ANTHROPOGENIC HEAT CONTRIBUTION TO AIR TEMPERATURE INCREASE AT PEDESTRIAN HEIGHT IN SINGAPORE'S HIGH DENSITY CENTRAL BUSINESS DISTRICT (CBD)

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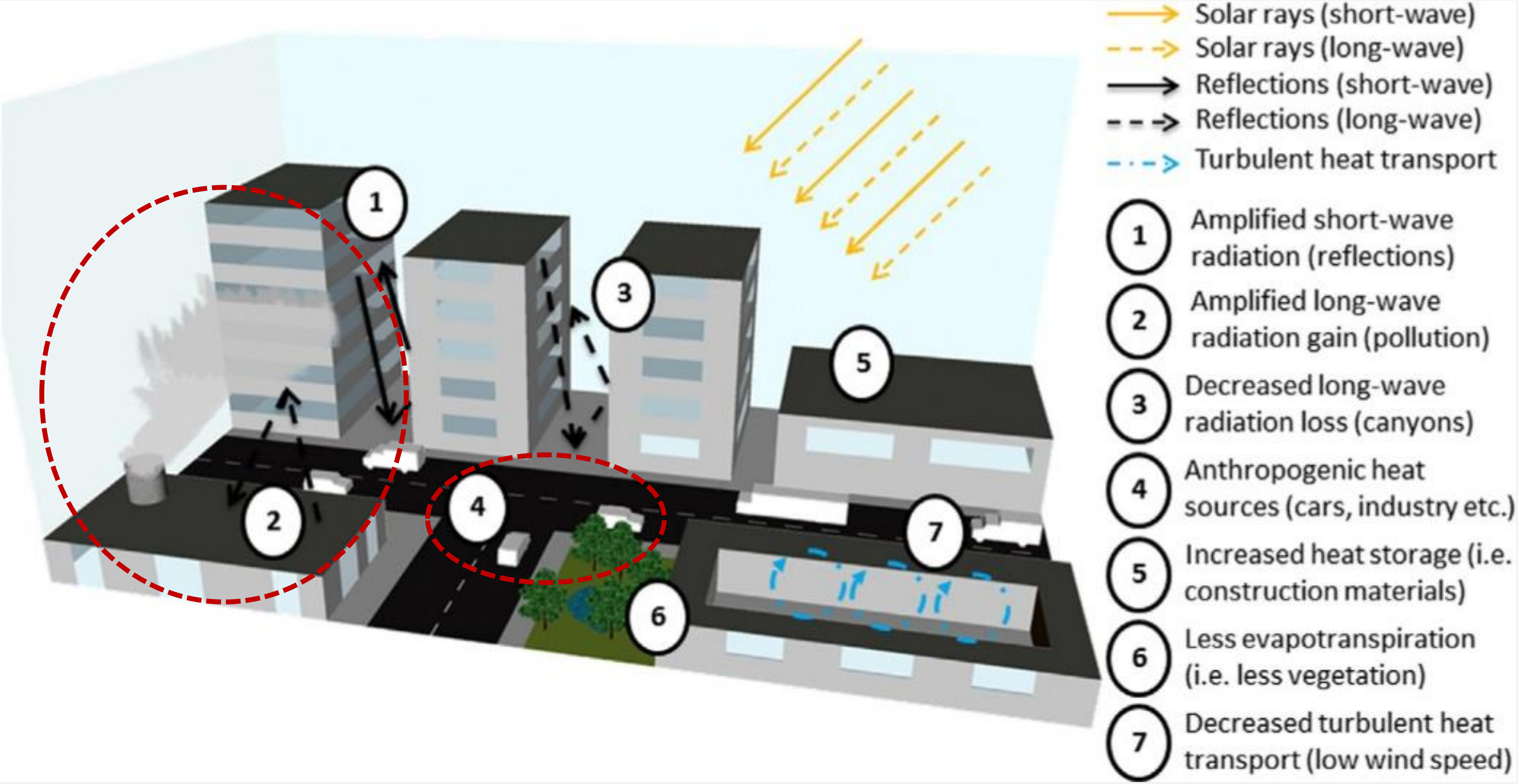
CONTENT

- INTRO (UHI & ANTHROPOGENIC HEAT)
- SITE MEASUREMENT
- PRELIMINARY STUDIES (ROADSIDE MEASUREMENT)
- PRELIMINARY STUDIES (CFD SIMULATION)
- CONCLUSION & FUTURE WORK

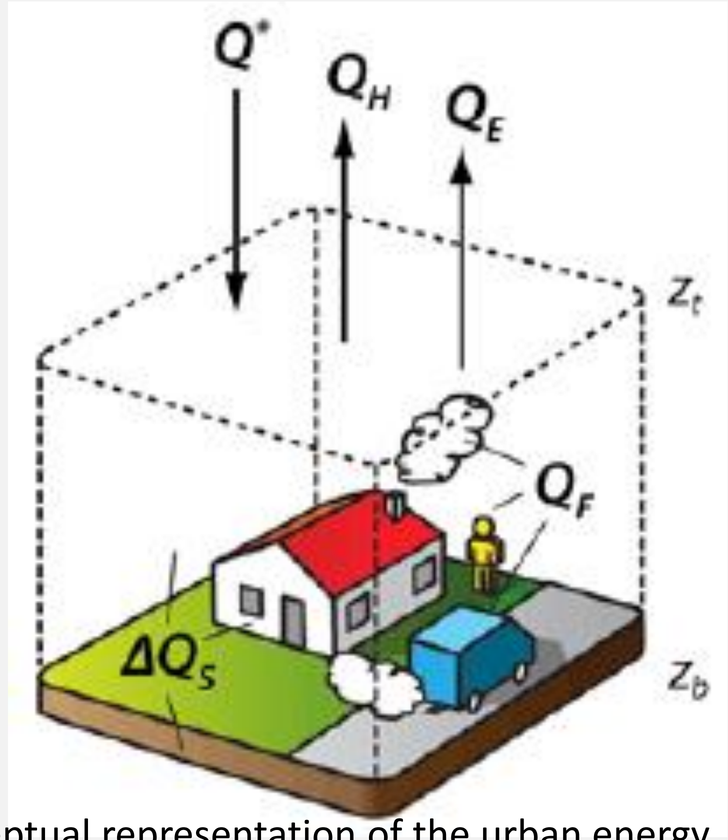
UHI



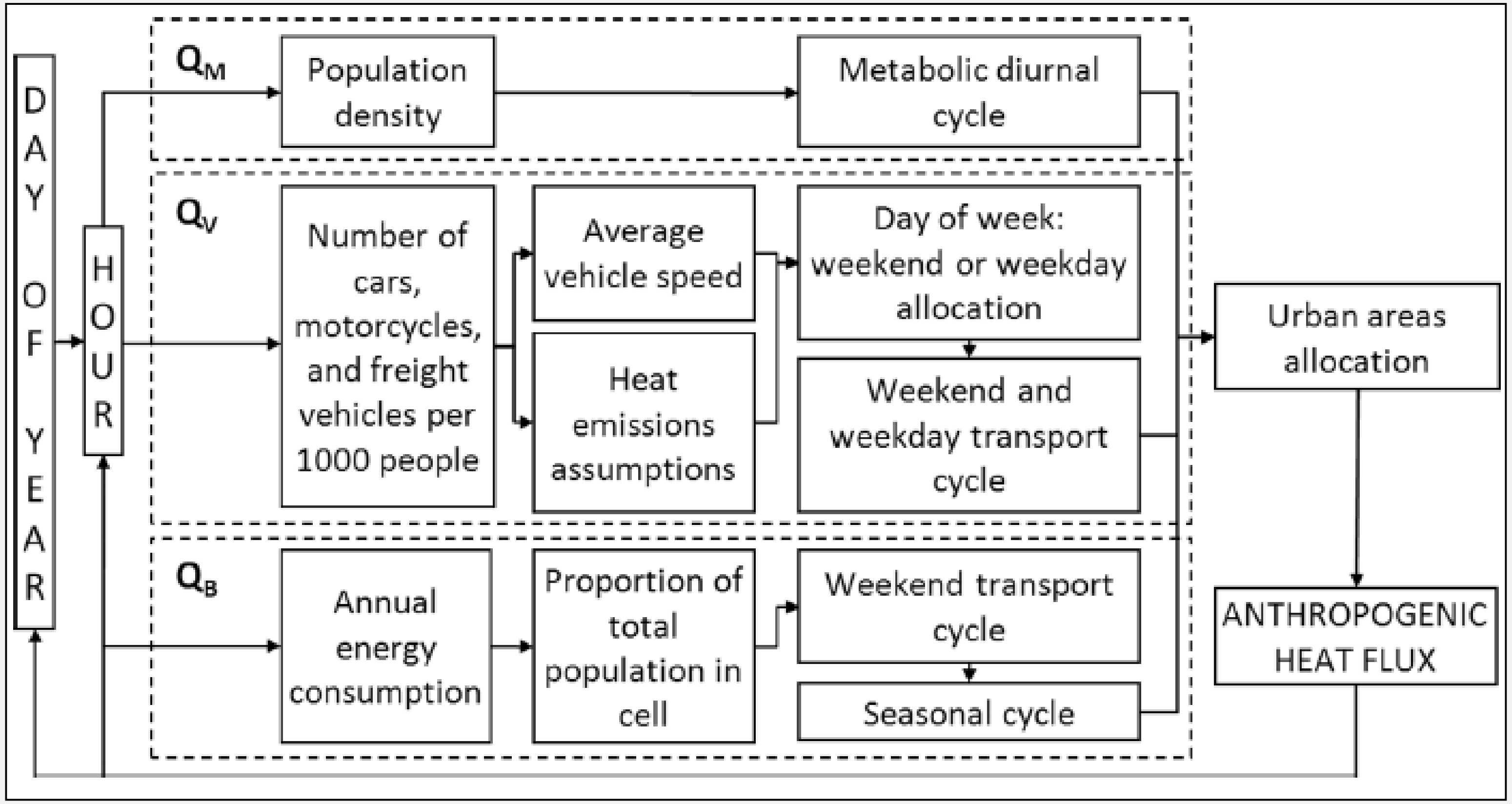
Representation of the possible causes of the UHI effect. (Toparlar et al.,2014)

ANTHROPOGENIC HEAT

$Q^* + \mathbf{Q_F} = Q_H + Q_E + \Delta Q_S$ $\mathbf{Q_F} = Q_M + Q_V + Q_B$



Conceptual representation of the urban energy balance for a balancing volume that reaches from the depth where no exchange with the subsurface is found (z_b) to the measurement height on a tower above the urban ecosystem (z_t). (Grimmond and Christen, 2012)



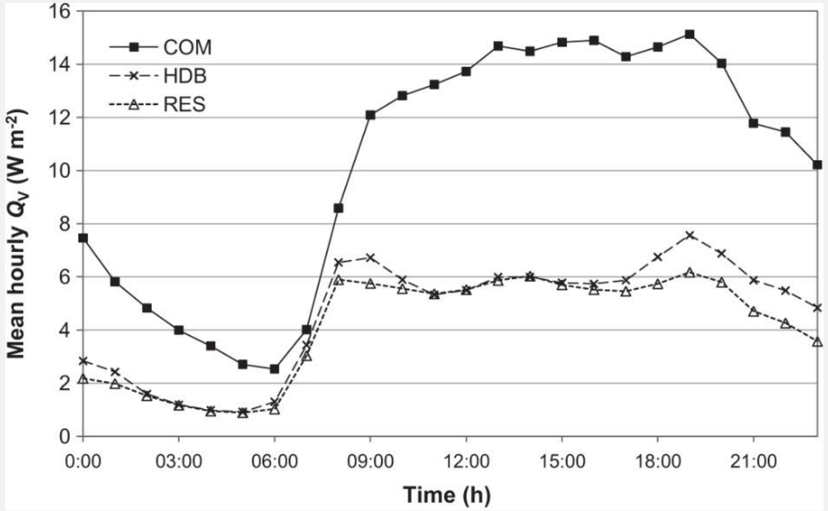
Flowchart of the LUCY global anthropogenic heat. (Allen et al., 2011)

ANTHROPOGENIC HEAT & AIR TEMPERATURE RISE

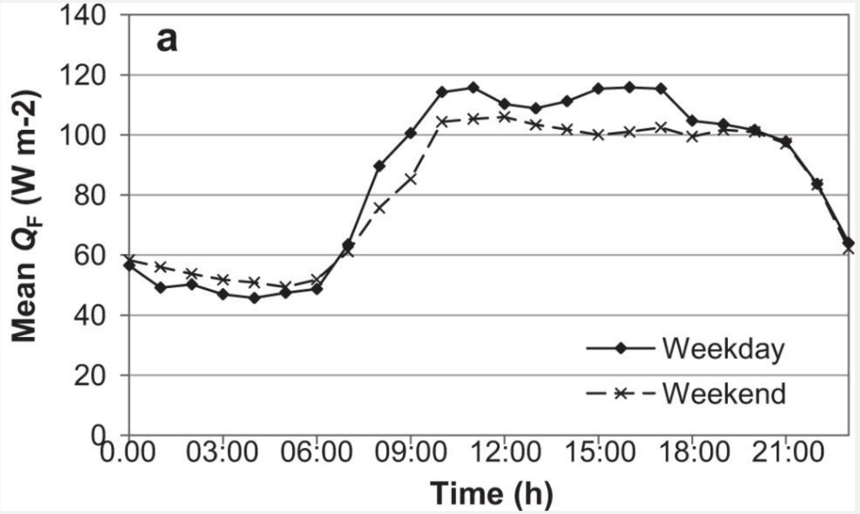
Ohashi et al. (2003) 1-2°C temperature rise within the building canopy.
Narumi et al. (2003) Osaka resulted 1°C temperature rise compared with baseline simulations.

Bohnenstengel et al. (2013), Chen et al. (2009); Kikegawa et al. (2014); Krpo et al. (2010); Li et al. (2014); Fan & Sailor (2005); Jusuf & Wong (2009)
Anthropogenic heat contributes 0.4 ^{o}C - 3^{o}C to the air temperature.

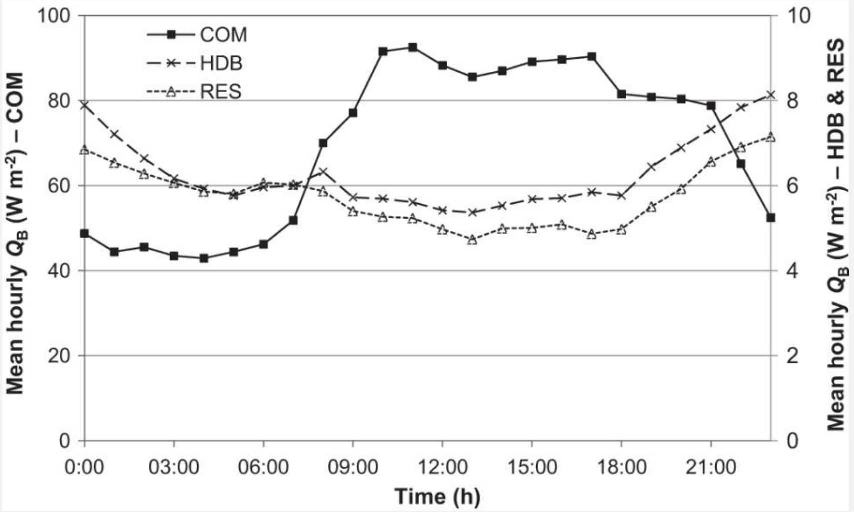
ANTHROPOGENIC HEAT IN SINGAPORE



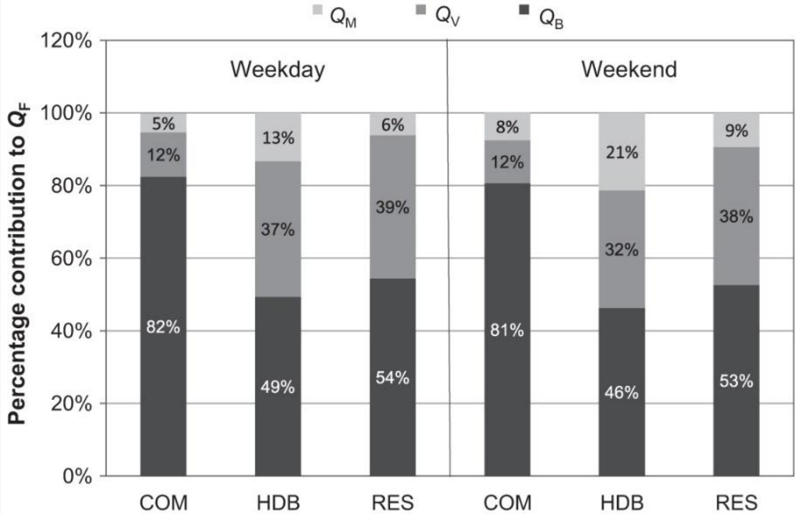
Q_V @ COM, HDB, RES



Q_F Weekday VS. Weekend @ COM



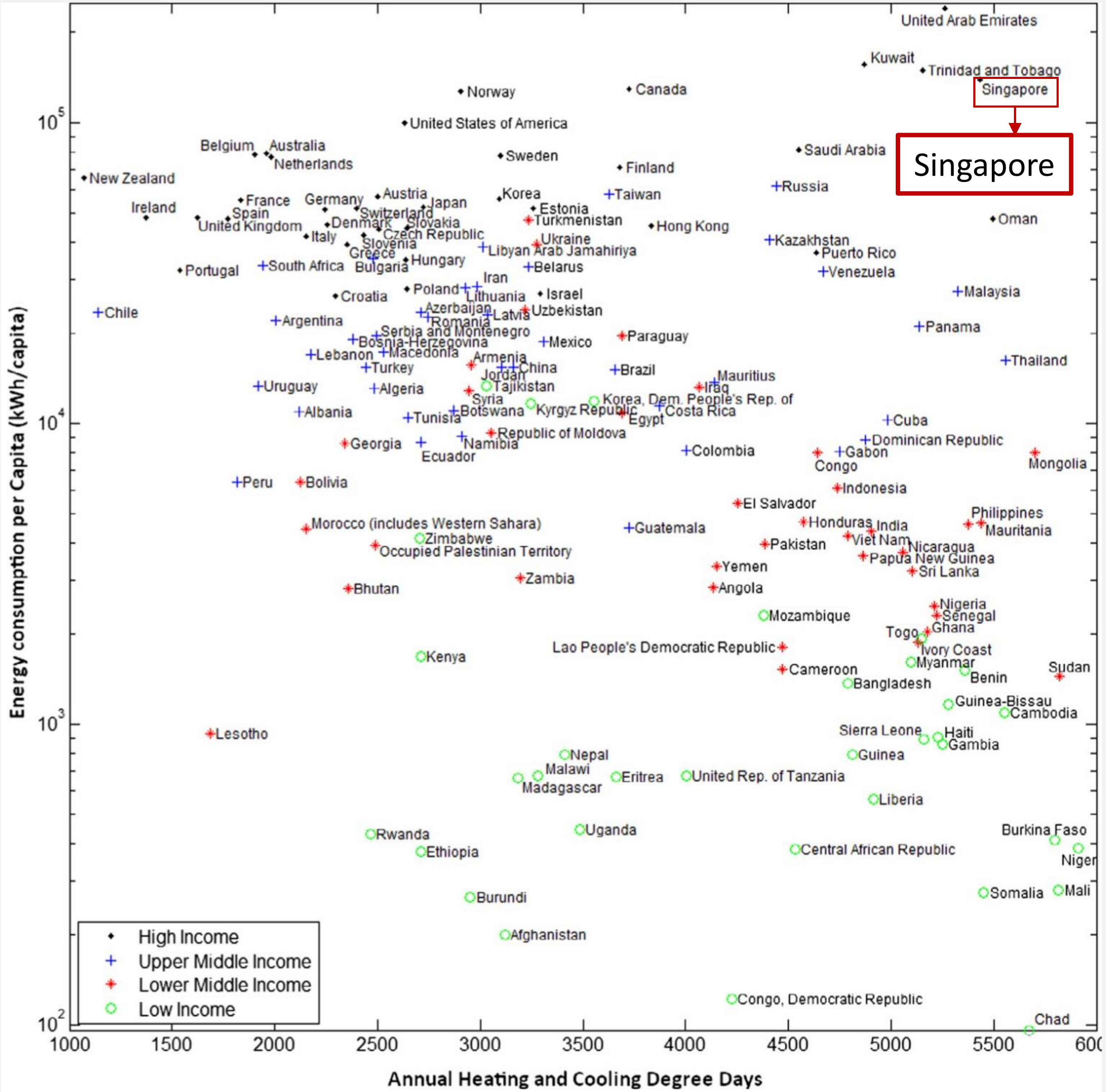
Q_B @ COM, HDB, RES



Q_F % between COM, HDB, RES

Singapore's diurnal and weekly variation of anthropogenic heat emissions. (Quah & Roth, 2012)

ANTHROPOGENIC HEAT



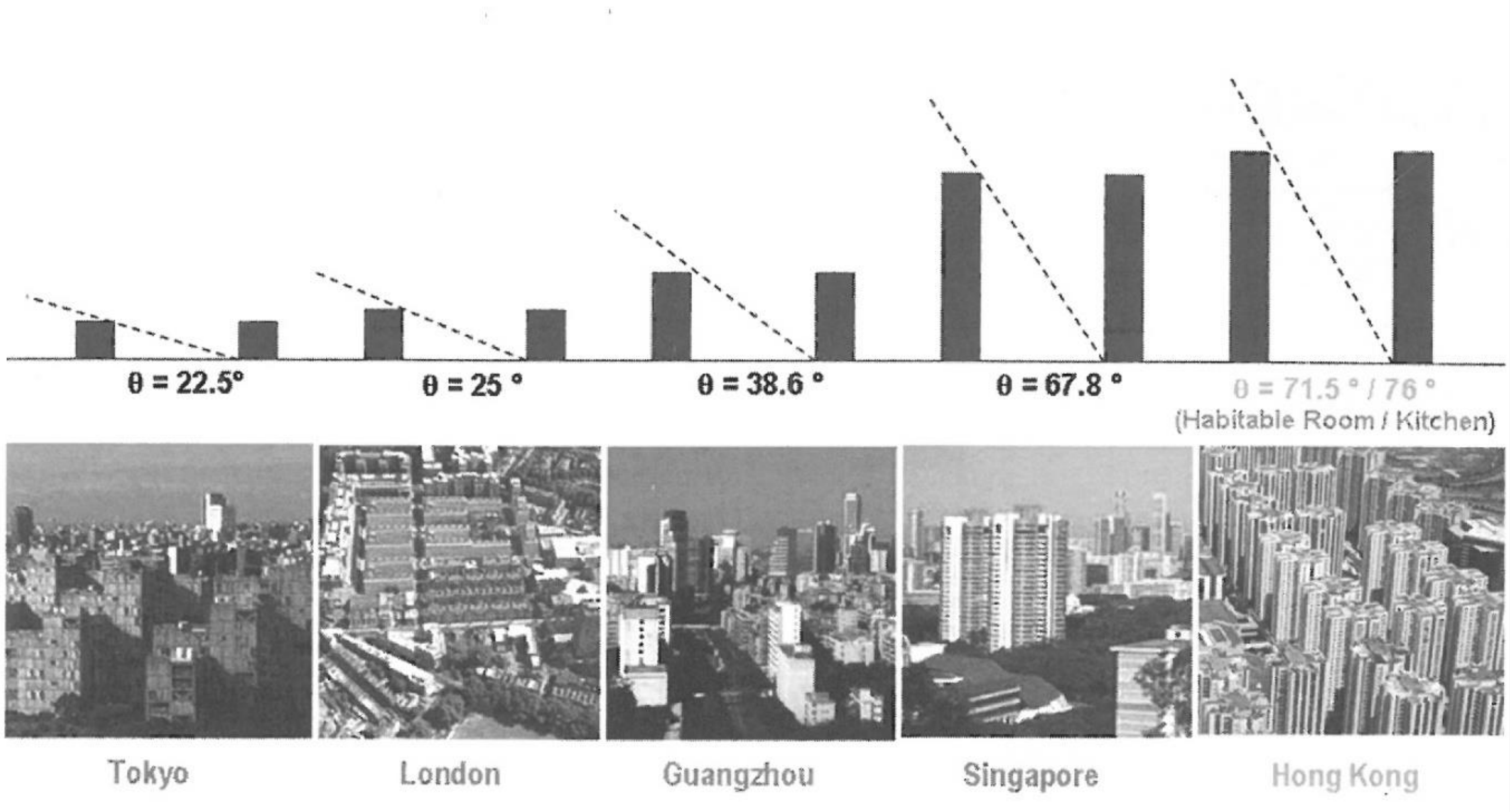
Annual energy consumption per capita versus combined total of annual heating and cooling degree days (°C) for countries with a population greater than 1 million for 2005. (Lindberg et al., 2013)

ANTHROPOGENIC HEAT

Cities population and vehicles density

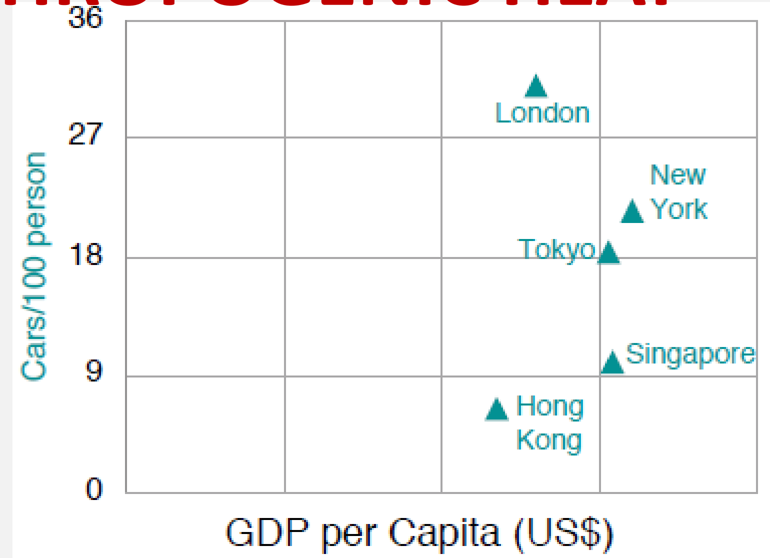
City:	Tokyo	London	Guangzhou	Singapore	Hong Kong
Motor Vehicles (per 1,000 people):	350 (cars)	317.2 (cars)	150	**149**	77
Population Density (/sqkm):	6,029	5,285	1,708	**7,669**	6,516
H/W Ratio:	0.4142	0.47	0.8	**2.45**	2.99 / 4.01

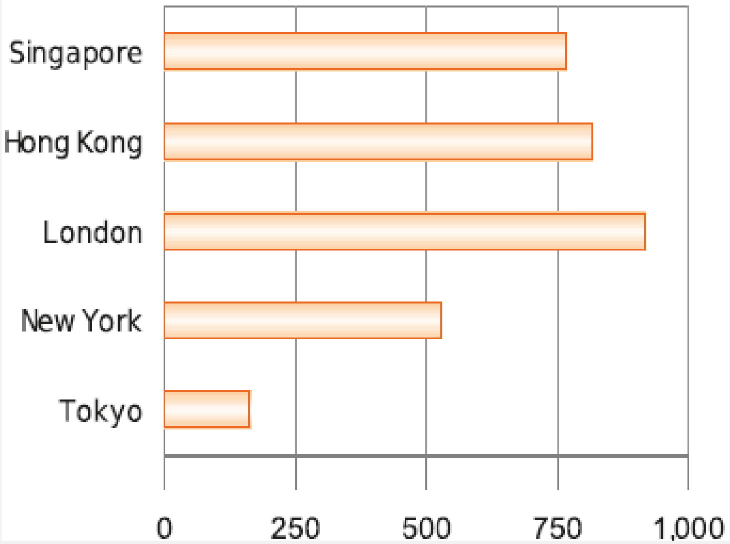
***H/W = Height to Width**



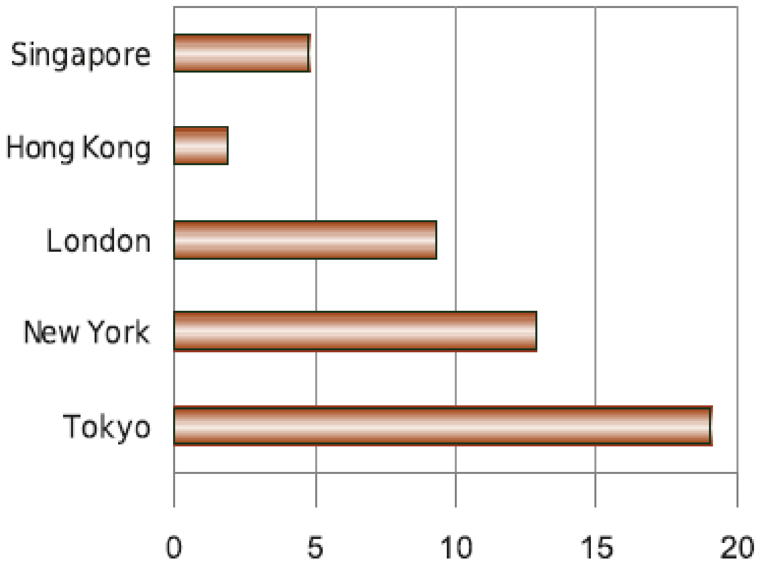
Vertical obstruction angle restrictions in different cities. (Ng, 2009 & Ng, 2012)

ANTHROPOGENIC HEAT





Public bus fleet/ million persons. (LTA, 2014)



Number of cars per 100 persons and road density (km/sqkm). (LTA, 2014)

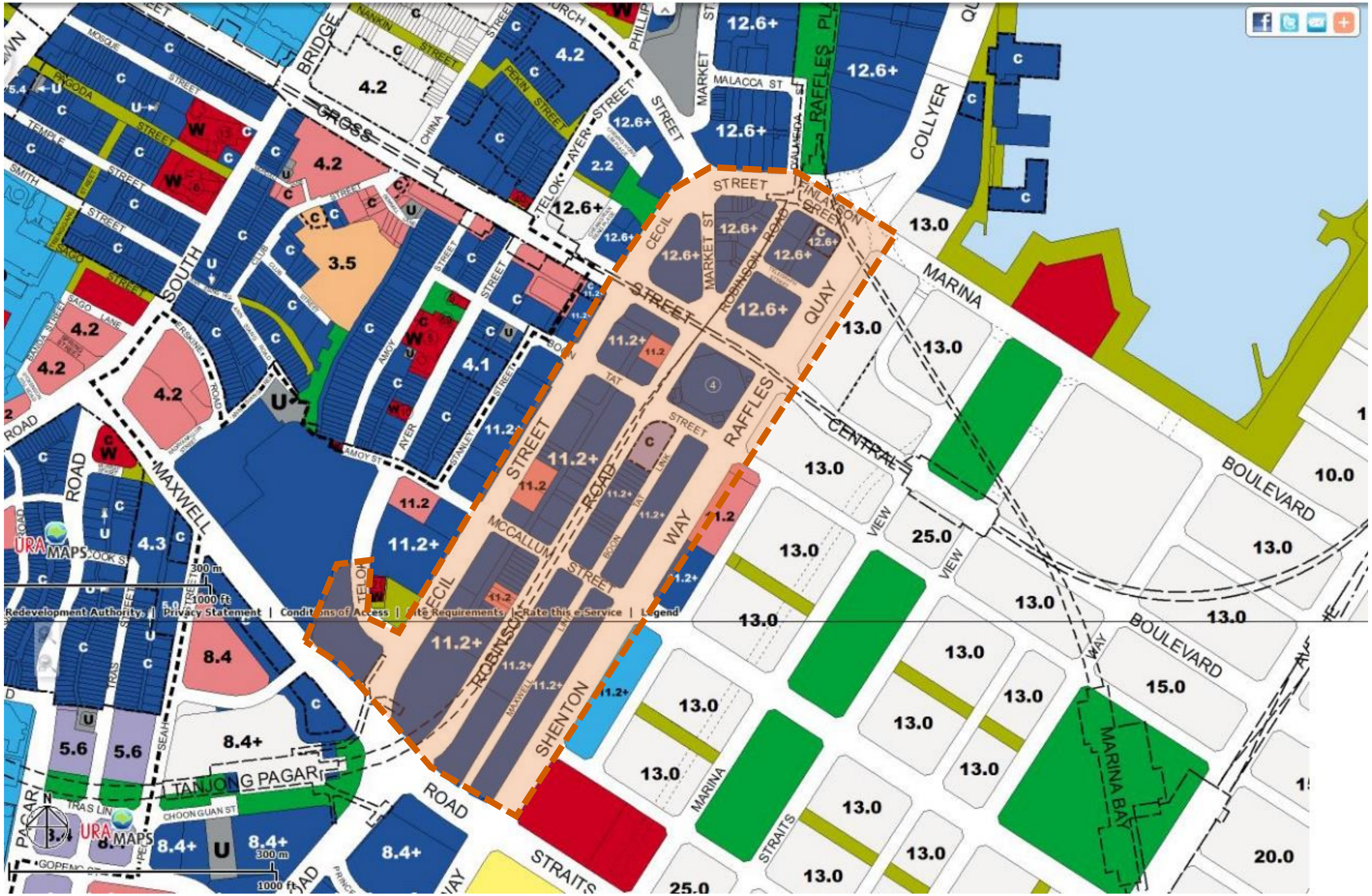
Motor vehicle population. (LTA, 2014)

Year	Amount
2002	706,956
2003	711,043
2011	956,704
2012	969,910

Average daily traffic volume entering the CBD. (LTA, 2014)

Year	Amount
2002	245,000
2003	244,000
2011	300,000
2012	292,000

SITE MEASUREMENT



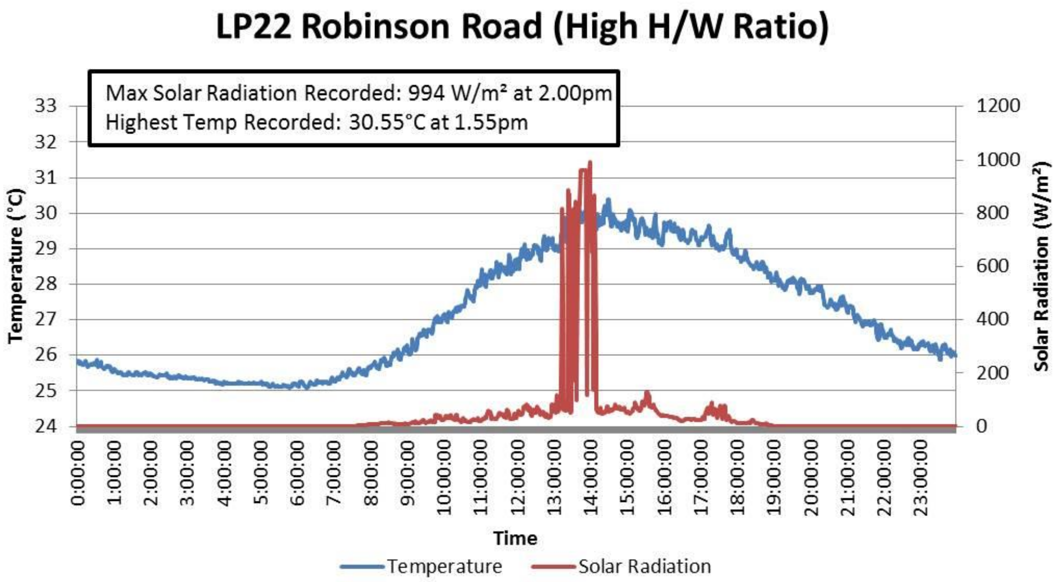
The URA Masterplan showing the plot ratio figures of the measurement site at the CBD above and the new Marina Bay development below. (URA, 2014)

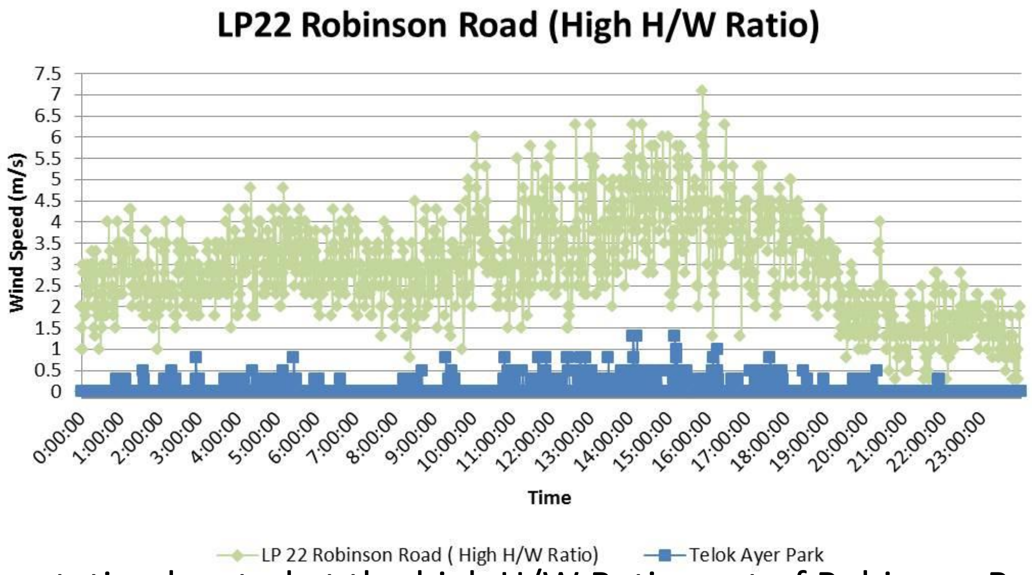
SITE MEASUREMENT

Lamp post locations on site.

SITE MEASUREMENT

Onset HOBO U30-NRC weather station kit.

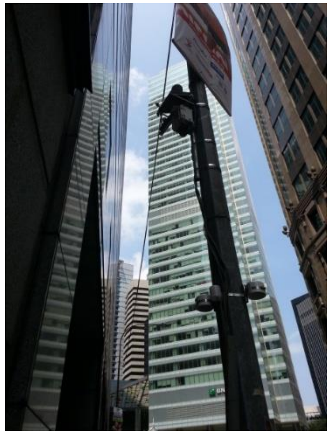
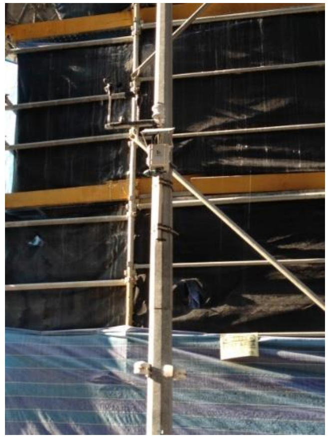




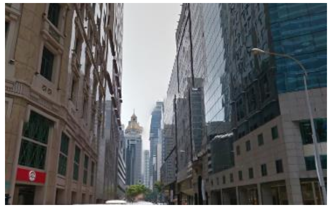
A weather station located at the high H/W Ratio part of Robinson Road on a clear, sunny day with profiles of solar radiation, air temperature and wind speed.

SITE MEASUREMENT

Weather Stations on CBD Site






Park (Baseline)	Water	Underground Carpark	High H/W Ratio	BBQ Satay

-Shading, cooling effect, idling vehicles, openness.

SITE MEASUREMENT

Weather Stations on CBD Site









Traffic Light Junction

Taxi

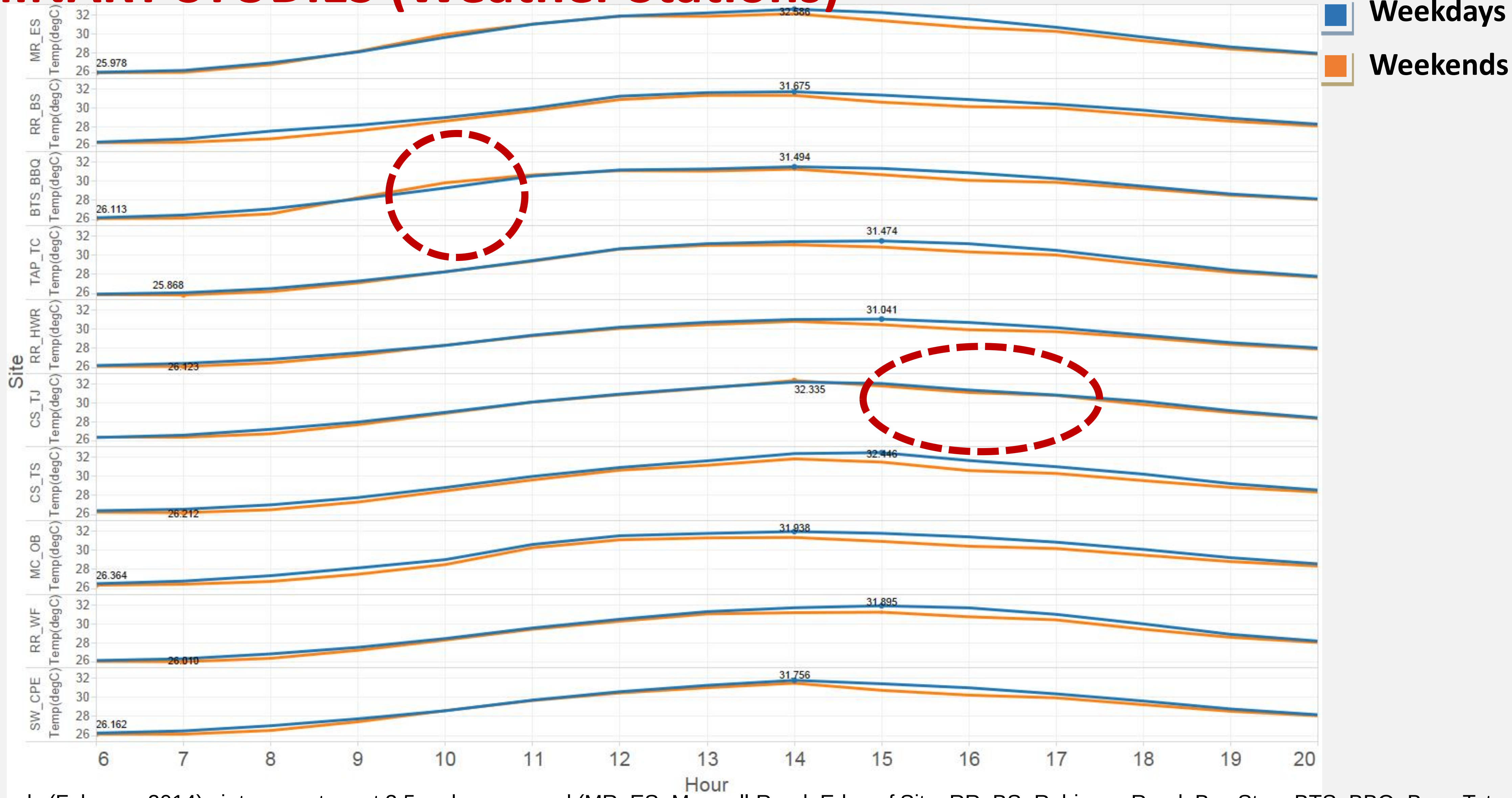
Bus

Canyon Edge

Overhead Bridge

-Shading, cooling effect, idling vehicles, openness.

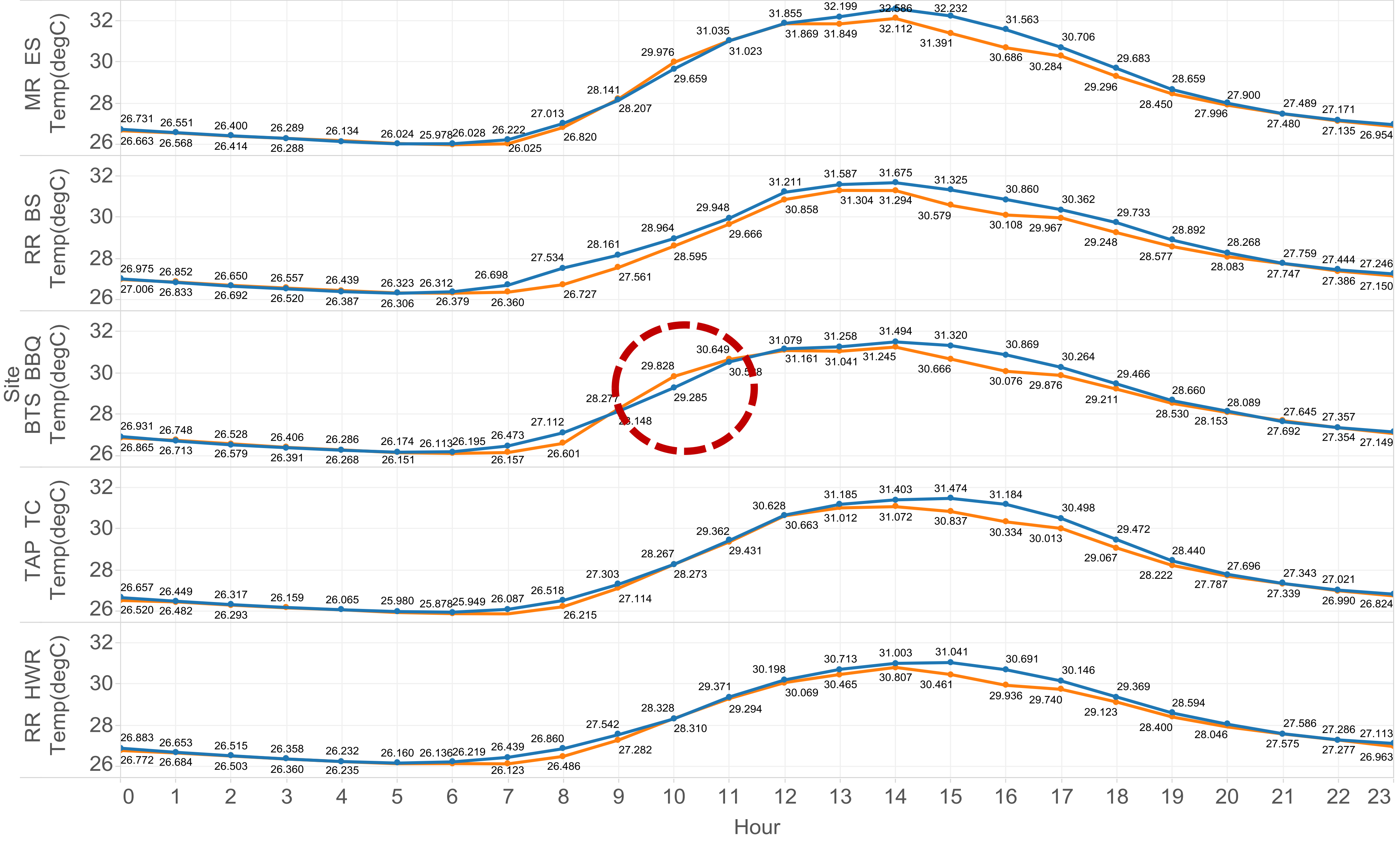
PRELIMINARY STUDIES (Weather Stations)



Weekdays and weekends (February 2014) air temperature at 3.5m above ground (MR_ES=Maxwell Road_Edge of Site, RR_BS=Robinson Road_Bus Stop, BTS_BBQ=Boon Tat Street_Barbeque Stalls, TAP_TC=Telok Ayer Park_Trees Canopy, RR_HWR=Robinson Road_High Height-to-Width Ratio, CS_TJ=Cecil Street_Traffic Junction,, CS_TS=Cecil Street_Taxi Stand, MC_OB=McCallum Street_Overhead Bridge, RR_WF=Robinson Road_Water Feature, SW_CPE=Shenton Way_Car Park Entrance).

PRELIMINARY STUDIES (Weather Stations)

The weekends for the month are
8th, 9th, 15th, 16th, 22nd and 23rd February 2014.



- Maxwell Road- Edge of the Site (MR_ES)
- Telok Ayer Park- Tree Canopy (TAR_TC)
- Robinson Road- Bus Stop (RR_BS)
- Robinson Road- High Height/Width-Ratio (RR_HWR)
- Boon Tat Street- BBQ (BTS_BBQ)

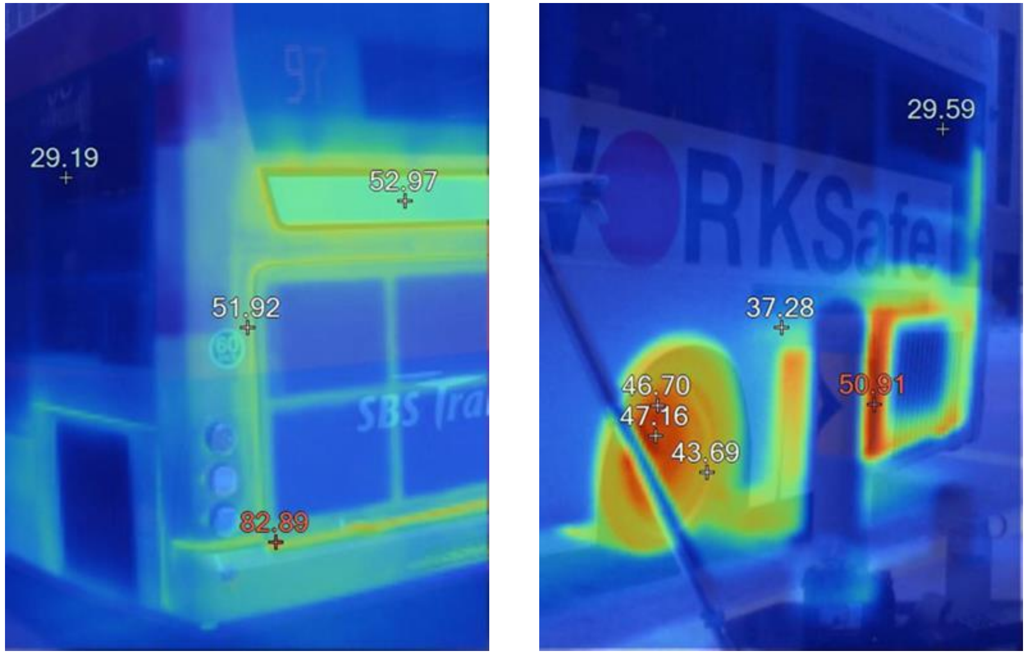
Type
Weekday
Weekend

Air Temperature distribution between weekdays and weekends (Feb 8-28, 2014) of the 5 locations.

PRELIMINARY STUDIES (Roadside Measurements)

Roadside measurement equipment on the 1.2m high tripod.

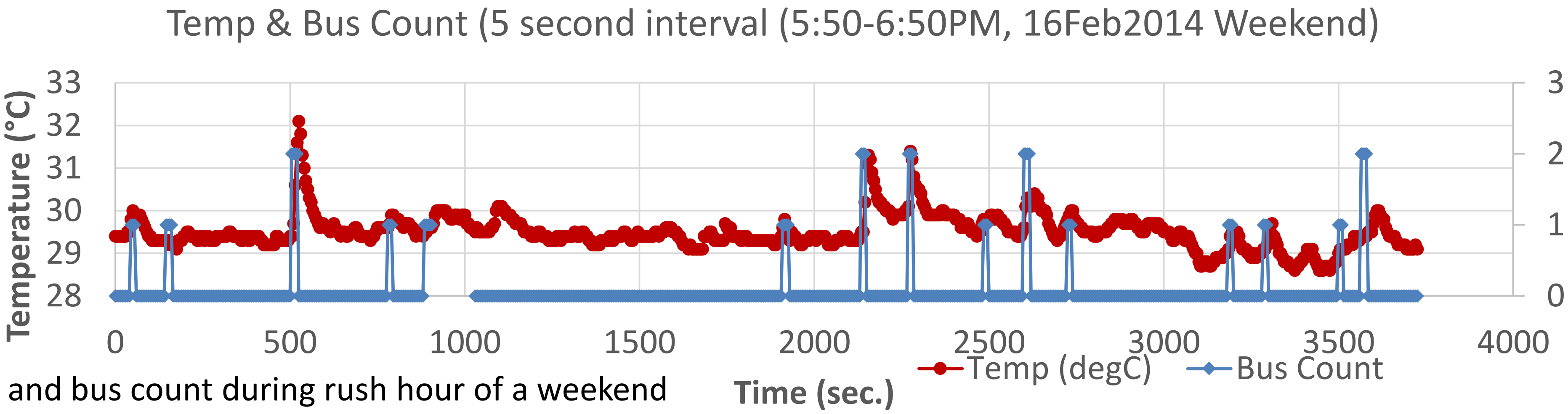
Fluke TiR125 thermal imager.



Bus surfaces under thermal imaging.

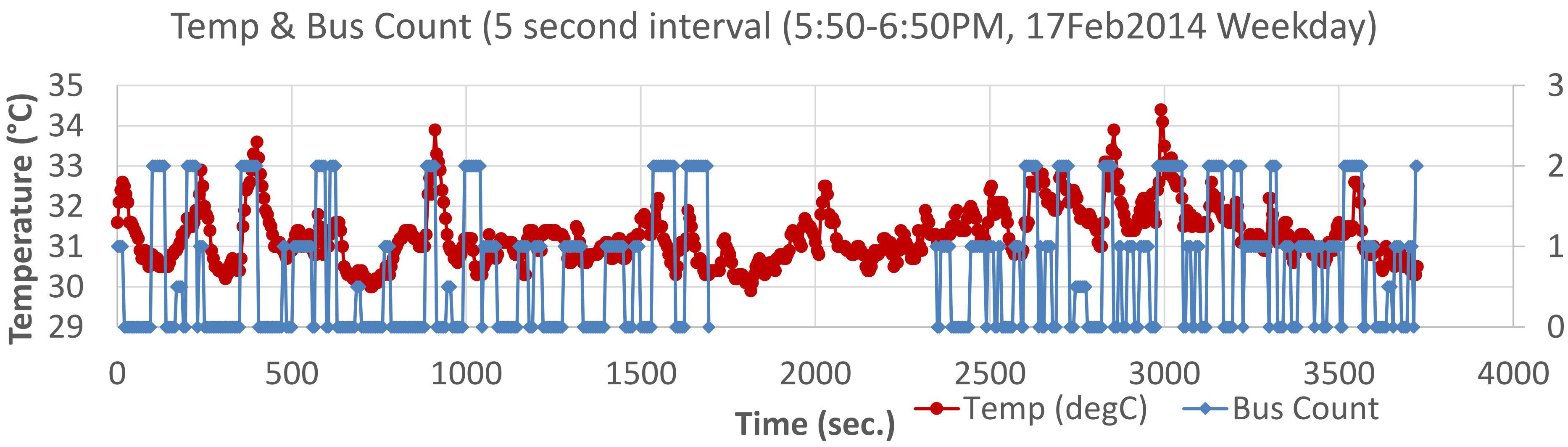
Roadside measurement at the bus stop in the urban canyon in the afternoon.

PRELIMINARY STUDIES (Roadside Measurements)



WEEKEND

Temperature and bus count during rush hour of a weekend



WEEKDAY

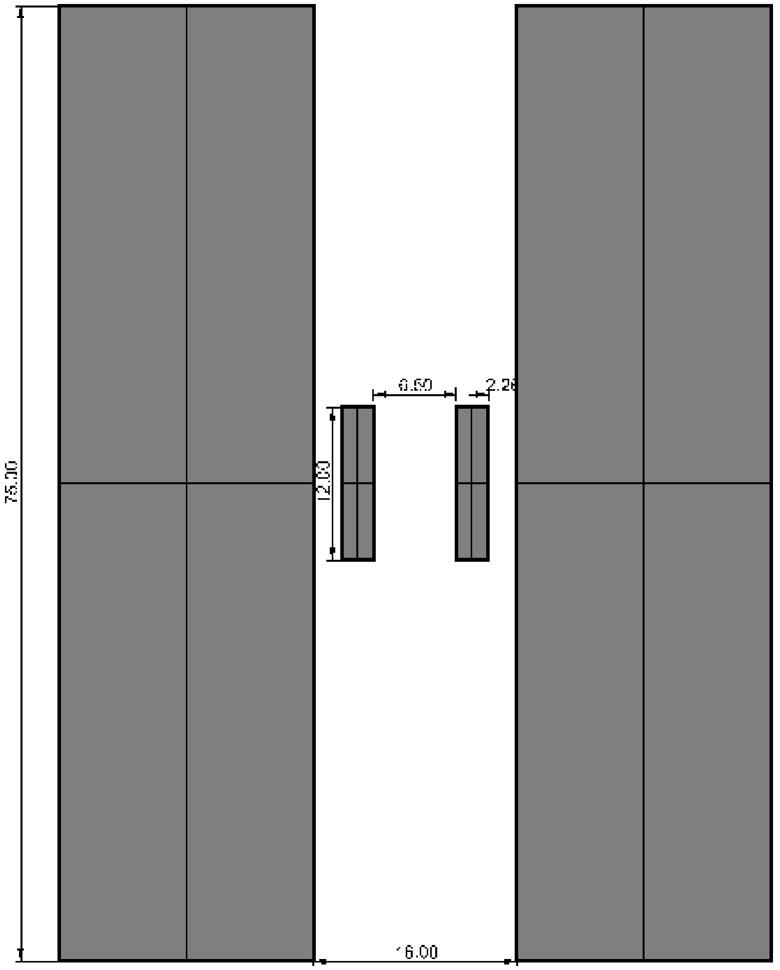
Temperature and bus count during rush hour of a weekday

PRELIMINARY STUDIES (CFD Simulation)

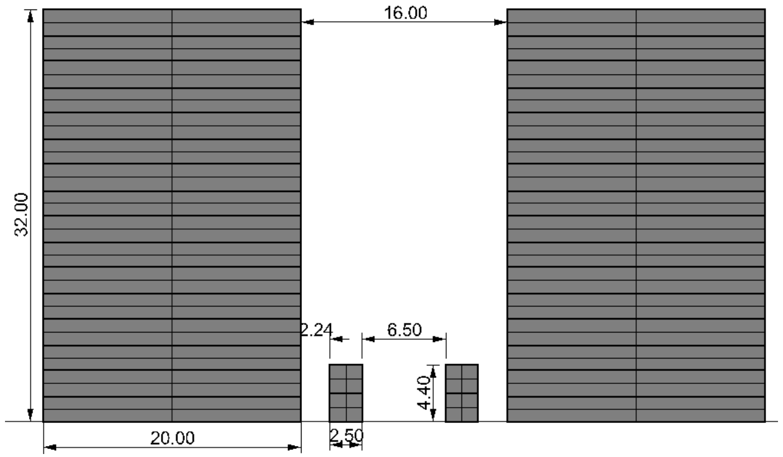
Computational Fluid Dynamics (CFD) Simulation

Fluent 15: Realizable K-Epsilon with buoyancy, solar load model & S2S radiation, transient

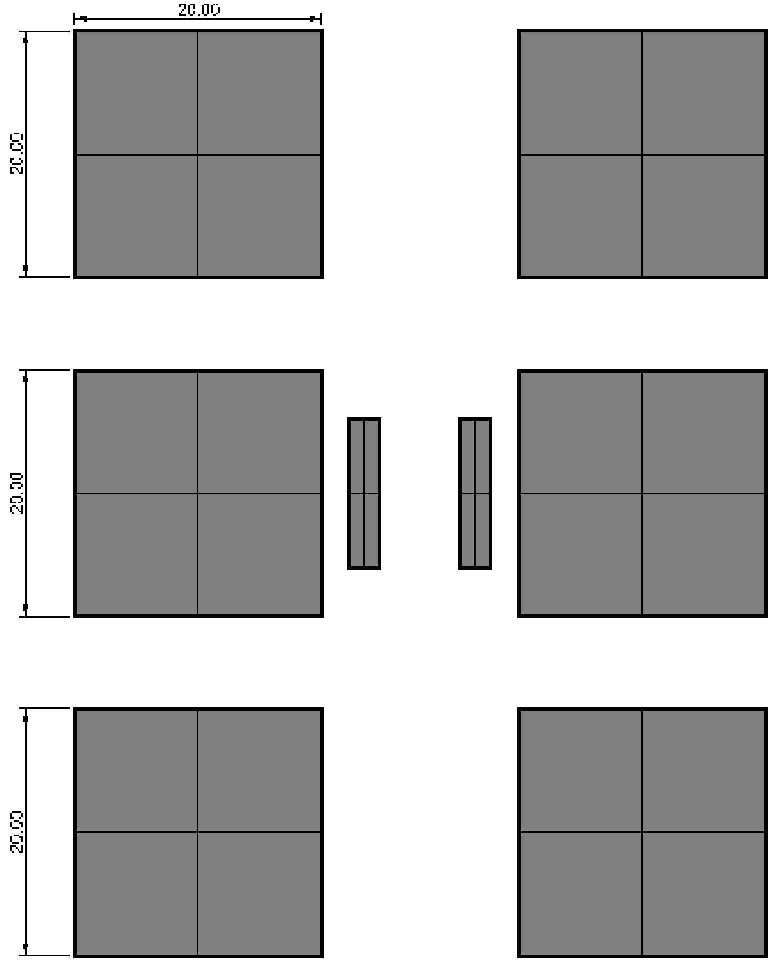
H/W 2 & 4
(8 & 16 stories)



SLAB PLAN

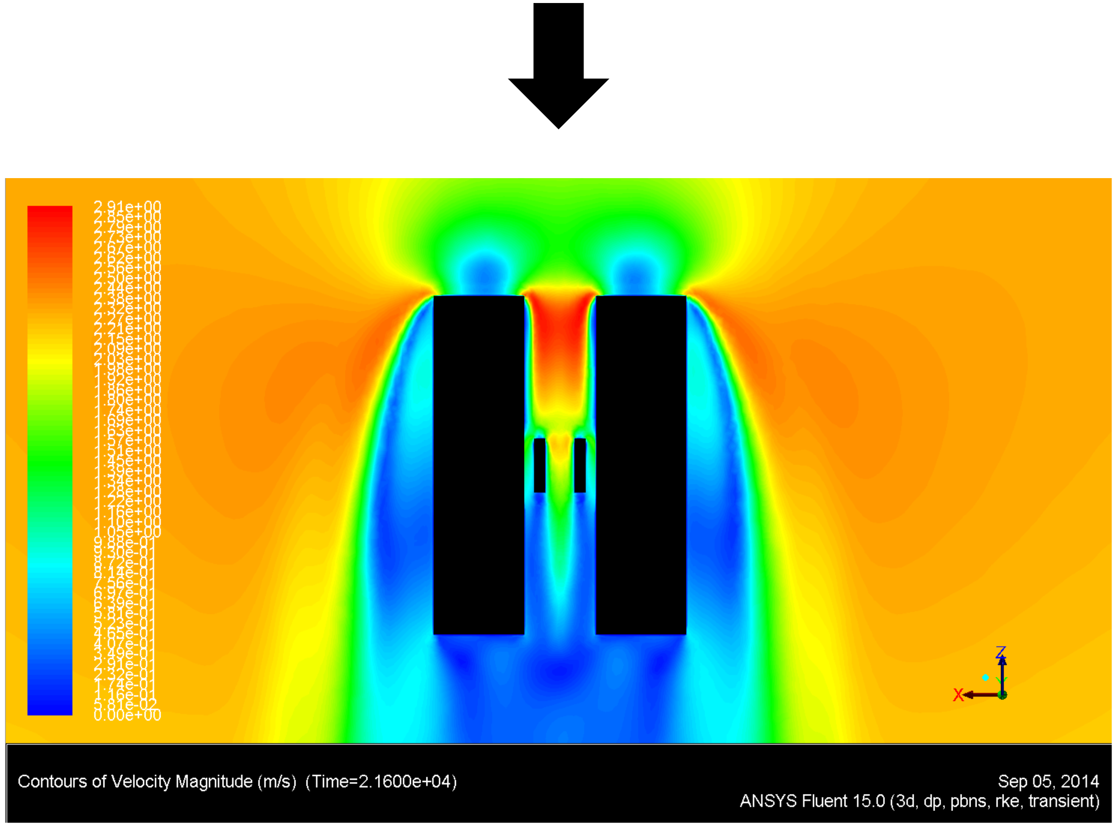


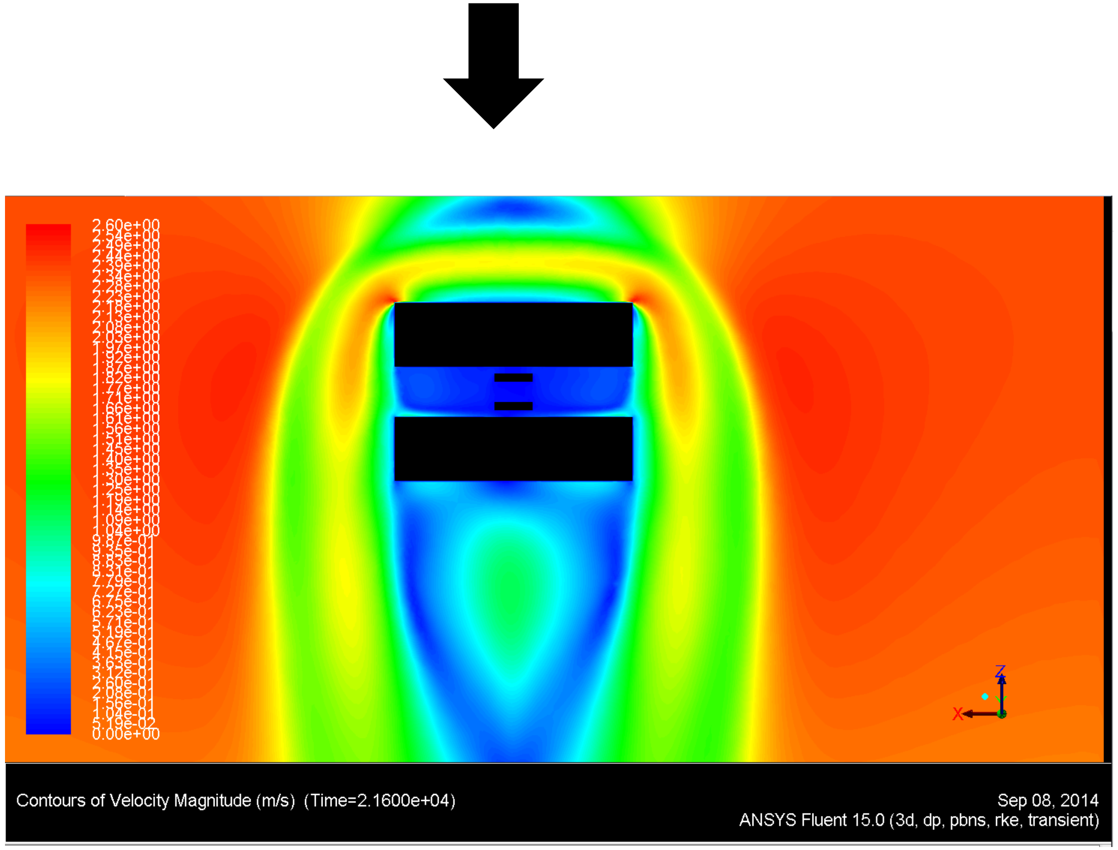
ELEVATION



POINT PLAN

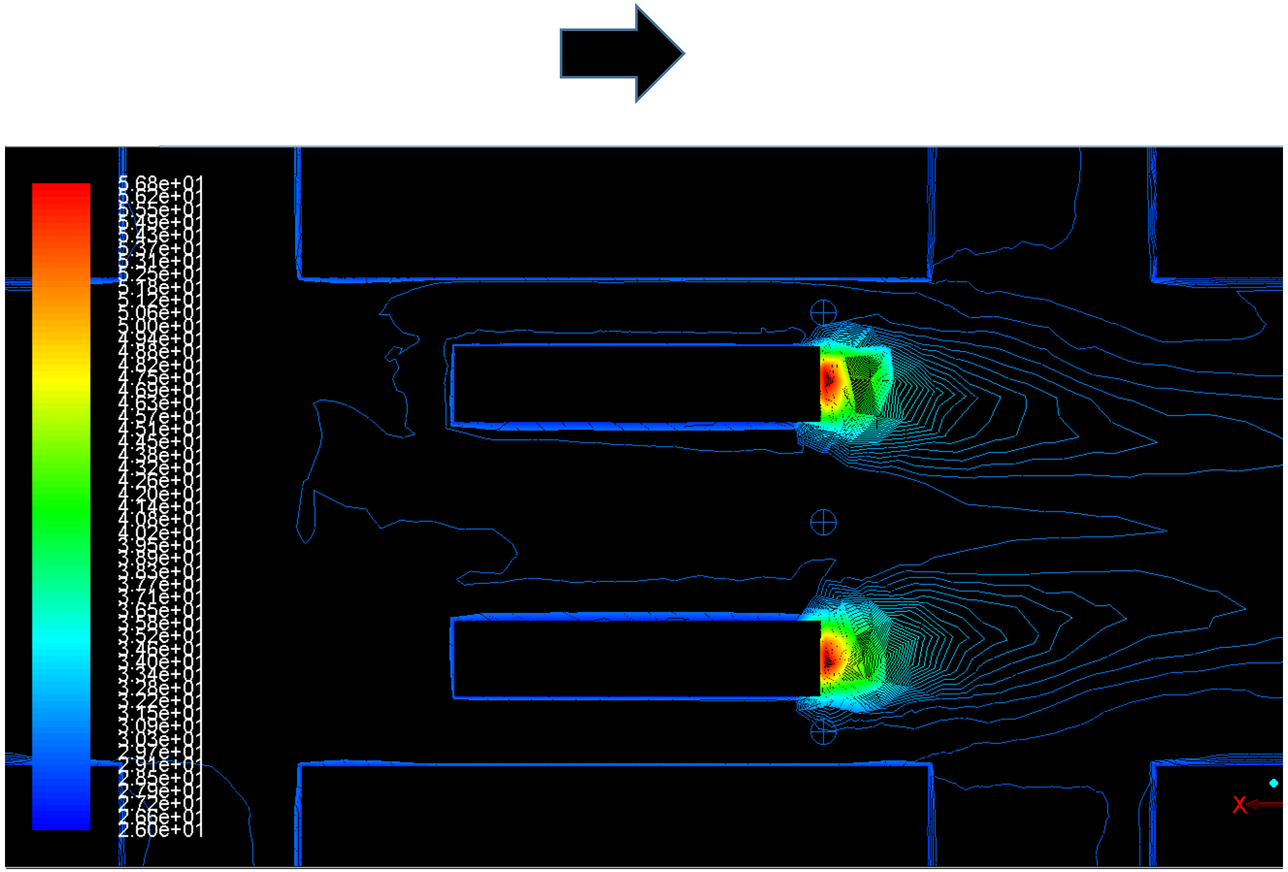
PRELIMINARY STUDIES (CFD Simulation)



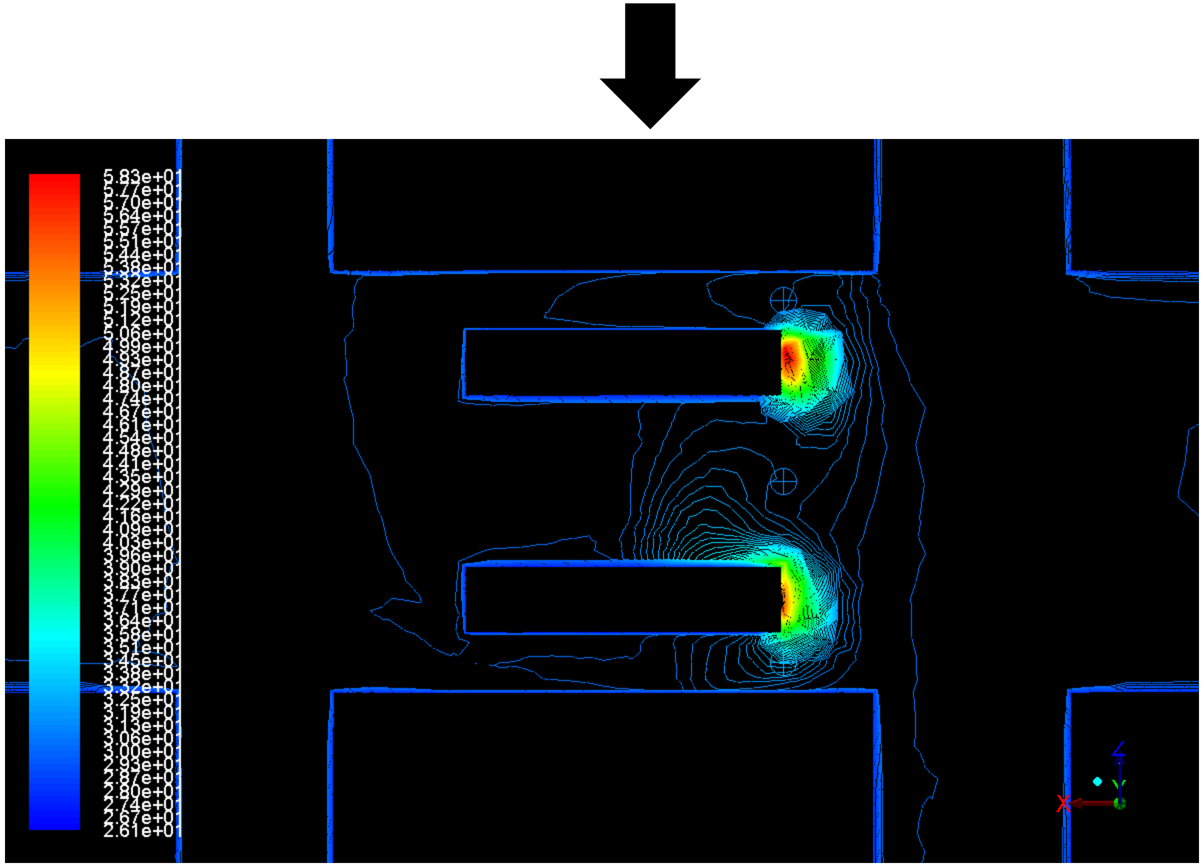


North & East Wind Directions 2m Pedestrian Height
2.3m/s @ 15m.

PRELIMINARY STUDIES (CFD Simulation)

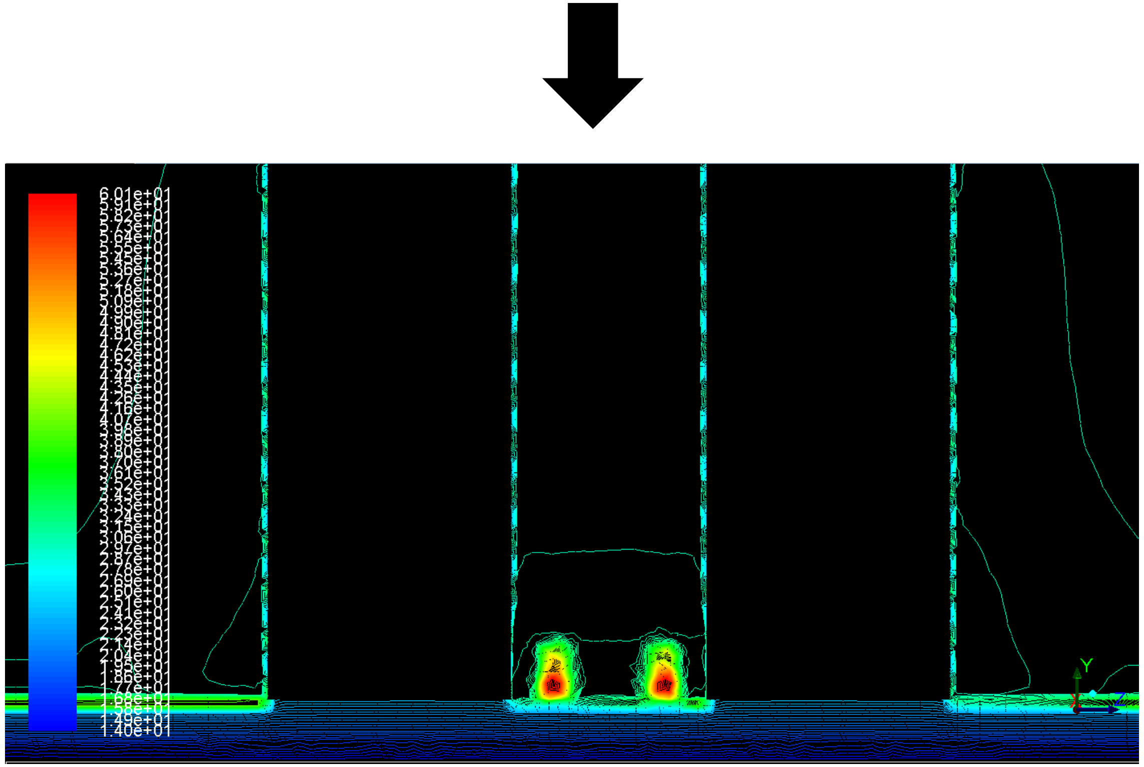


Parallel Flow (Plan)

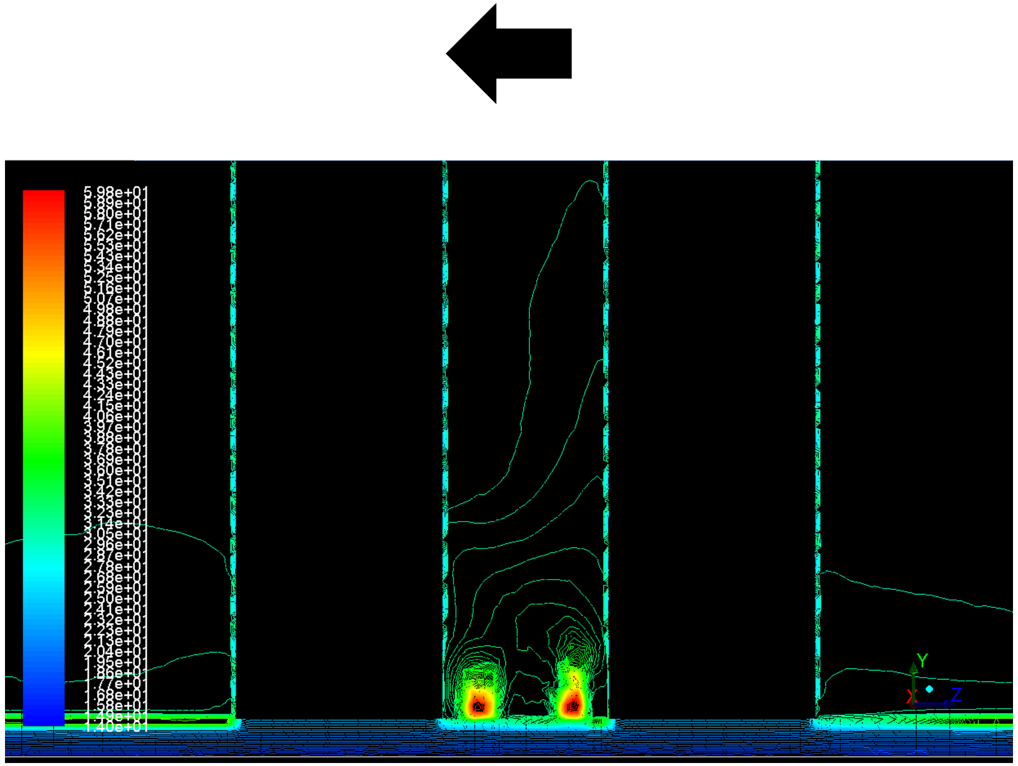


Perpendicular Flow (Plan)

PRELIMINARY STUDIES (CFD Simulation)

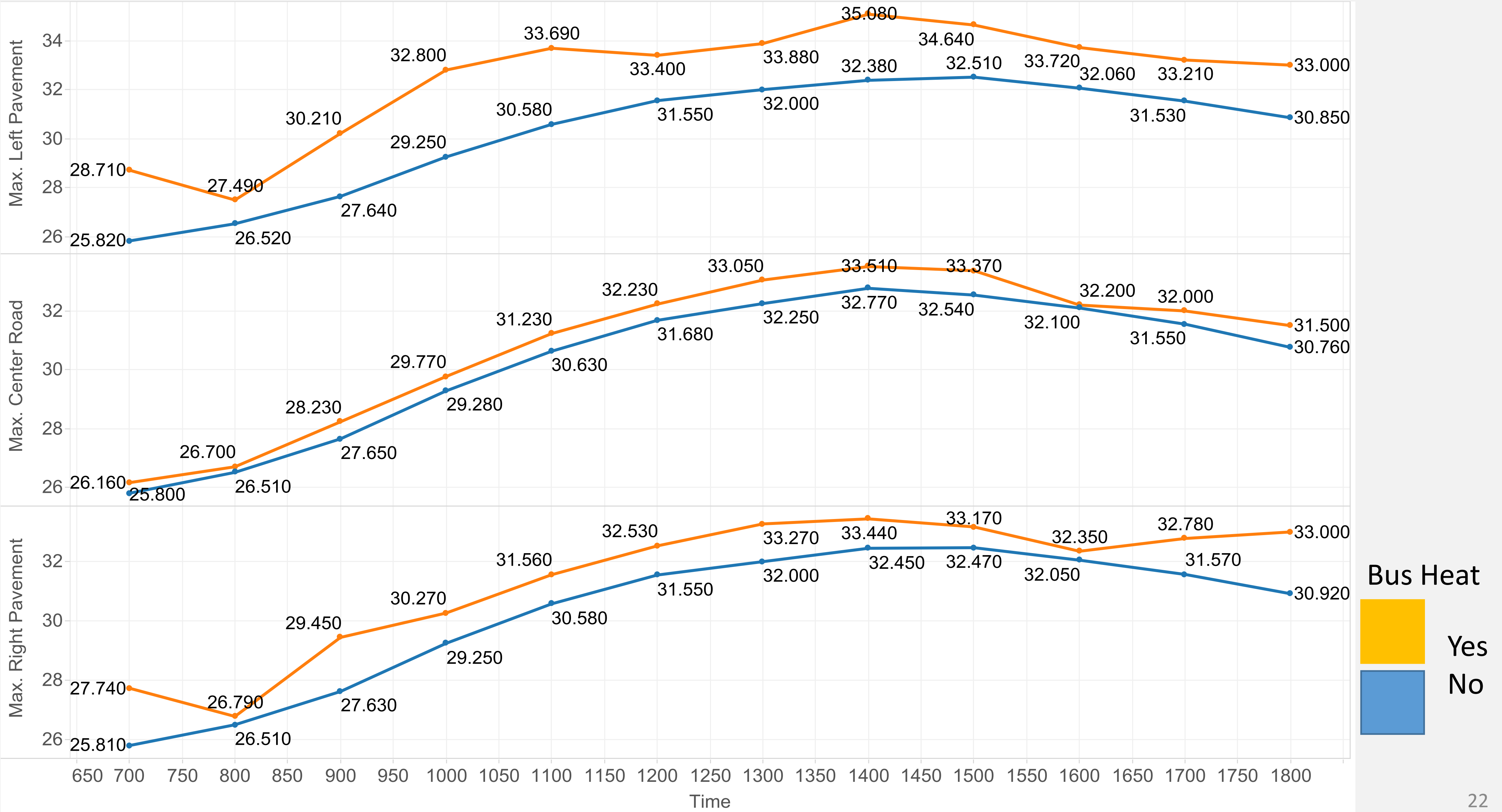


Parallel Flow (Left Elevation)



Perpendicular Flow (Left Elevation)

PRELIMINARY STUDIES (CFD Simulation)

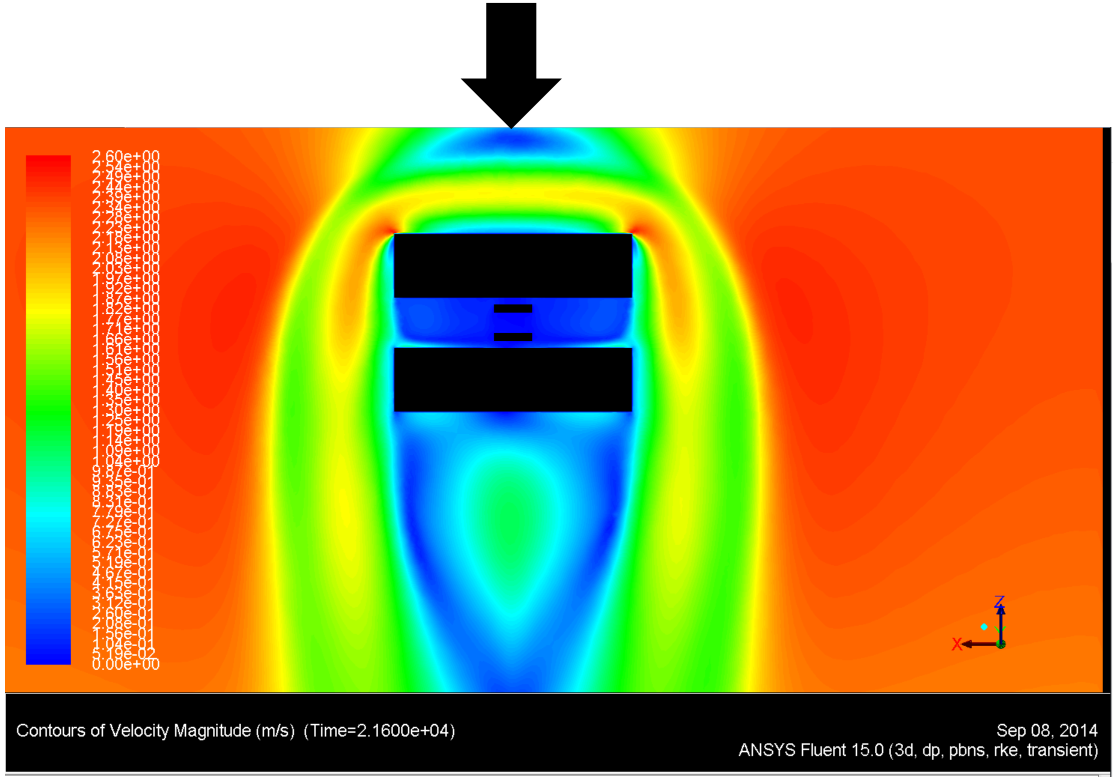


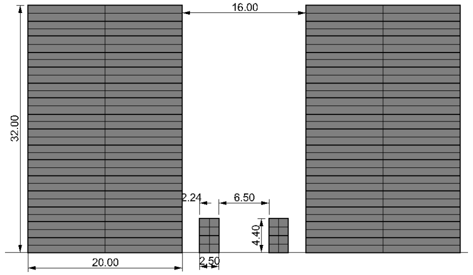
Without and with bus heat.

PRELIMINARY STUDIES (CFD Simulation)

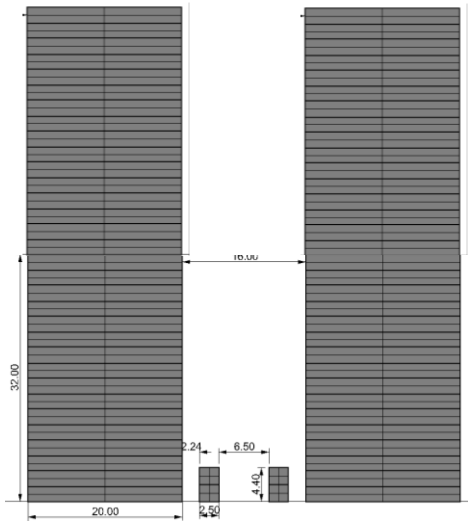
Density Comparison – Slab 8 stories VS. Slab16 stories perpendicular flows

Higher density (floors) is worse in terms of heat trap & low wind speed, heat trapped by recirculating zones
Lower density (floors) enables the heat to dissipate over the shallow canyon





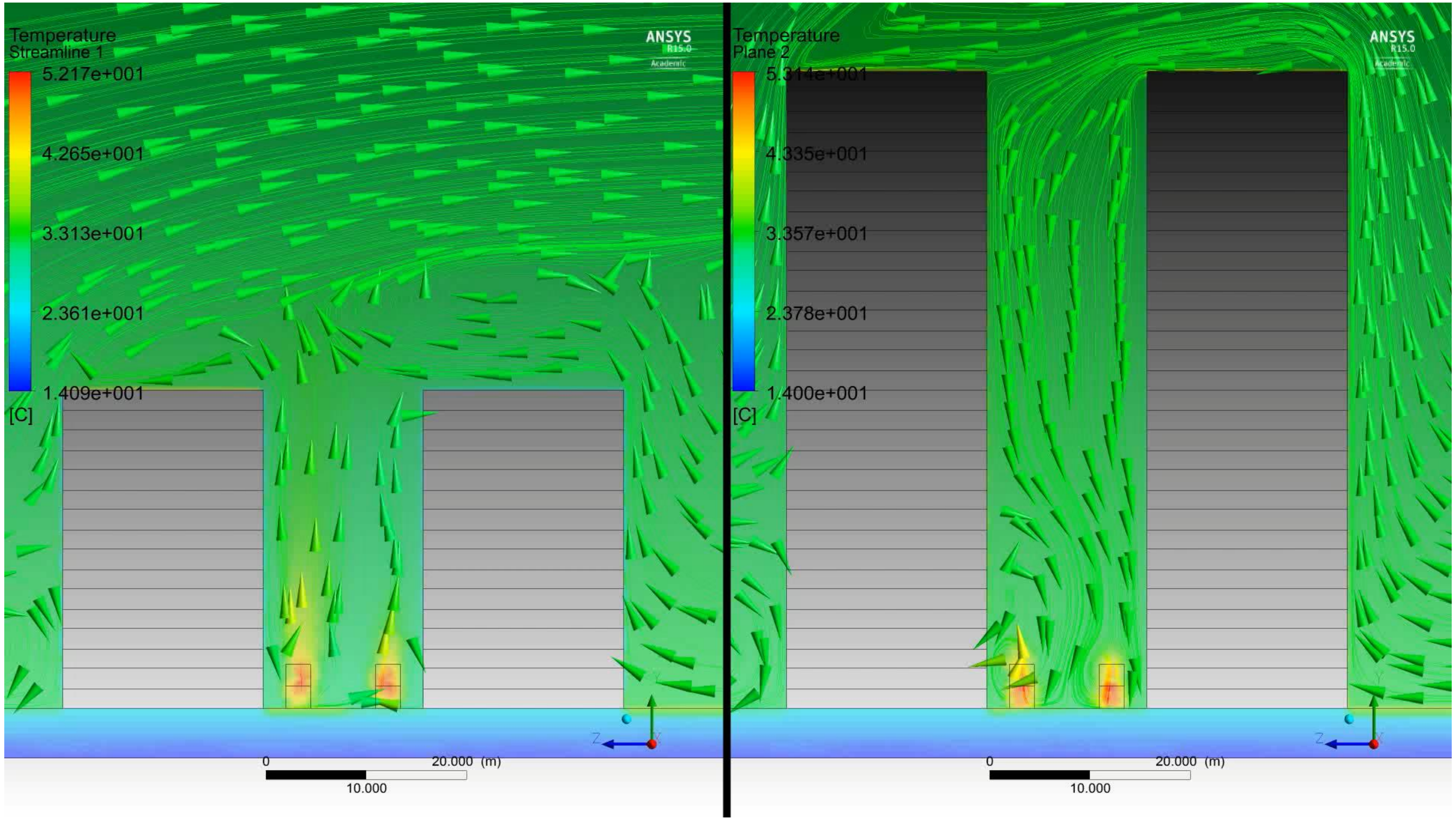
Slab 8 stories



Slab 16 stories

PRELIMINARY STUDIES (CFD Simulation)

Density Comparison for Perpendicular Flow (Section View)

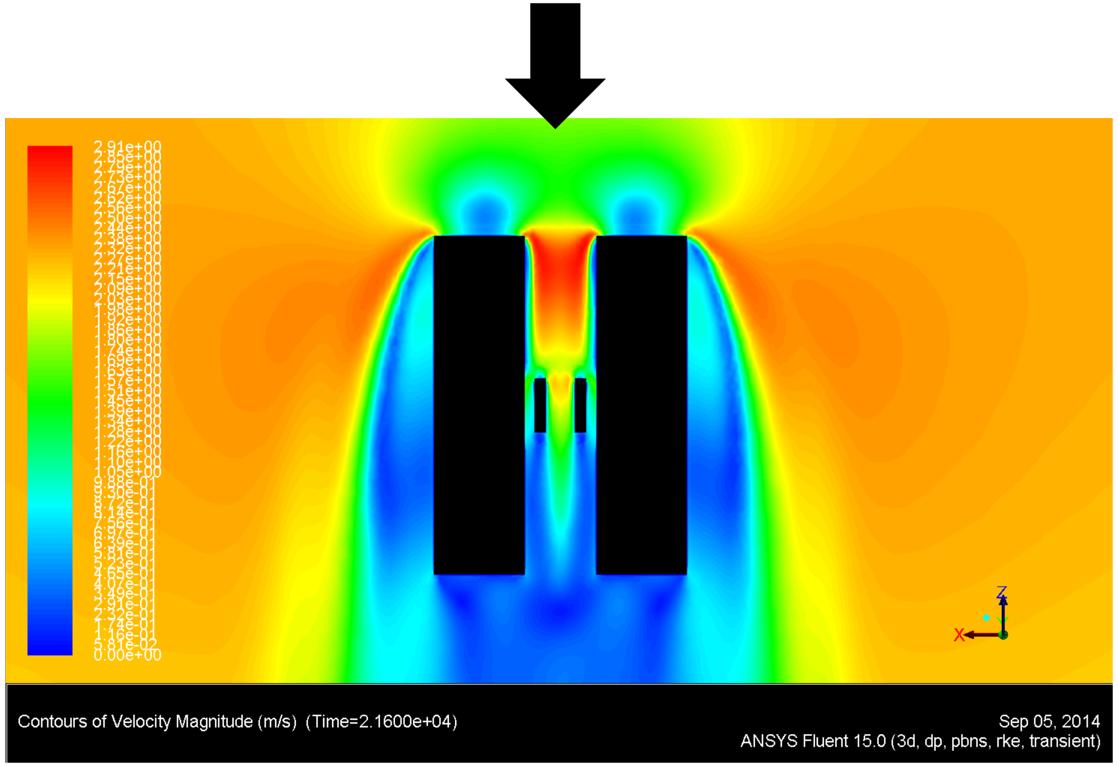


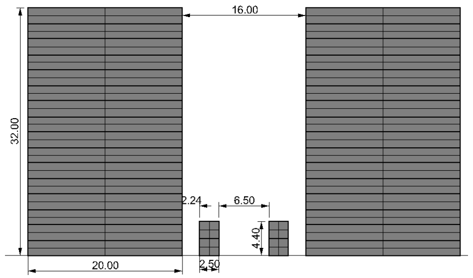
Slab 8 stories **VS.** **Slab 16 stories**

PRELIMINARY STUDIES (CFD Simulation)

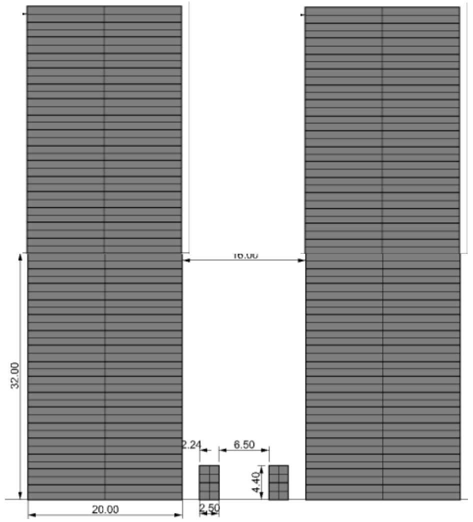
Density Comparison – Slab 8 stories VS. Slab 16 stories parallel flows

Higher density (floors) has better channeling effect (concentrated), higher wind speed, lower heat concentration
Lower density (floors) can also release heat but not as fast





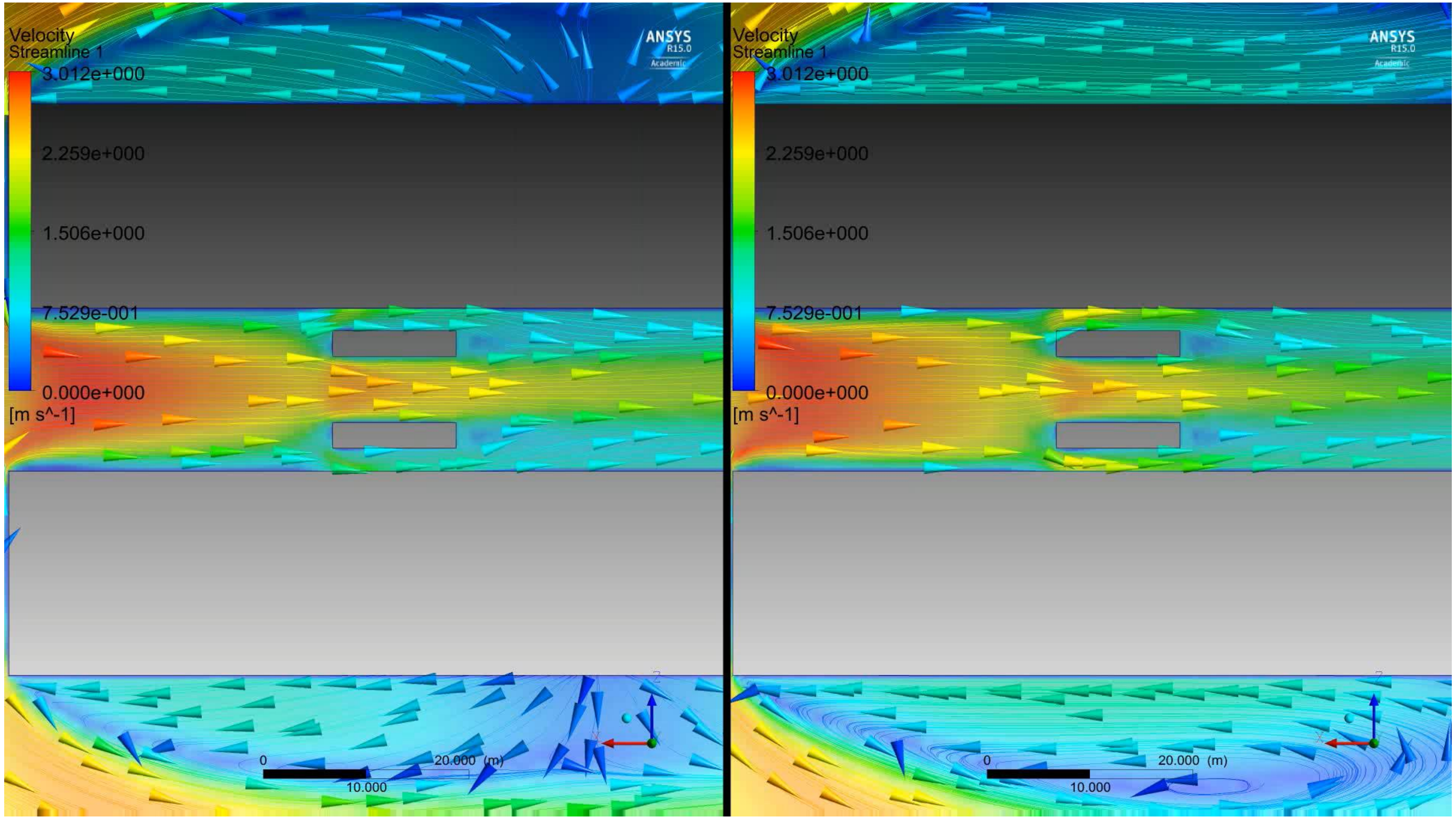
Slab 8 stories



Slab 16 stories

PRELIMINARY STUDIES (CFD Simulation)

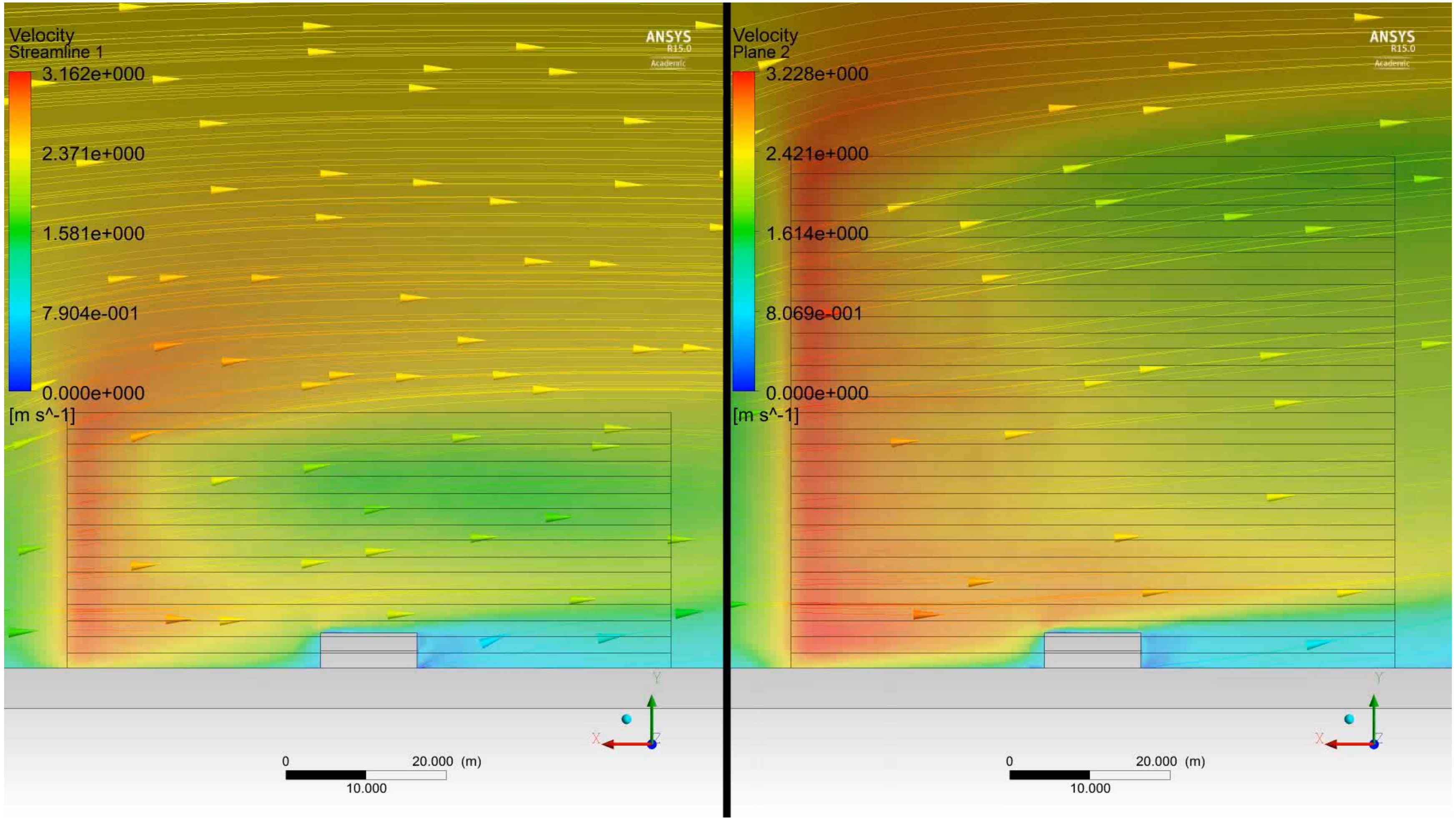
Density Comparison for Parallel Flow (Plan View)



Slab 8 stories **VS.** **Slab 16 stories**

PRELIMINARY STUDIES (CFD Simulation)

Density Comparison for Parallel Flow (Section View)

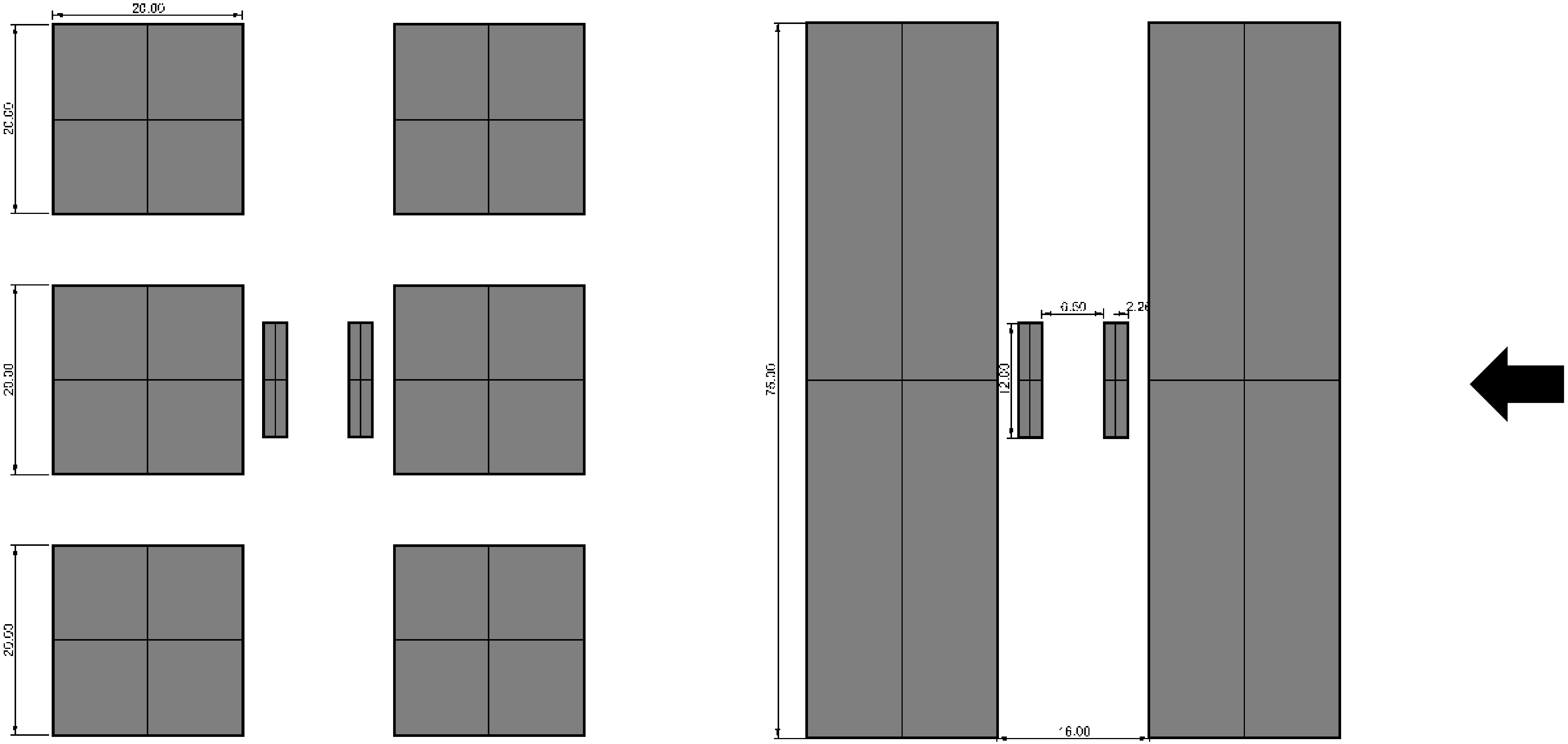


Slab 8 stories **VS.** **Slab 16 stories**

PRELIMINARY STUDIES (CFD Simulation)

Form Comparison – Slab 16 stories VS. Points16 perpendicular flows

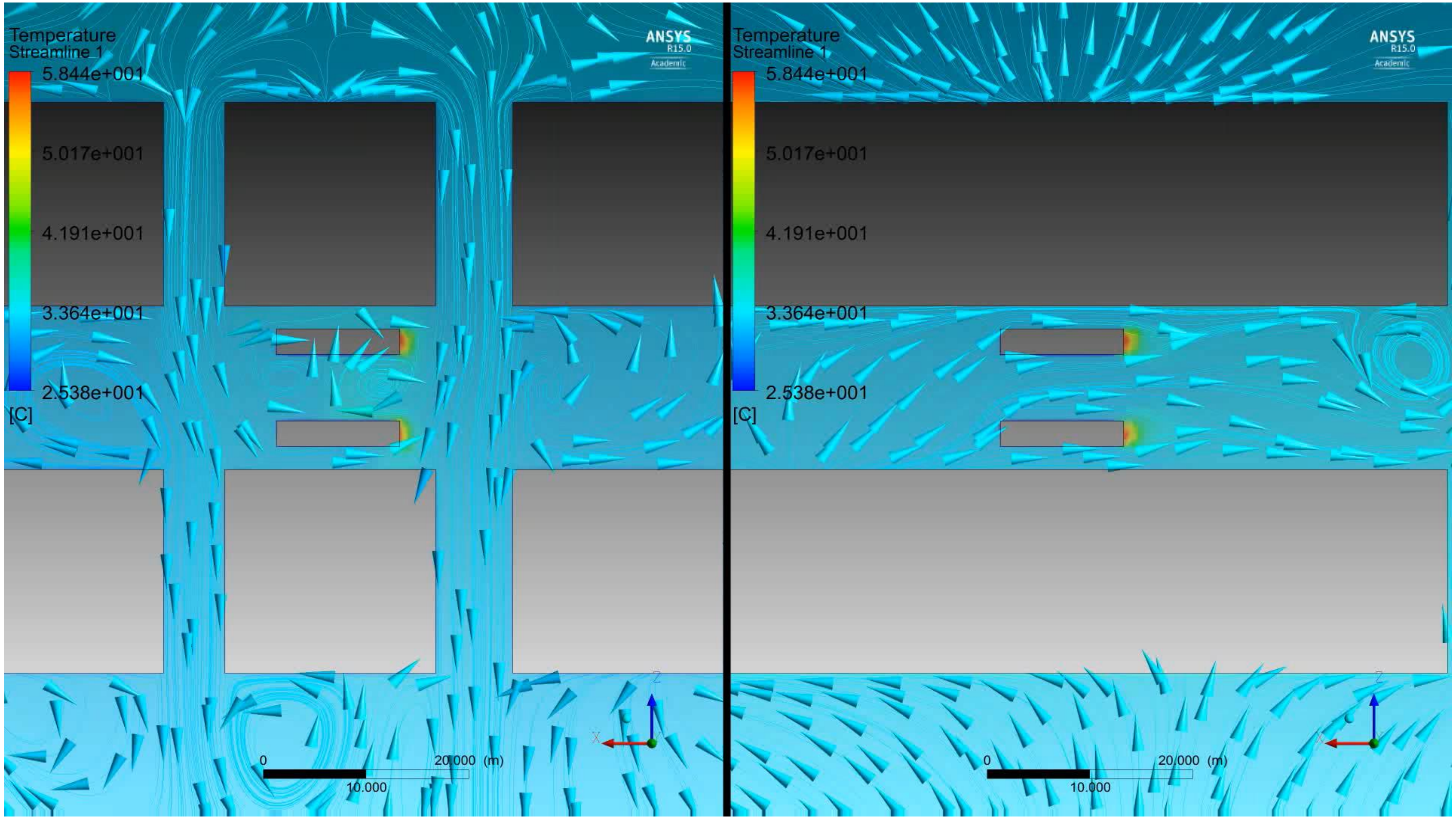
Points are better at dissipating heat and higher wind speed because of porosity



Points 16 stories **VS.** **Slab 16 stories**

PRELIMINARY STUDIES (CFD Simulation)

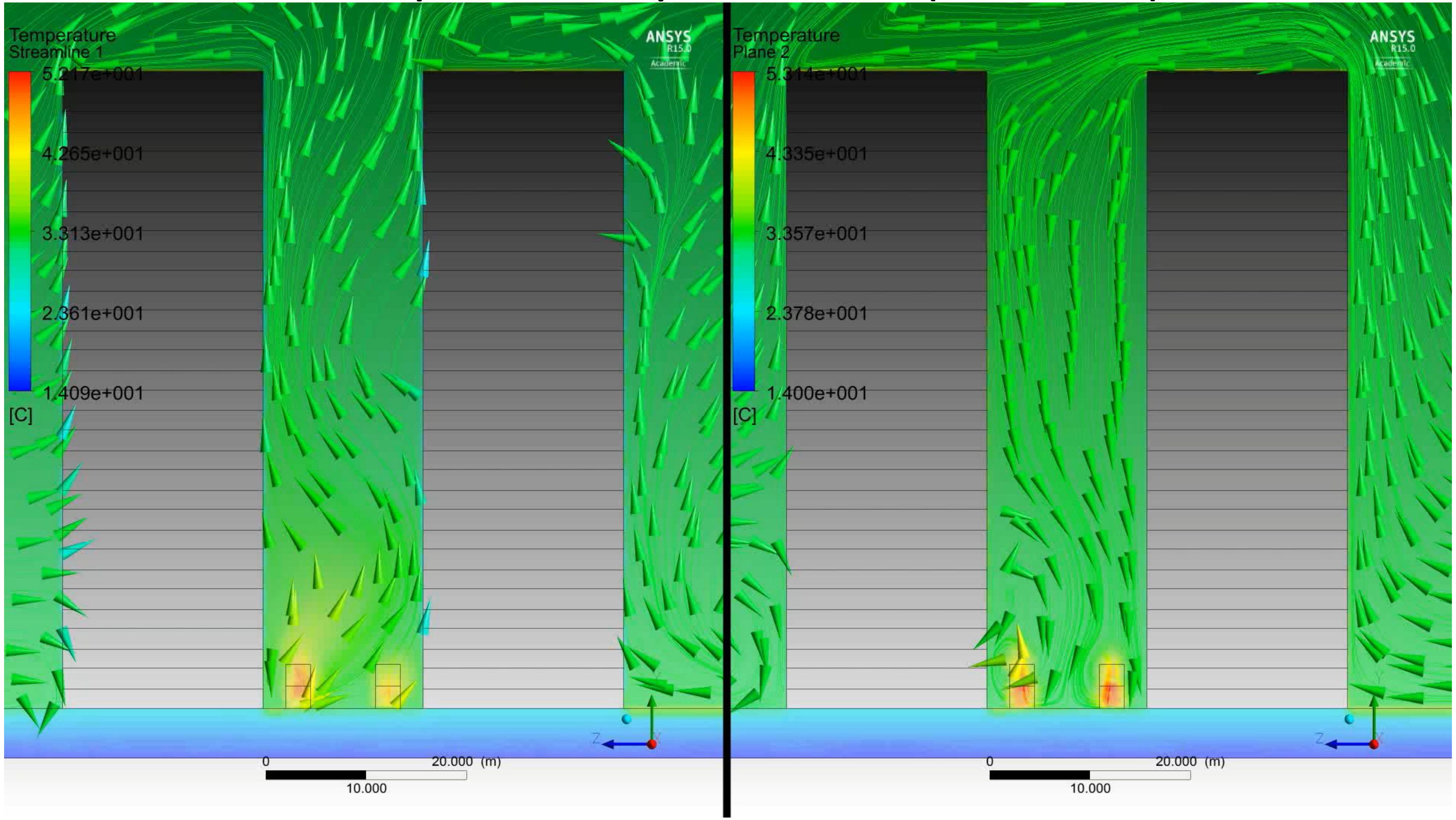
Form Comparison for Perpendicular Flow (Plan View)



Points 16 stories **VS.** **Slab 16 stories**

PRELIMINARY STUDIES (CFD Simulation)

Form Comparison for Perpendicular Flow (Section View)



Points 16 stories **VS.** **Slab 16 stories**

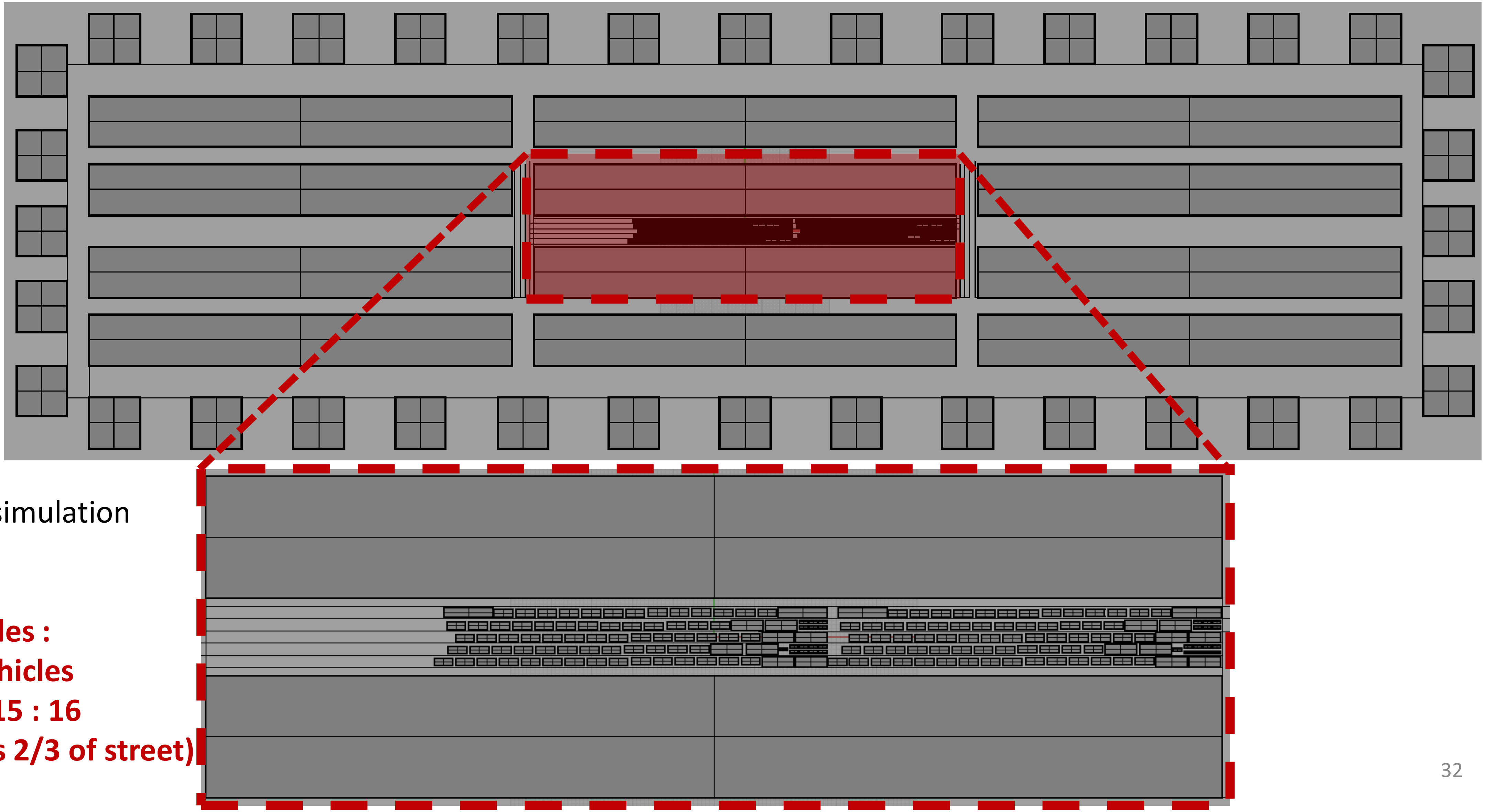
PRELIMINARY STUDIES (CFD Simulation)

Wind flow regulates the air temperature inside the canyon well by **parallel flow**. Higher H/W ratio receives better **channeling effect** causing **higher wind speed** and **more shading**.

Higher H/W ratio cases has **higher air temperature** and **lower wind speed** with for **perpendicular flow**.

If design **against predominant wind direction**, form permeability is more important while for design **with predominant wind direction**, density may help to create better urban ventilation.

FUTURE WORK (CFD Simulation)



Ratio for simulation

Cars :

Buses :

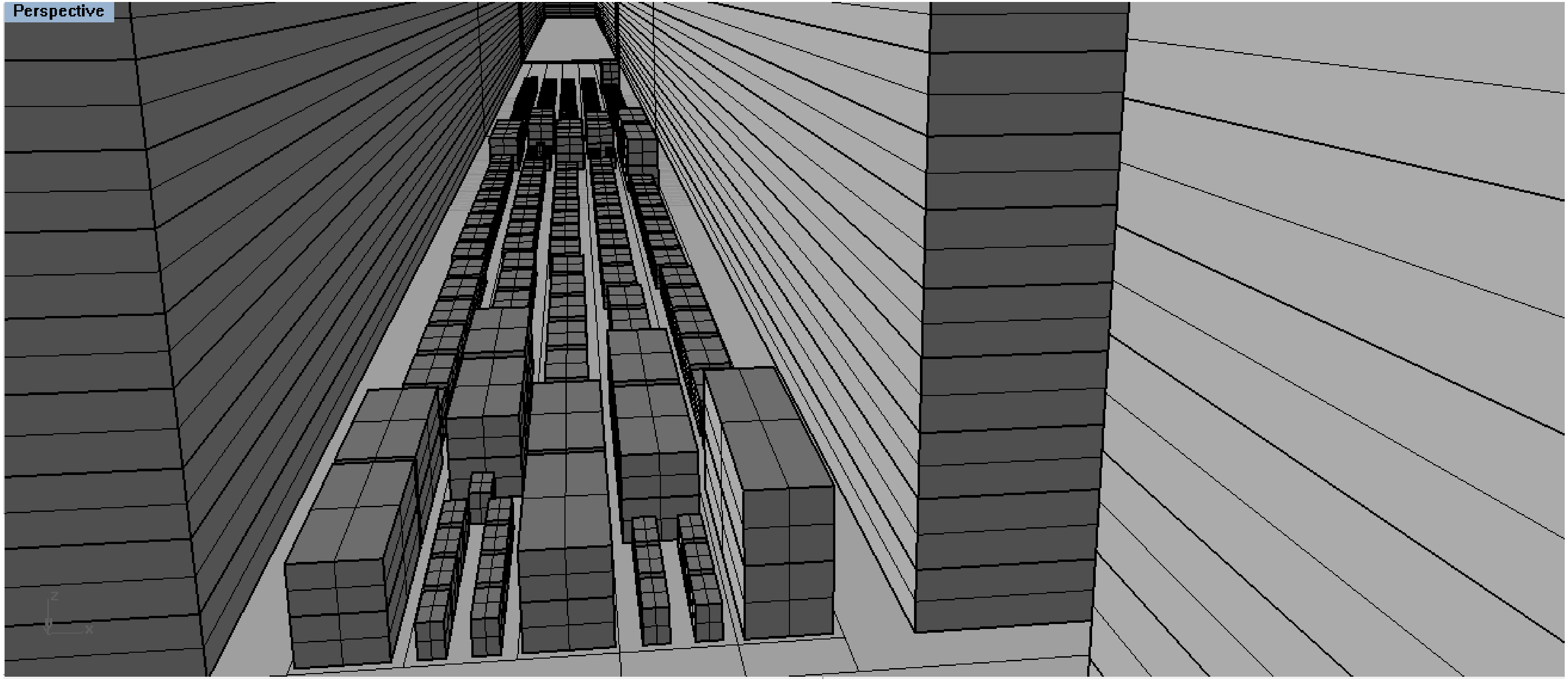
Motorcycles :

Goods Vehicles

= 67 : 2 : 15 : 16

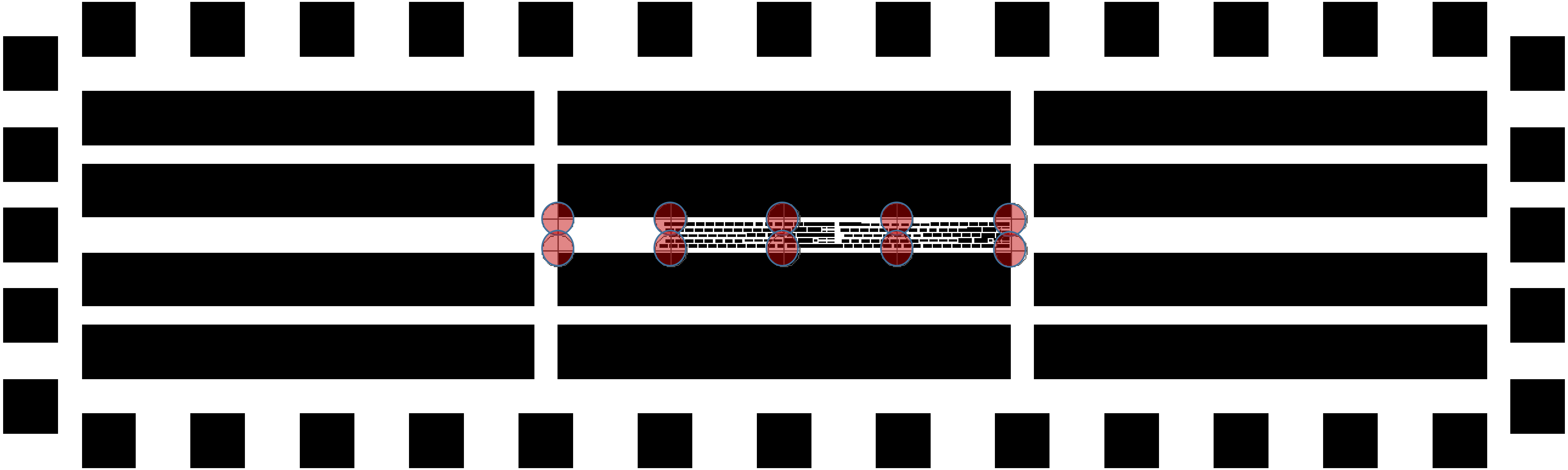
(*2 covers 2/3 of street)

FUTURE WORK (CFD Simulation)



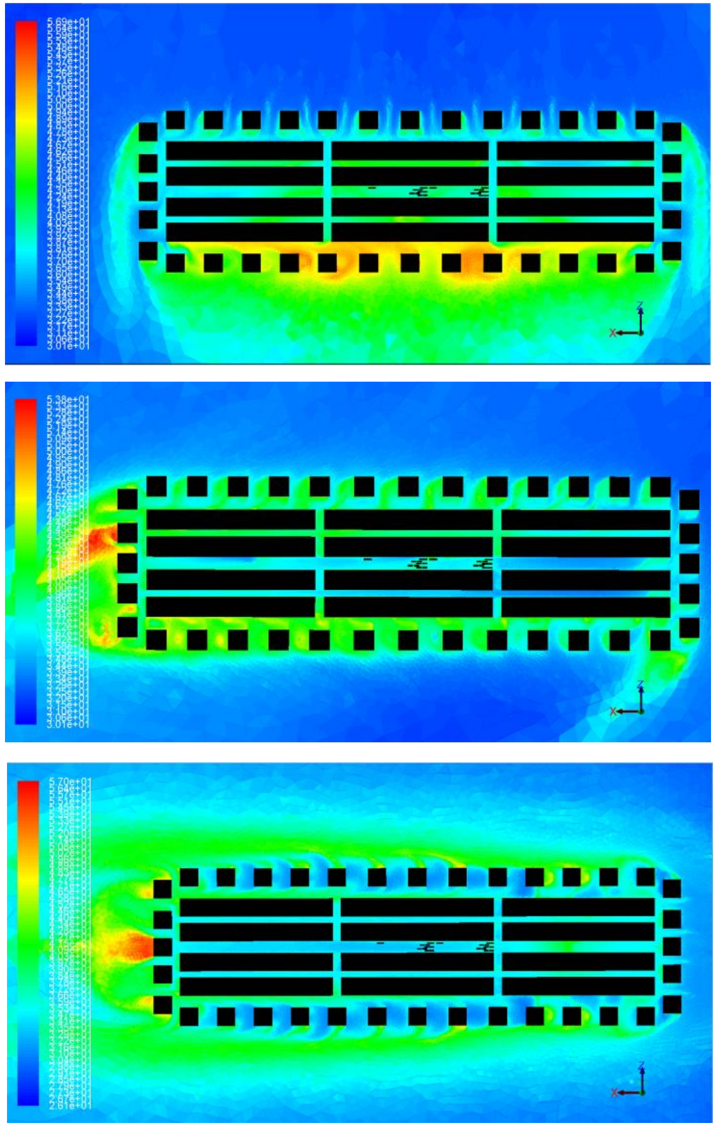
View of the 100 vehicles in the canyon – towards worst case scenario.

FUTURE WORK (CFD Simulation)

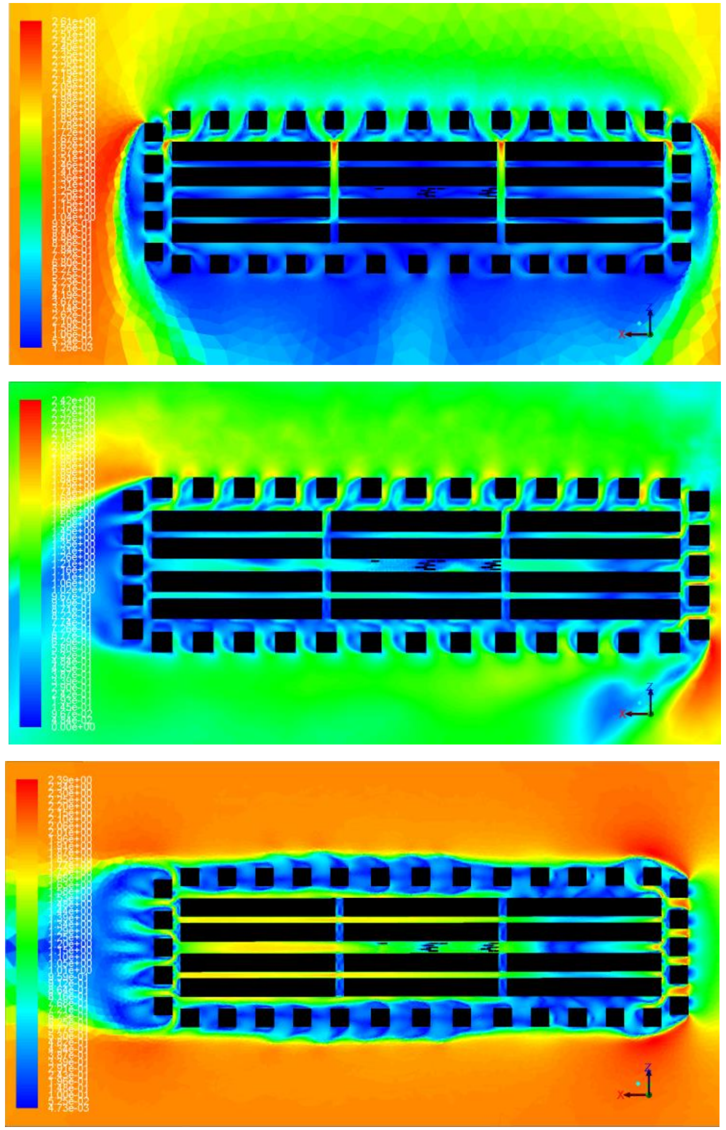


Air temperature, wind velocity values taken at 10 spots (5 on left pedestrian, 5 on right pedestrian) in the canyon.

FUTURE WORK (CFD Simulation)



Air Temperature



Wind Speed

North Wind Flow

Highest average canyon air temperature, lowest canyon wind velocity

North East Wind Flow

Medium average canyon air temperature, lowest canyon wind velocity

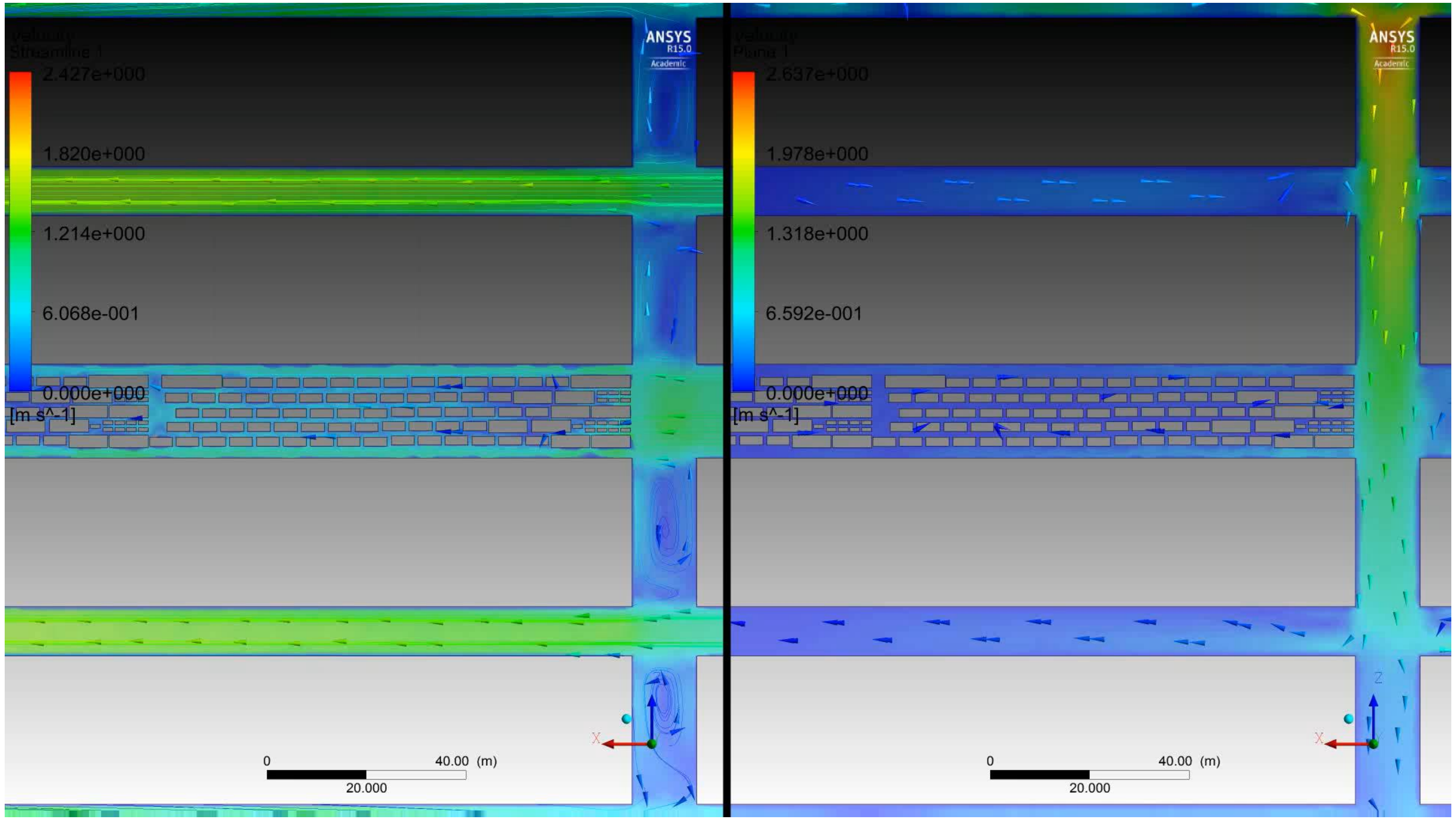
East Wind Flow

Lowest average canyon air temperature, lowest canyon wind velocity

FUTURE WORK (CFD Simulation)

Parallel VS. Perpendicular Flow Difference (Plan)

Parallel flow has higher wind speed, lower recirculating zones
Perpendicular flow has lower wind speed, higher temperature because of recirculating zones

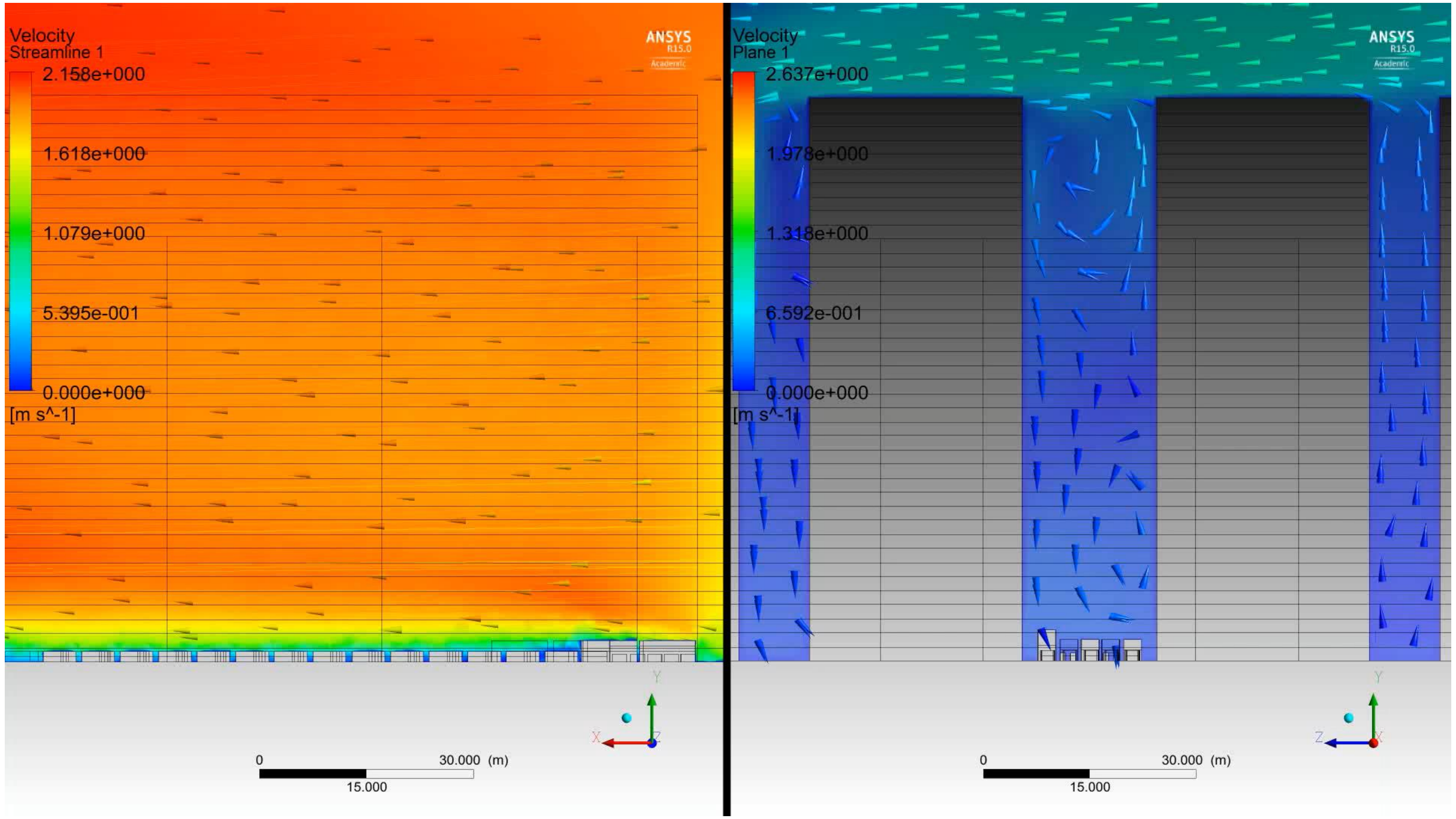


Parallel Flow VS. Perpendicular Flow

FUTURE WORK (CFD Simulation)

Parallel VS. Perpendicular Flow Difference (Section)

Parallel flow has higher wind speed, lower recirculating zones
Perpendicular flow has lower wind speed, higher temperature because of recirculating zones

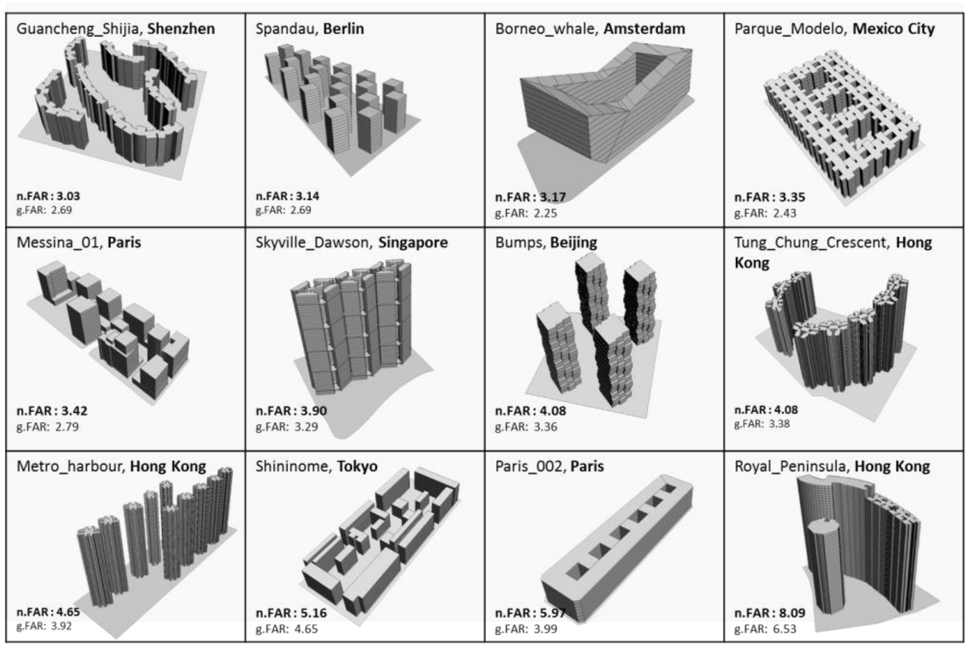


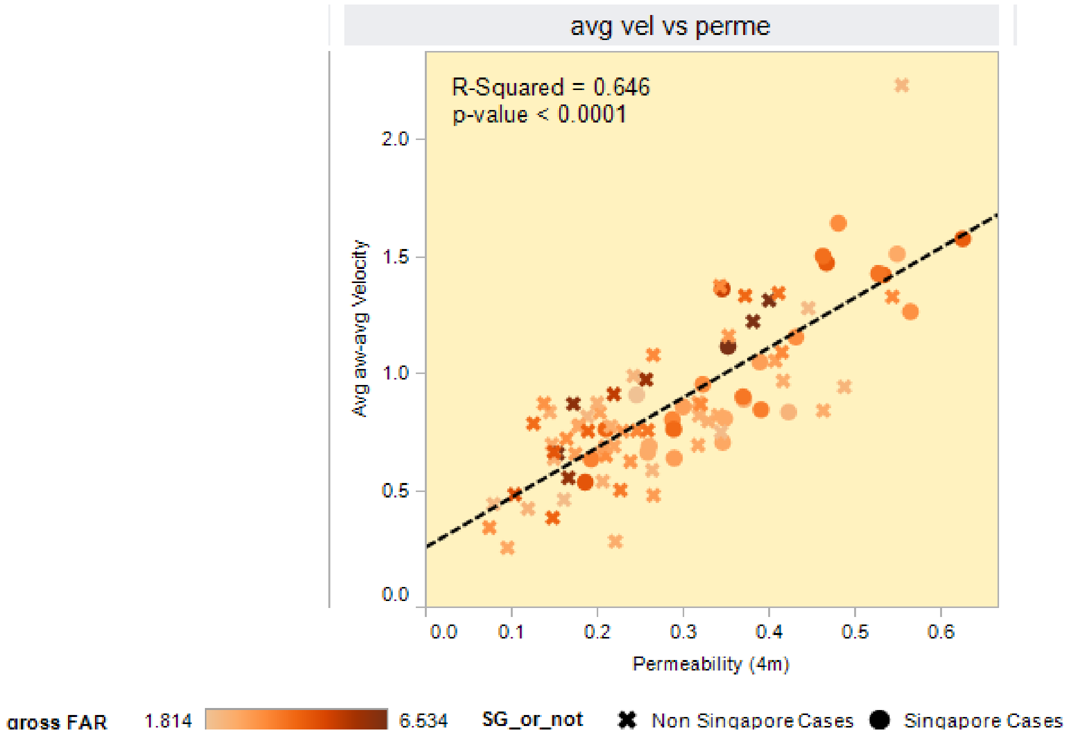
Parallel Flow VS. Perpendicular Flow

FUTURE WORK

Wind direction plays a major role in keeping the canyon air temperature low as demonstrated by the simulation, where the **parallel direction** gives the best performance (because of no obstruction).

Hence, the **porosity (especially at pedestrian height)** of the urban form will likely play a major role in determining how much heat can be transported out from the canyon.

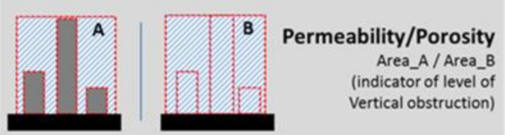


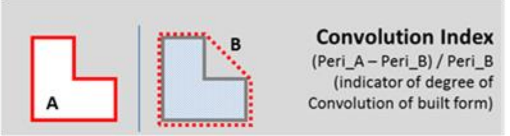
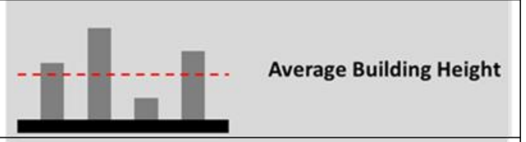


FUTURE WORK

Other urban morphologies / geometric variables will be explored together to find their correlations to urban ventilation and air temperature of pedestrian heigt.

Considering **EUI (Energy Use Intensity)** rejecting from building rooftops as well (QB).

For wind study only	• **Frontal Area Index** Frontal Area Index (FAI) is the ratio of total windward facade area to site area. It is an indicator of the roughness of the urban geometries.	
	• **Permeability** Permeability is the ratio of unobstructed area within the planar bounding rectangular defined by site boundary and maximum building height to the area of that bounding rectangular perpendicular to a given wind direction. It is an indicator of vertical obstruction regarding a given wind direction.	

• **Built Density** Built density is indicated by Floor Area Ratio (FAR), or Plot Ratio as used in other studies. It is calculated as the ratio of total usable floor area to site area.	
• **Site Coverage** Site coverage is another indicator of ground level building footprint coverage. It is calculated as the ratio of total building footprint area to site area.	
• **Open Space Ratio** Open Space Ratio (OSR) is an indicator of the amount of average shared open space. It is calculated as the ratio of total ground open space area to total usable floor area. (Berghauser & Haupt, 2009)	
• **Area-to-Perimeter Ratio** Area-to-perimeter ratio (APR) is an indicator of building depth. It is calculated as ratio of the area of the floor plane to the perimeter length of the floor plane.	
• **Compacity** Compacity is calculated as the ratio between building envelop area and building volume ($S_{envelop}/V_{building}^{2/3}$), which is an indicator of the compactness of a given building mass.	
• **Convolution Index** Convolution Index is calculated according to the formula below and it is an indicator of the degree of convolution of a given built form. (Leung, 2009) Convolution Index = ($Perimeter_A$-$Perimeter_B$)/ $Perimeter_B$	
• **Average Building Height** Average Building Height is an indicator of the average height of the built volumes.	

Key density and morphology variables.

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THANK YOU!

Q & A

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