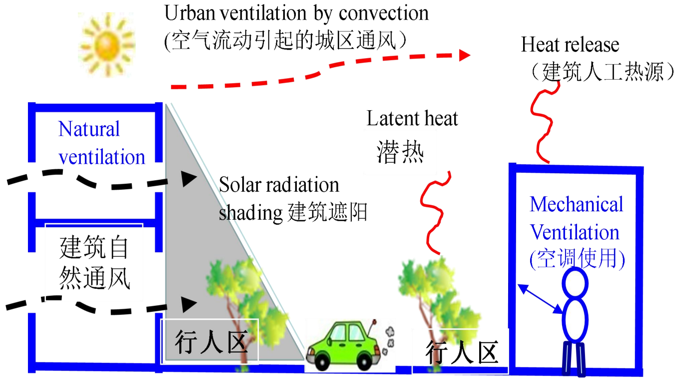
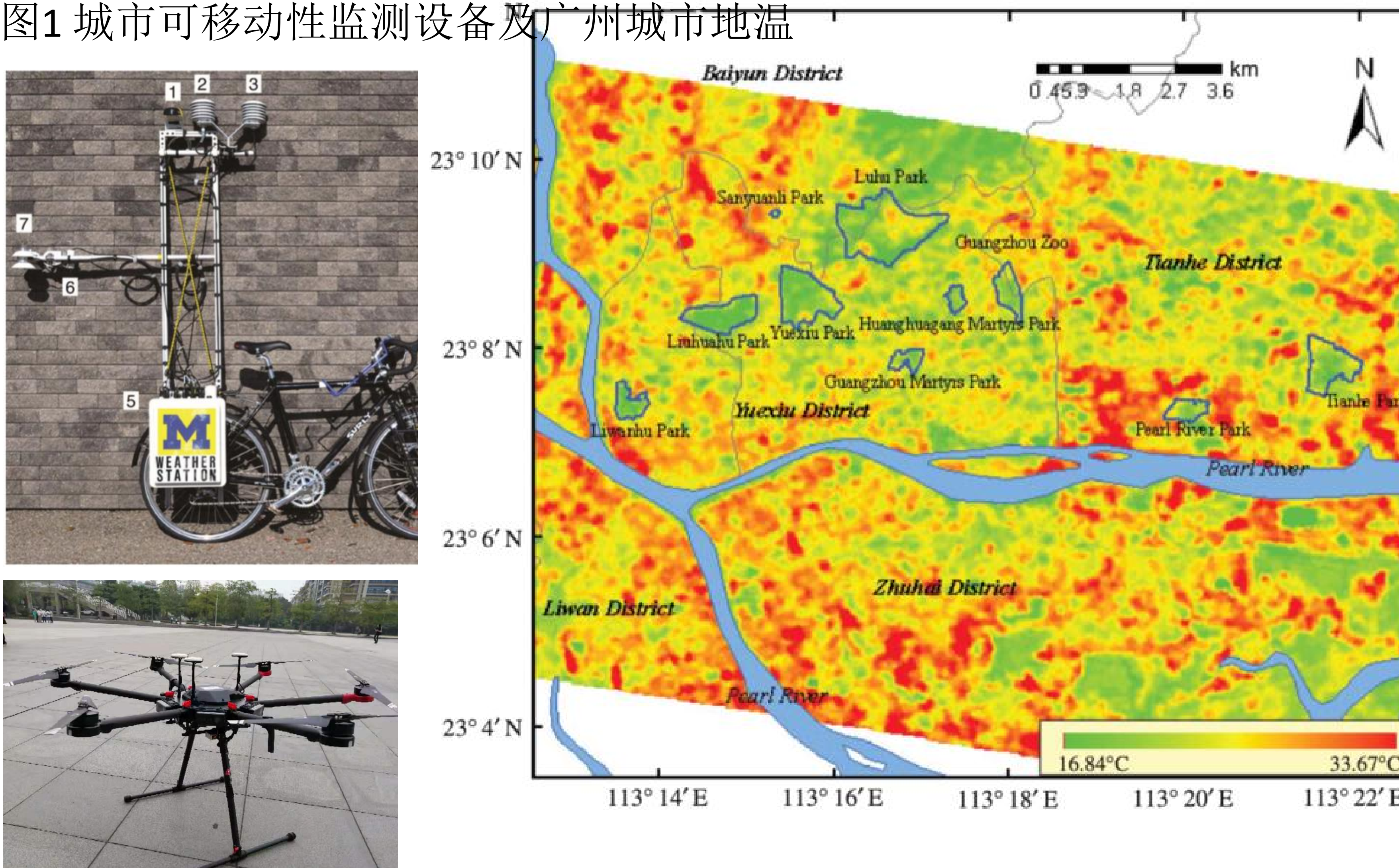


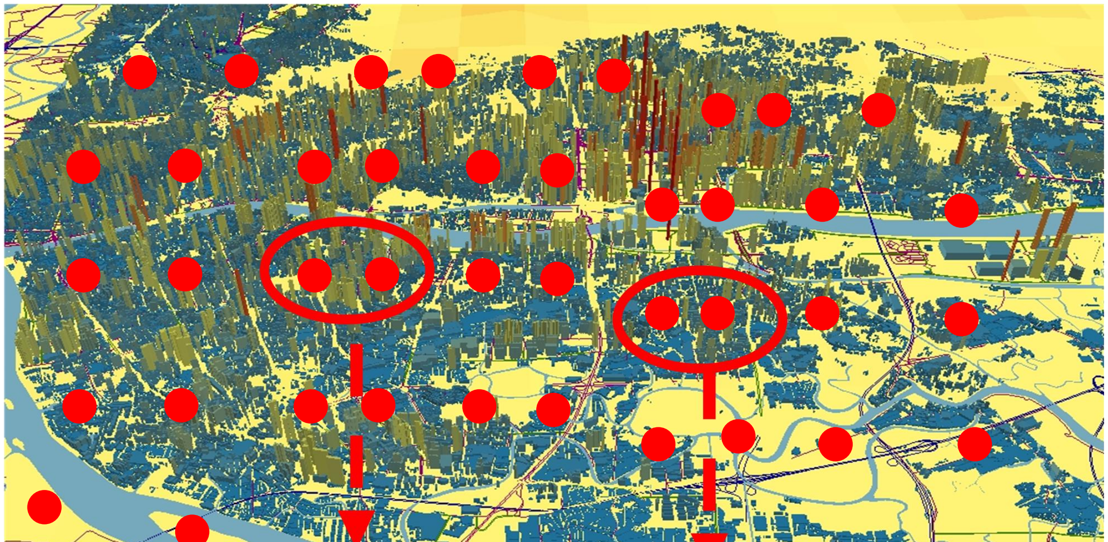
图1 城市可移动性监测设备及广州城市地温

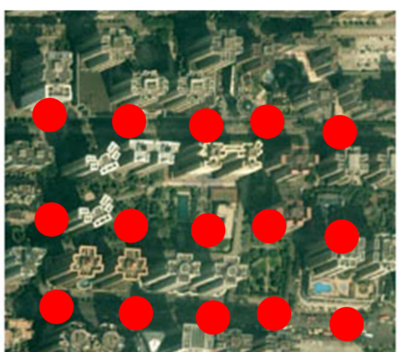


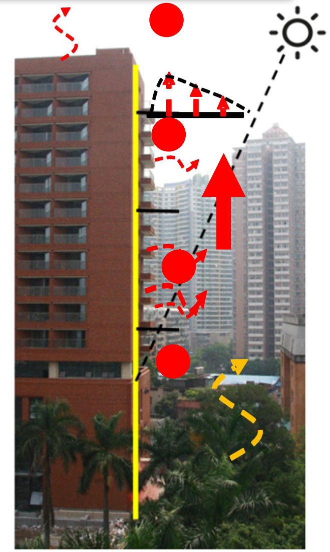
精细化-真实城区微气候实验观测和数值模拟研究

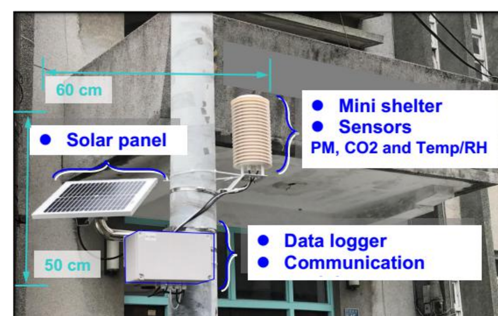
城市空气污染及其暴露研究

城市热岛及室外热舒适研究

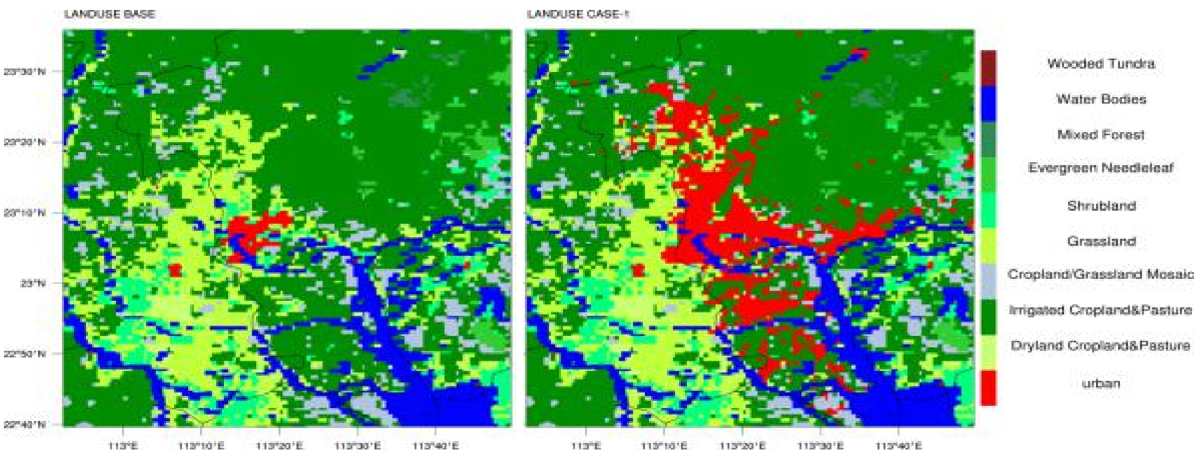






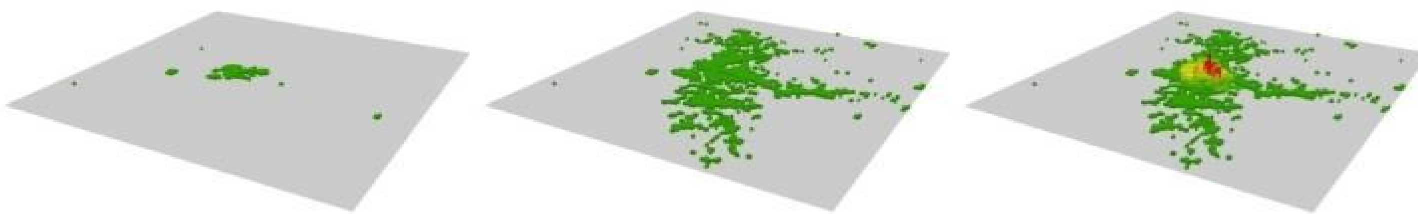


WRF-Urban Experiment Setup



Base   Case1 & Case2

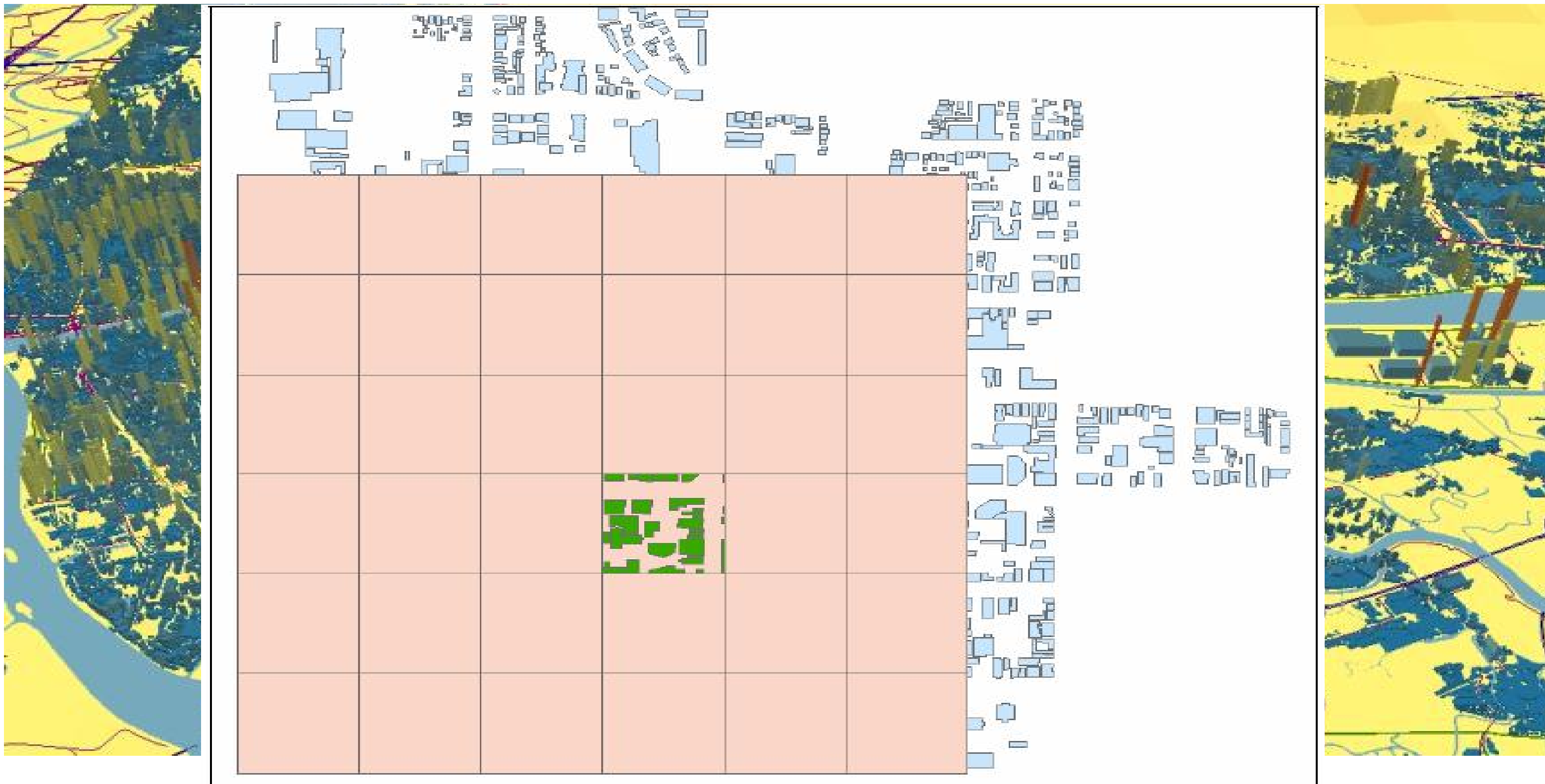
- Base: Before rapid urbanization (USGS 1993)
- Case1: Urbanized Guangzhou city (MODIS 2001)
- Case2: Urbanized Guangzhou city with GZ-UCPs



Base   Case1   Case2

Dai W. and Wang X.M., 2015

A 3D map of building models in Guangzhou city to Urban database in grids 广州建筑信息网格化数据库



Dai W. and Wang X.M., 2015

Over 77 thousand 3D building models

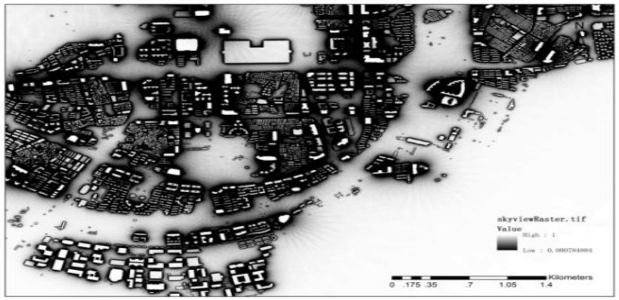
Urban Morphology Parameters

- mean building height: $\bar{h} = \frac{\sum_{i=1}^{N} h_i}{N}$
- mean building height weighted by building plan area: $\bar{h}_{AW} = \frac{\sum_{i=1}^{N} A_i h_i}{\sum_{i=1}^{N} A_i}$
- building plan area fraction: $\lambda_p = \frac{A_p}{A_T}$
- Building Plan Area Density: $a_p(z) \cong \frac{\lambda_p(z)}{\Delta z}$
- Roof Area Density: $L(z) = \int_z^{h_c} a_r(z')\,dz'$
- Building Frontal Area Index: $\lambda_f(\theta) = \frac{A_{proj}}{A_T}$
- Frontal Area Density: $a_f(z,\theta) = \frac{A(\theta)_{proj\,(\Delta z)}}{A_T \Delta z}$
- Complete Aspect Ratio: $\lambda_c = \frac{A_c}{A_T} = \frac{A_W + A_R + A_G}{A_T}$
- Building Surface Area to Plan Area Ratio: $\lambda_B = \frac{A_W + A_R}{A_T}$
- Height-to-Width Ratio: $\lambda_S = \frac{(H_1 + H_2)/2}{S_{12}}$

Burian et al., 2007, Development and assessment of the second generation national building statistics database.

所在团队的城市冠层精细结构研究

卫星遥感



算法改进

形态计算

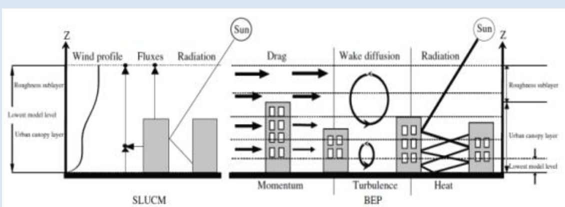
$$\bar{h} = \frac{\sum_{i=1}^{N} h_i}{N}$$

平均高度

$$\lambda_S = \frac{(H_1 + H_2)/2}{S_{12}}$$

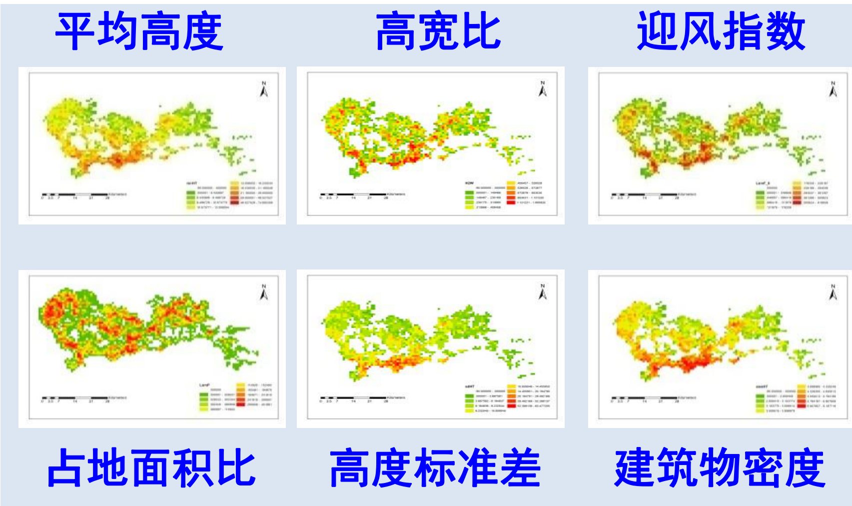
高宽比

模式输入



城市冠层模式

构建精细化的城市结构参数



解决了真实城市结构参数化方法问题，改进和完善了基于精细结构的城市冠层模式，并将之嵌入中尺度WRF模式中

Wang X.M.*, Liao J.B., Zhang J. *et al.*, 2014. ***J. Appl. Meteorol. Clim.***, 53, 346-362.

科学问题 城市冠层热力过程的参数化方案需要改进（即城市冠层模式）

Int. J. Climatol. 31: 244–272 (2011)
Published online 7 October 2010 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.2227

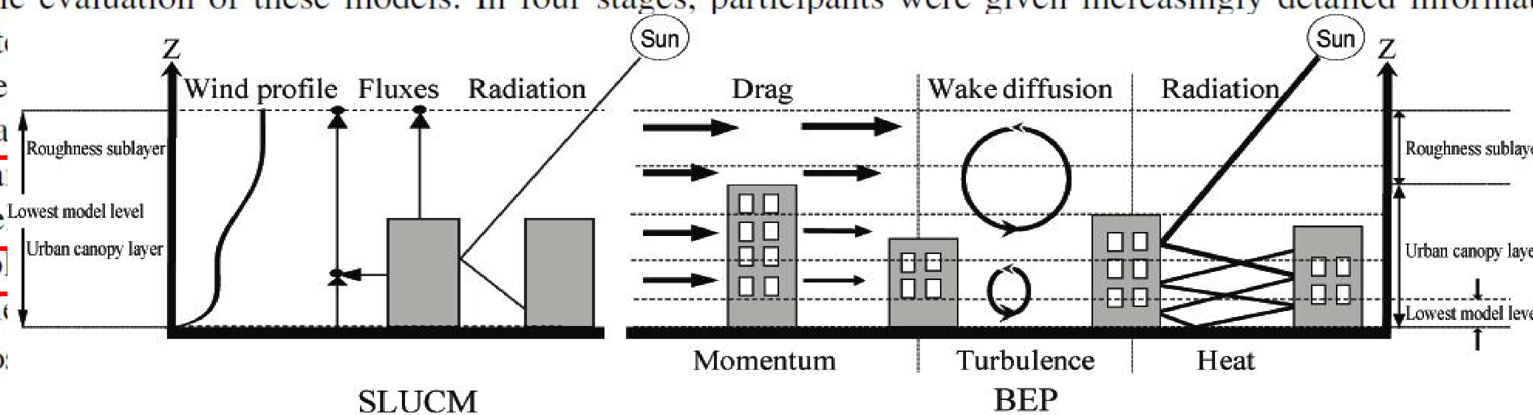
Royal Meteorological Society

32个城市能量平衡模型中，没有一个模型能对所有通量都效果最好，参数的选择不当能导致模型糟糕的结果，需要在应用时非常小心，清楚其适用性

Initial results from Phase 2 of the international urban energy balance model comparison

C. S. B. Grimmond,[a*] M. Blackett,[a] M. J. Best,[b] J.-J. Baik,[c] S. E. Belcher,[d] J. Beringer,[e] S. I. Bohnenstengel,[d] I. Calmet,[f] F. Chen,[g] A. Coutts,[e] A. Dandou,[i] K. Fortuniak,[j] M. L. Gouvea,[a] R. Hamdi,[k] M. Hendry,[b] M. Kanda,[l] T. Kawai,[m] Y. Kawamoto,[n] H. Kondo,[o] E. S. Krayenhoff,[p] S.-H. Lee,[c] T. Loridan,[a] A. Martilli,[q] V. Masson,[r] S. Miao,[s] K. Oleson,[h] R. Ooka,[n] G. Pigeon,[r] A. Porson,[b,d] Y.-H. Ryu,[c] F. Salamanca,[q] G.J. Steeneveld,[t] M. Tombrou,[i] J. A. Voogt,[u] D. T. Young[a] and N. Zhang[v]

ABSTRACT: Urban land surface schemes have been developed to model the distinct features of the urban surface and the associated energy exchange processes. These models have been developed for a range of purposes and make different assumptions related to the inclusion and representation of the relevant processes. Here, the first results of Phase 2 from an international comparison project to evaluate 32 urban land surface schemes are presented. This is the first large-scale systematic evaluation of these models. In four stages, participants were given increasingly detailed information about an
urban sit… s' calculated
surface e… l fluxes. No
individua… ults in better
performa… performance
for mode… or caution in
their app… ight © 2010
Royal Me…



KEY WORD… e cities;

城市风热环境的多尺度、精细化研究（SOMUCH）
(Scaled Outdoor Modelling of Urban Climate and Health)

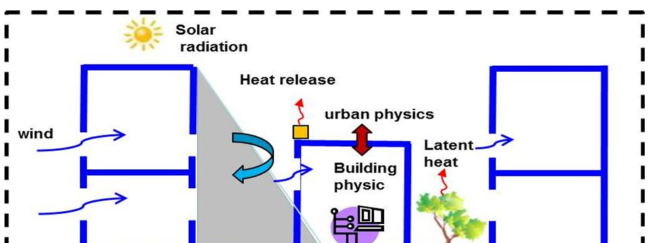
多尺度城市风温环境和空气污染物扩散及人群暴露示意图

以污染物扩散和输运为例

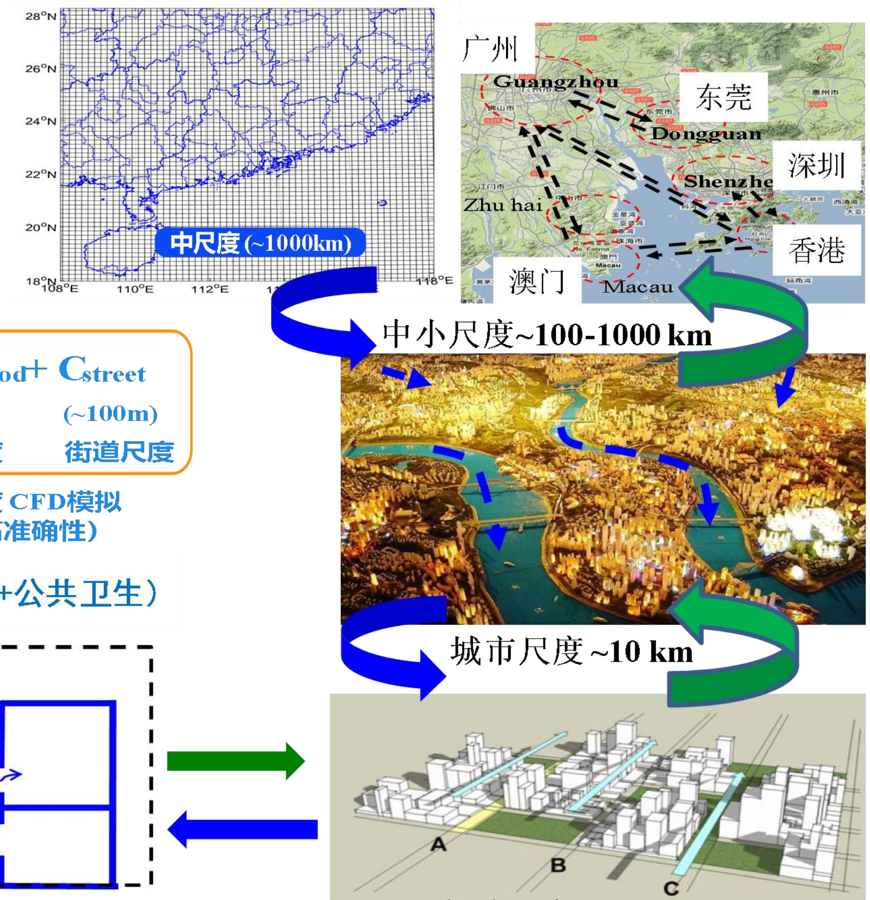
$$C = C_{regional} + C_{city} + C_{neighborhood} + C_{street}$$

$C_{regional}$	C_{city}	$C_{neighborhood}$	C_{street}
(~1000km)	(~10km)	(~1km)	(~100m)
中尺度	城市尺度	邻域尺度	街道尺度
区域模式	城市冠层模式 (修正和改进)	微尺度 CFD模拟 (提高准确性)	

（中尺度气象+城市气象+建筑环境+公共卫生）

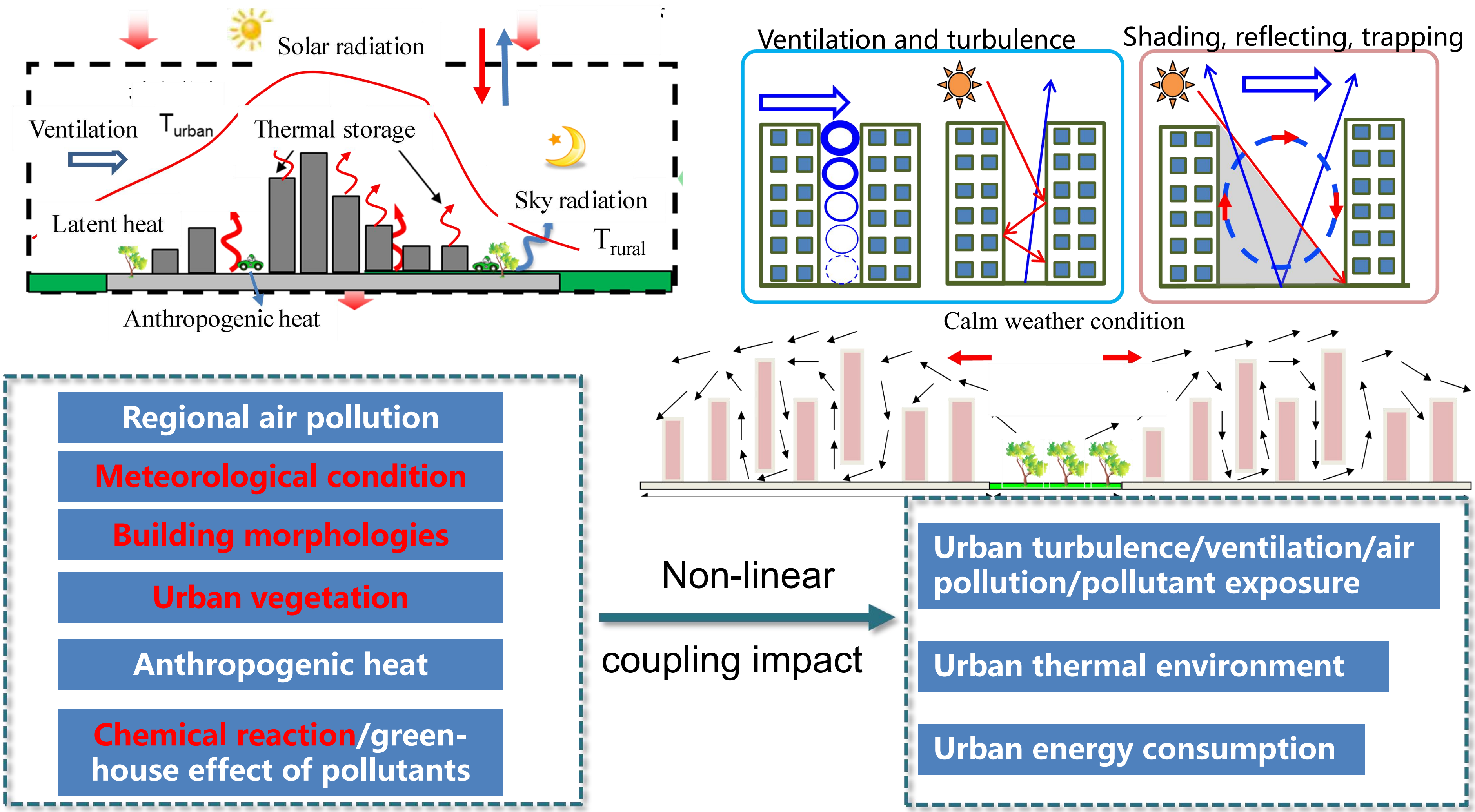


街道和建筑尺度人群暴露~10-100m

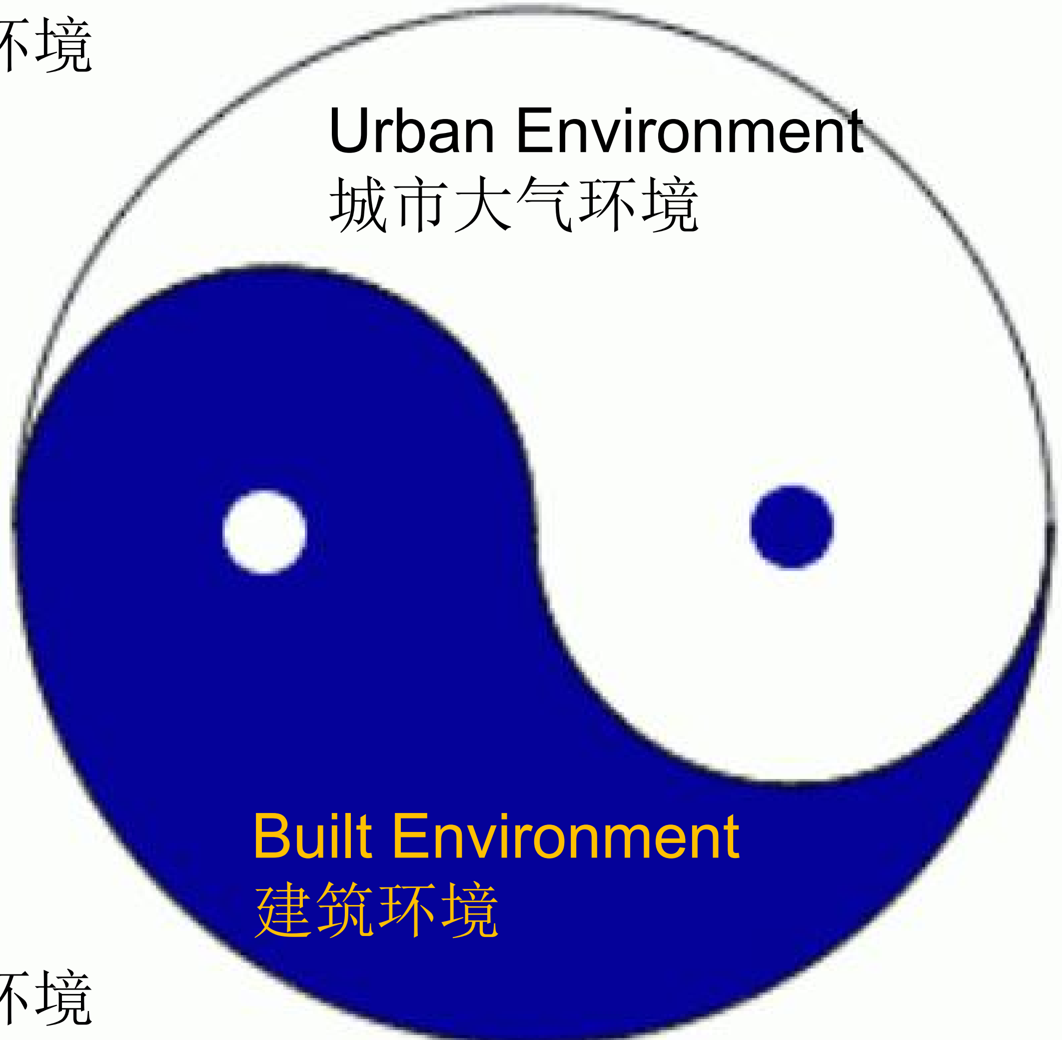


邻域尺度~1km

To quantify the influencing mechanisms of each factors



大气环境 大气环境



大气环境 大气环境

- 城市气候与健康研究团队包括：副教授2人、研究员1人、副研究员3人、博士后1人。
- 正在求职加入团队者：副教授1人、助理教授2人、博士后1人。
- 每年招收博士1名、硕士2人。

- 副教授、助理教授、专职科研系列岗位(特聘研究员、副研究员和博士后)招聘：**城市冠层模式研究（边界层参数化研究）、城市湍流和能量平衡及热岛实验观测、城市风温环境数值模拟(中尺度与微尺度)、城市空气污染观测与人群暴露研究等研究方向。**

- 中山大学大气科学学院 杭建
- 电邮:hangj3@mail.sysu.edu.cn
- 电话：13710248541

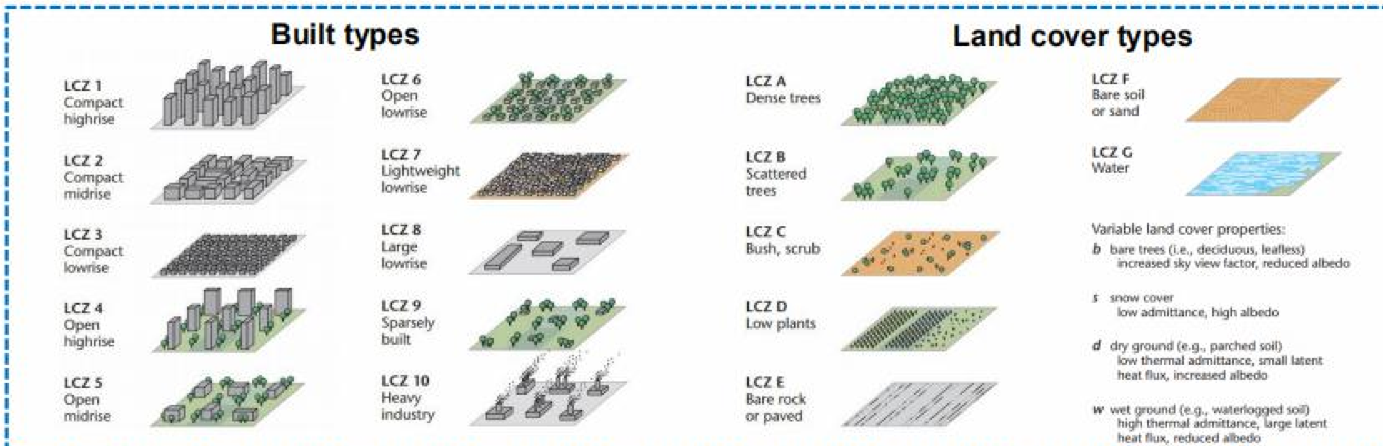
Thanks for your attention

谢谢各位专家学者！

城市局地气候分区模型

Surface structure | **Surface cover** | **Surface fabric** | **Human activity**

$$Z = f\,(P)$$



From **Stewart & Oke (2012)**