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A study of heat transfer effects on air pollution dispersion in street canyons by numerical simulations

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MIMO

⇨3D, prognostic microscale model.

⇨Predicts air motion near building structures.

⇨Solves conservation equations for:

- Mass
- Momentum
- Scalar quantities like potential temperature, TKE & specific humidity

⇨Heating module calculates heat transfer through:

- Conduction
- Convection
- Radiation

MIMO validation (1/3)

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- vs. wind tunnel experiments of Rafailidis (1997) for the isothermal case (cf. Assimakopoulos, 2001)
- vs. field measurements of Panskus et.al. (2002) for the heated walls case
- vs. wind tunnel experiments of Bezpalcová (2003) for pollutants dispersion.

MIMO validation (2/3)

Windward wall heated case

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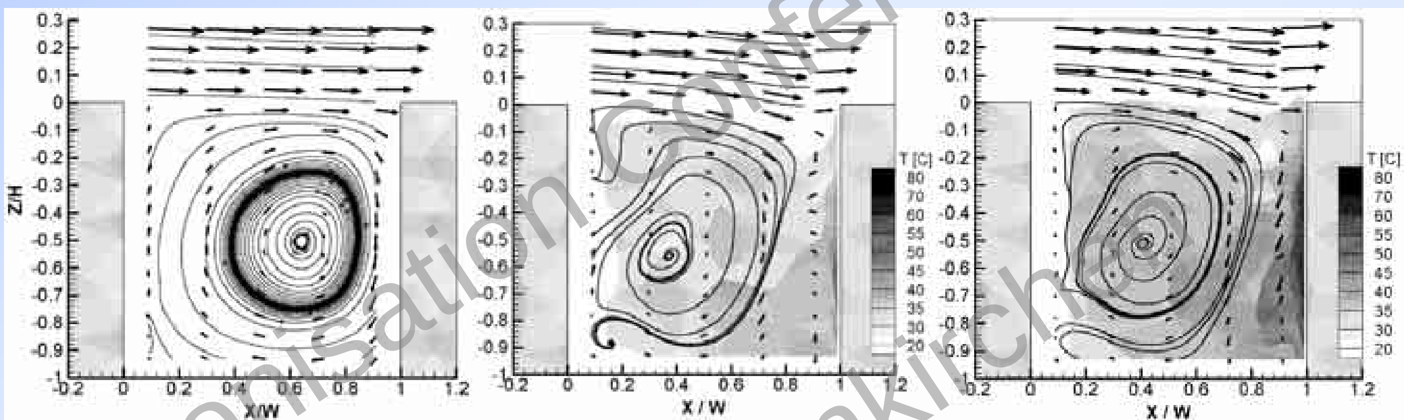
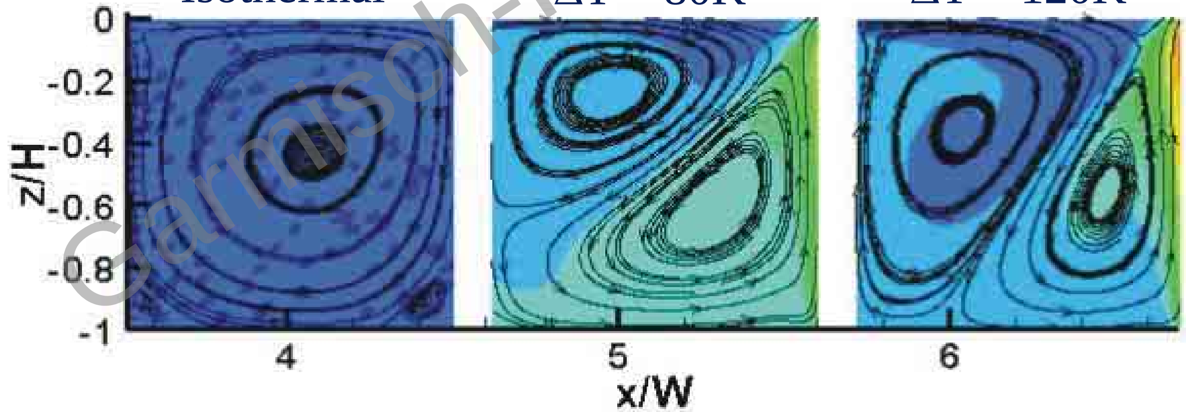
Field measurements results

Isothermal	ΔT = 80K	ΔT = 120K



MIMO model results

Isothermal	ΔT = 80K	ΔT = 120K



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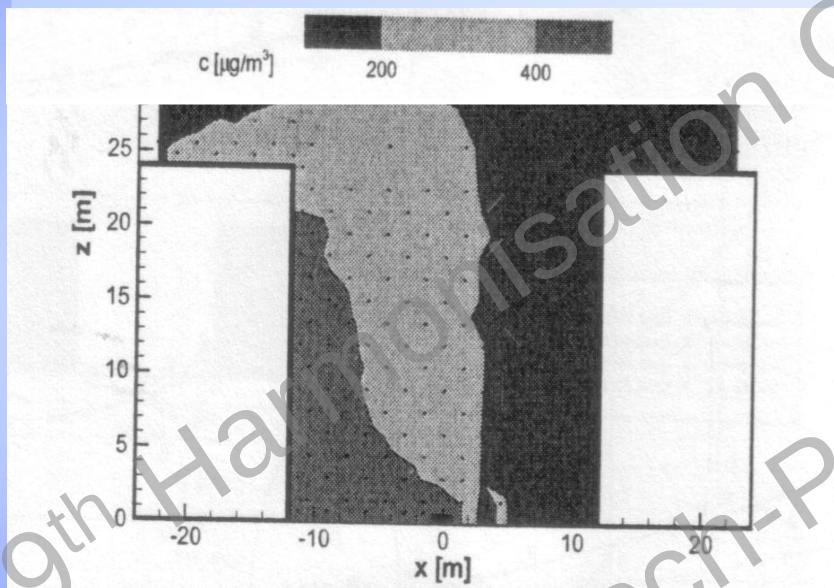
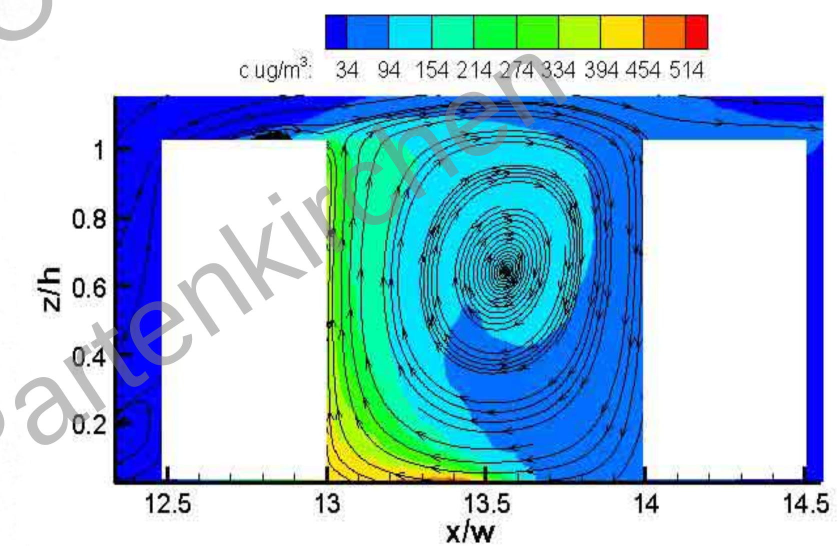
MIMO validation (3/3)

Pollutant dispersion case





Wind tunnel results

MIMO model results

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Current study

⇨ Effect of heated street canyon walls on the dispersion of pollutants is considered.

⇨ Heat transfer from the street canyon walls to the air through convection based on the heat transfer coefficient α.

⇨ Heat transfer coefficient α calculated by:

$$\alpha = \frac{|Q_f|}{(T_0 - T_\infty)} = \frac{\rho c_p |u_* \theta_*|}{(T_0 - T_\infty)}$$

- u_* is the friction velocity
- θ_* is the surface layer temperature scale

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- ⇨ **Simulations in 2D were performed for street canyons with aspect ratios of 0.33, 1.0 & 2.0**
- ⇨ **For all aspect ratios:**
  - ➢ **Either the leeward or the windward wall was heated**
  - ➢ **ΔT between heated wall and ambient air assumed at:**
    - **a) 0 K (Isothermal case)**
    - **b) 5 K**
    - **c) 10 K**
    - **d) 15 K**
- ⇨ **Current discussion focuses on the isothermal case and the cases of (leeward or windward) heating by 15K**
- ⇨ **Results of MIMO compared with those of TASCflow.**

Assumed boundary conditions:

⇨**Inlet power law wind profile with U_δ=5 m/s**

⇨**Surface layer height δ = 100 m**

⇨**Roughness length z_o = 0.05m**

⇨**Inflow turbulence intensity = 0.03**

⇨**Mass flow of passive pollutants Qs = 1.5mg/s**

⇨**Turbulence model: standard k-ε with standard wall functions**

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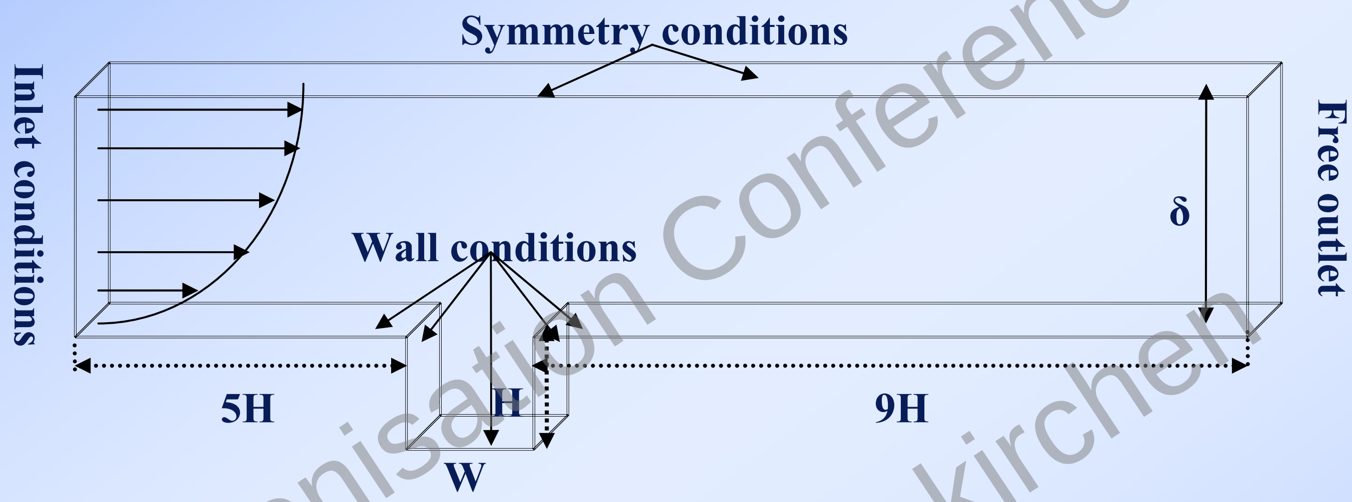
Same computational domain used for all cases



⇨ Grid size

- ➢ Aspect ratio 0.33 142×115 cells
- ➢ Aspect ratio 1.0 167×115 cells
- ➢ Aspect ratio 2.0 207×115 cells

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⇨Results obtained for

- **In-street canyon flow & concentration field**
- **Calculated concentration across the street canyon at Y/H 0.15, 0.5 & 1.0**
- **Non dimensional values of the calculated concentration obtained:**

$$C^* = CU_\delta H / \left(Q_s / L\right)$$

- ***C**** **is the non-dimensional concentration**
- ***C*** **is the calculated inert pollutant concentration**
- U_δ **is the reference wind velocity**
- ***H*** **is the height of the street canyon**
- Q_s ***is*** **the mass flow of the passive pollutants**
- ***L*** **is the characteristic length of the source**

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Aspect ratio 0.33, isothermal case

⇨MIMO predicts a system of two counter rotating vortices.

⇨TASCflow predicts a system of three vortices with adjacent ones rotating in opposite directions.

⇩

➢MIMO: maximum concentrations near the windward side

➢TASCflow: maximum concentrations near the leeward side

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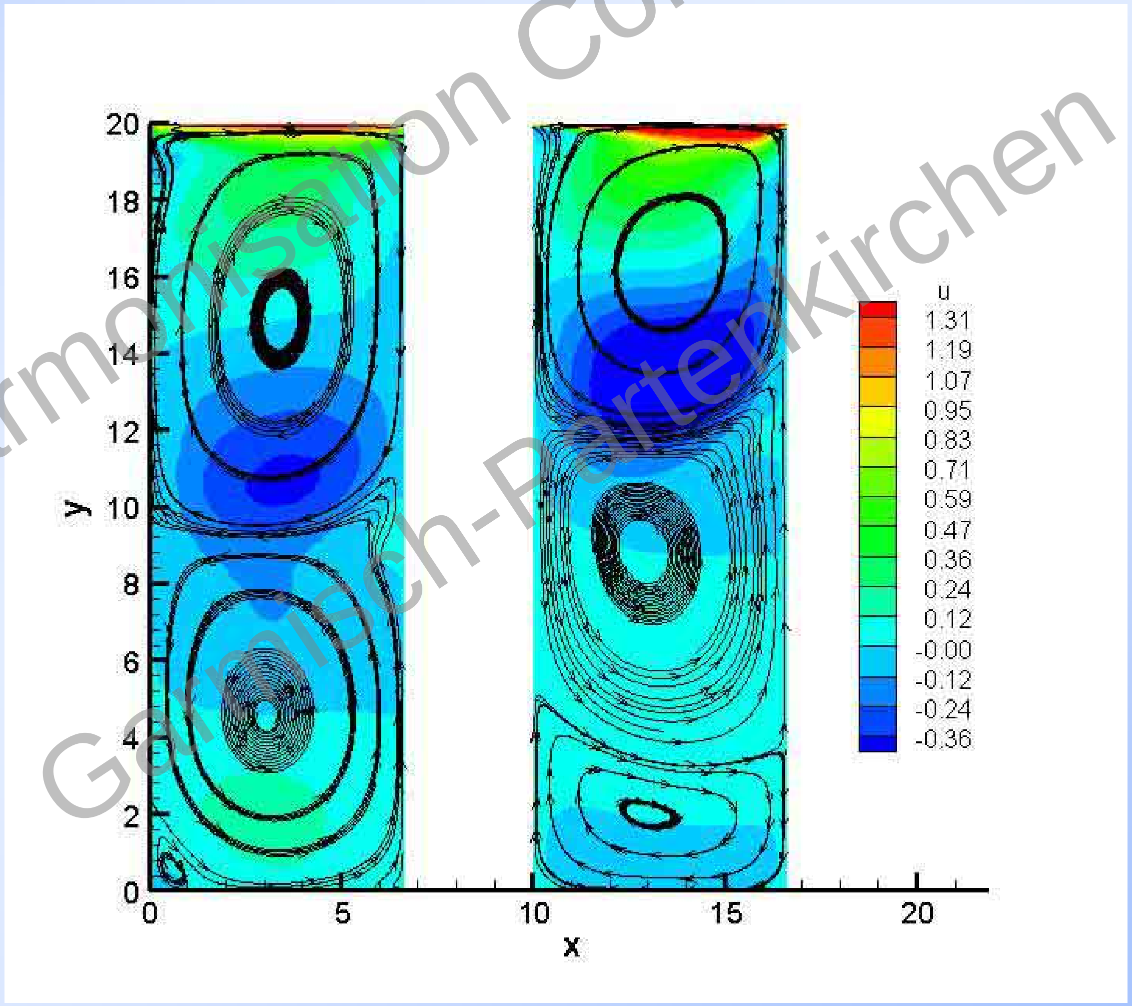
Flow field comparison for aspect ratio 0.33 for the isothermal case

(a) MIMO *(b) TASCflow*



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Aspect ratio 0.33, leeward wall heated (ΔT = 15K)

⇨Both codes predict a system of three vortices:

- ➢One large primary vortex
- ➢Two small ones at the lower part of the street canyon

⇨Disagreement between MIMO & TASCflow regarding the size of the vortices:

- ➢MIMO predicts a much smaller vortex near the leeward wall side than TASCflow

➢MIMO: relatively equal concentrations near the two wall sides

➢TASCflow: maximum concentration near the windward wall side

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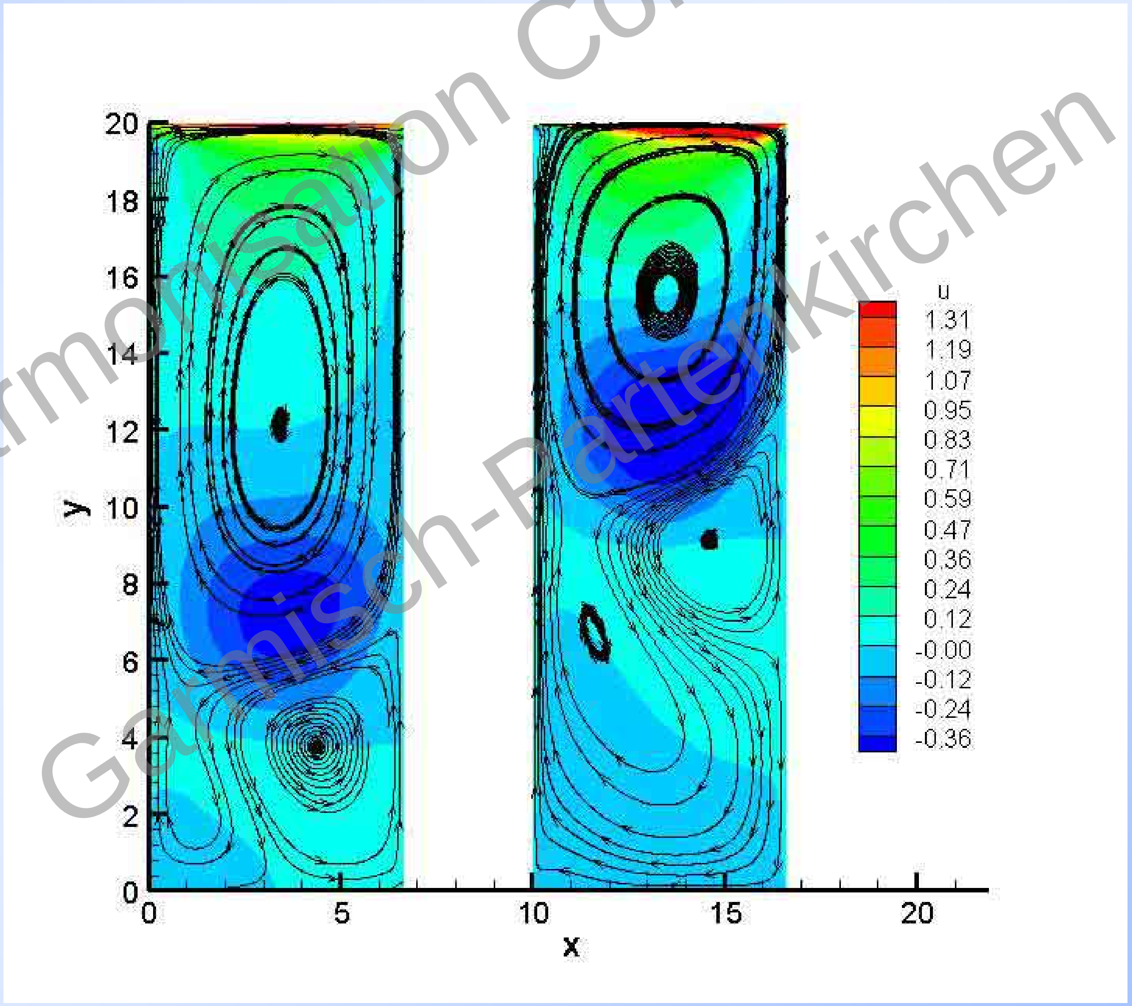
Flow field comparison for aspect ratio 0.33 with the leeward wall heated, for ΔT = 15K

(a) MIMO *(b) TASCflow*



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Aspect ratio 0.33, windward wall heated (ΔT = 15K)

⇨ MIMO predicts a system of three vortices:

- One vortex near the roof level
- One large, centrally located vortex
- One small at the lower part of the street canyon

⇨ TASCflow predicts a system of two counter rotating vortices:

- One near the roof level
- One large vortex covering ~75% of the total street canyon area

➢ MIMO: maximum concentrations near the leeward side while TASCflow near the windward side

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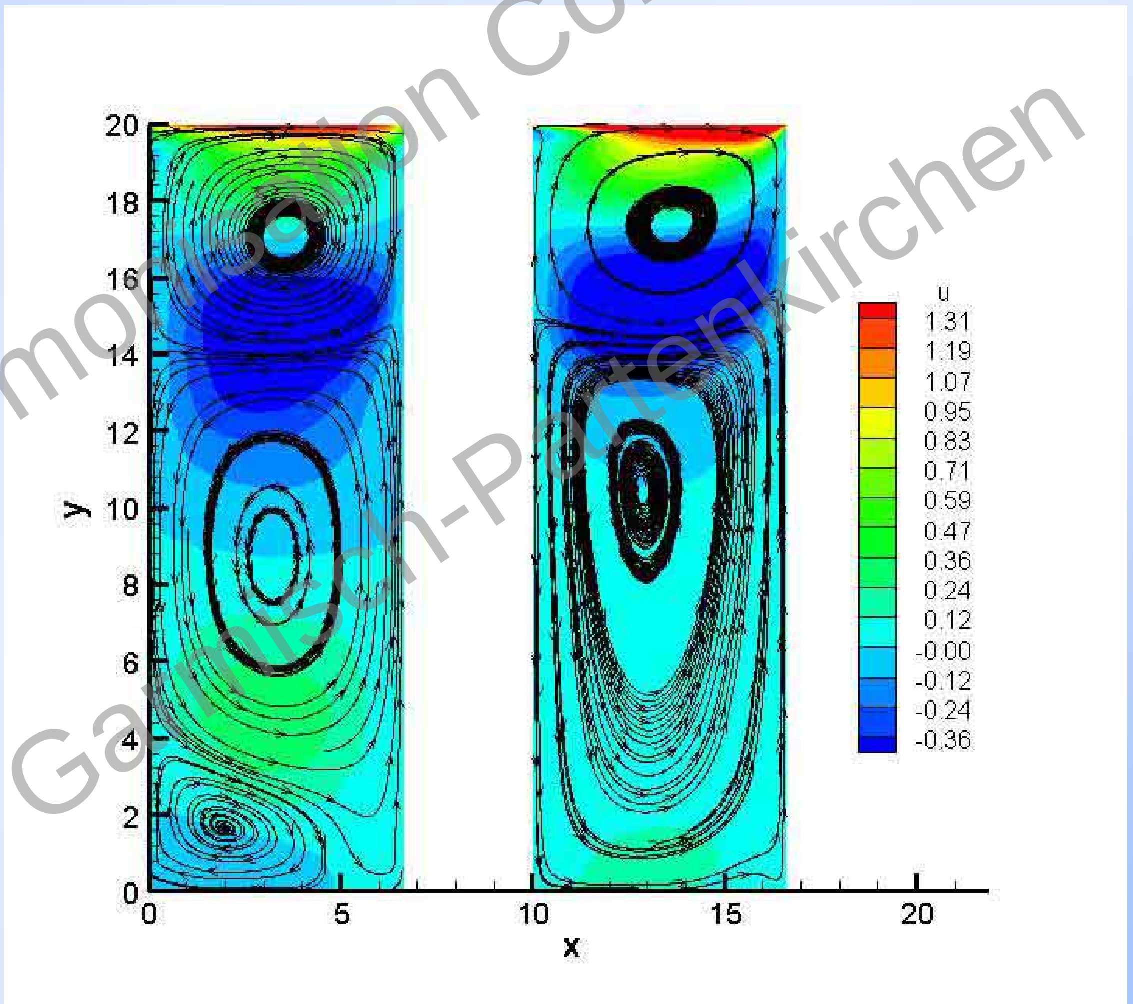
Flow field comparison for aspect ratio 0.33 with the windward wall heated, for ΔT = 15K

(a) MIMO *(b) TASCflow*



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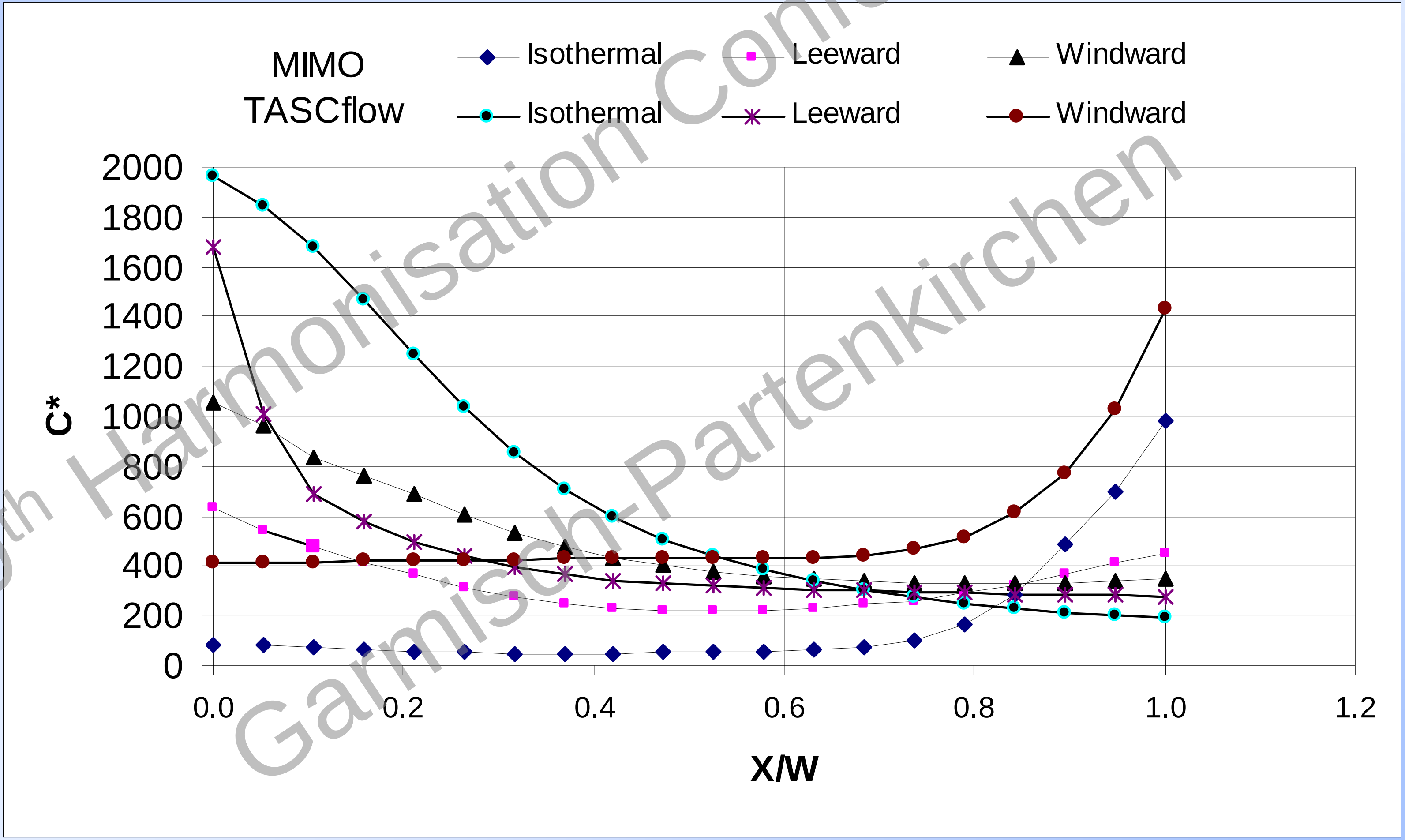
Calculated dimensionless concentration across the street canyon for aspect ratio 0.33

(a) **Y/H=0.15**



Calculated dimensionless concentration across the street canyon for aspect ratio 0.33

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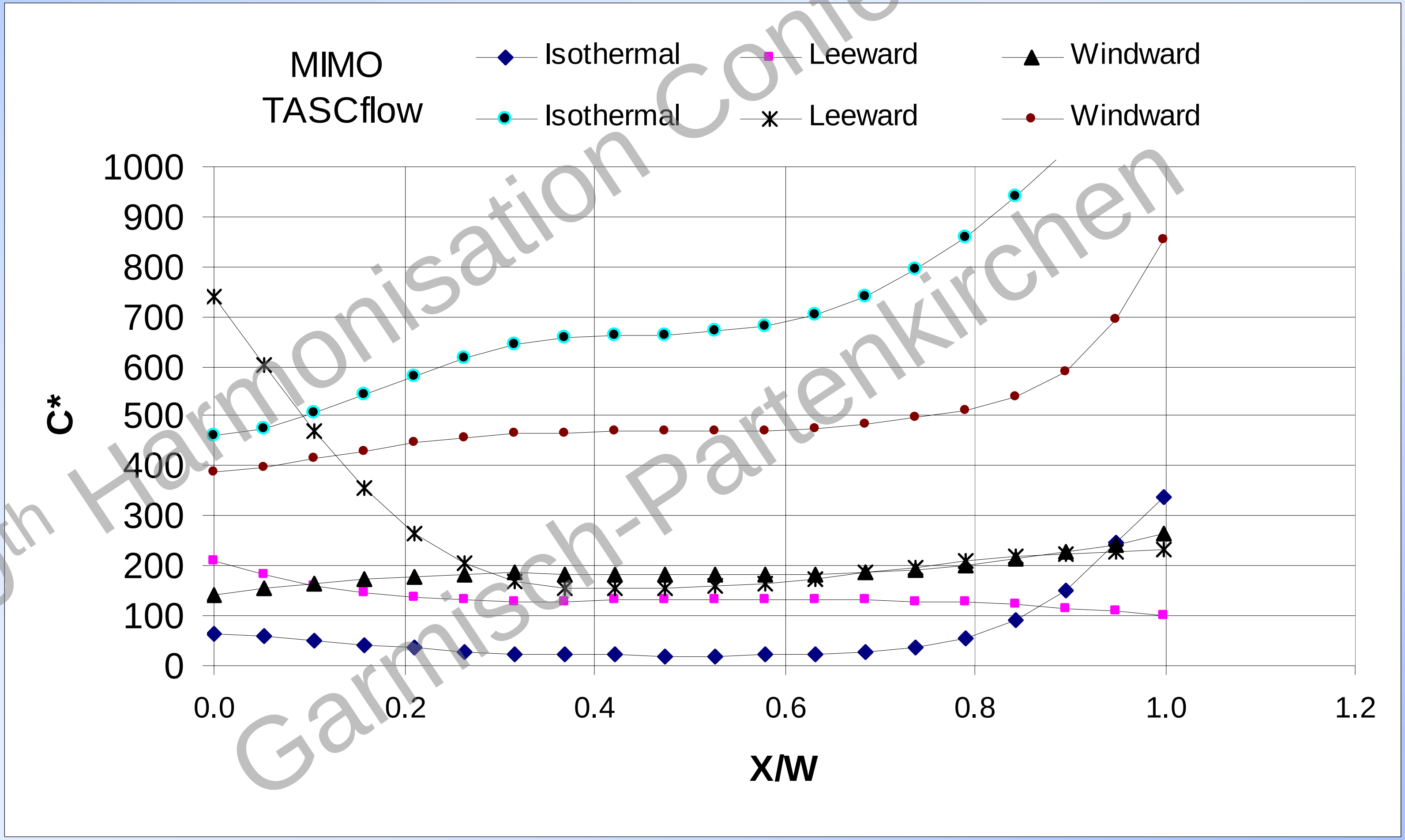
(b) **Y/H=0.5**



Calculated dimensionless concentration across the street canyon for aspect ratio 0.33

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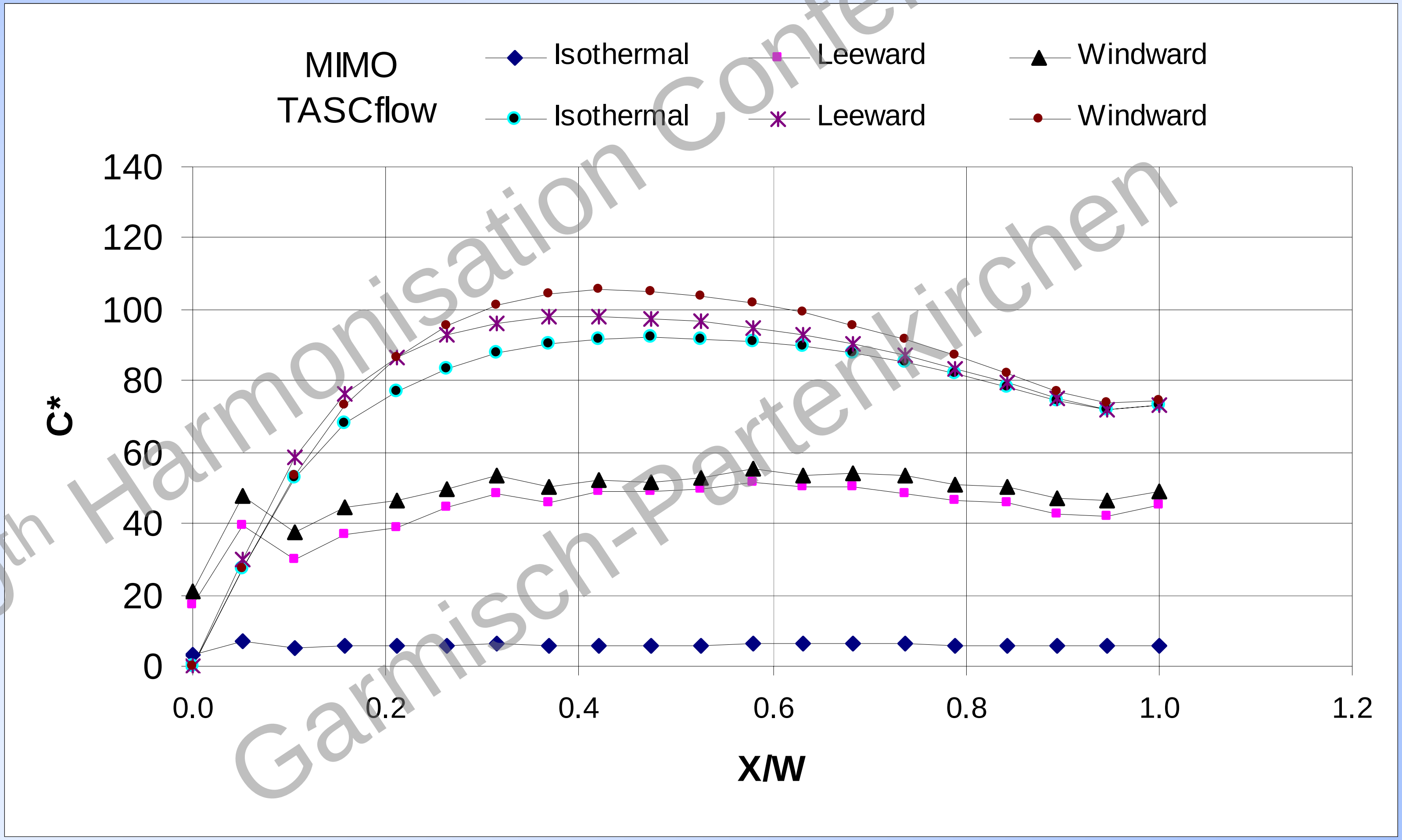
(c) Y/H=1.0



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Aspect ratio 1.0

⇨ The flow fields predicted by both codes are in good agreement

- ➢ One centrally located vortex
- ➢ Two small ones at the street canyon ground level near each of the building walls

⇨ For all cases for $Y/H \leq 0.5$, both codes predict maximum concentrations near the leeward side

⇨ For $Y/H = 1.0$ both codes predict maximum concentrations near the windward side

⇨ Heat transfer phenomena do not affect markedly the flow field

⇨ Calculated concentrations increase when either the leeward or the windward wall is heated

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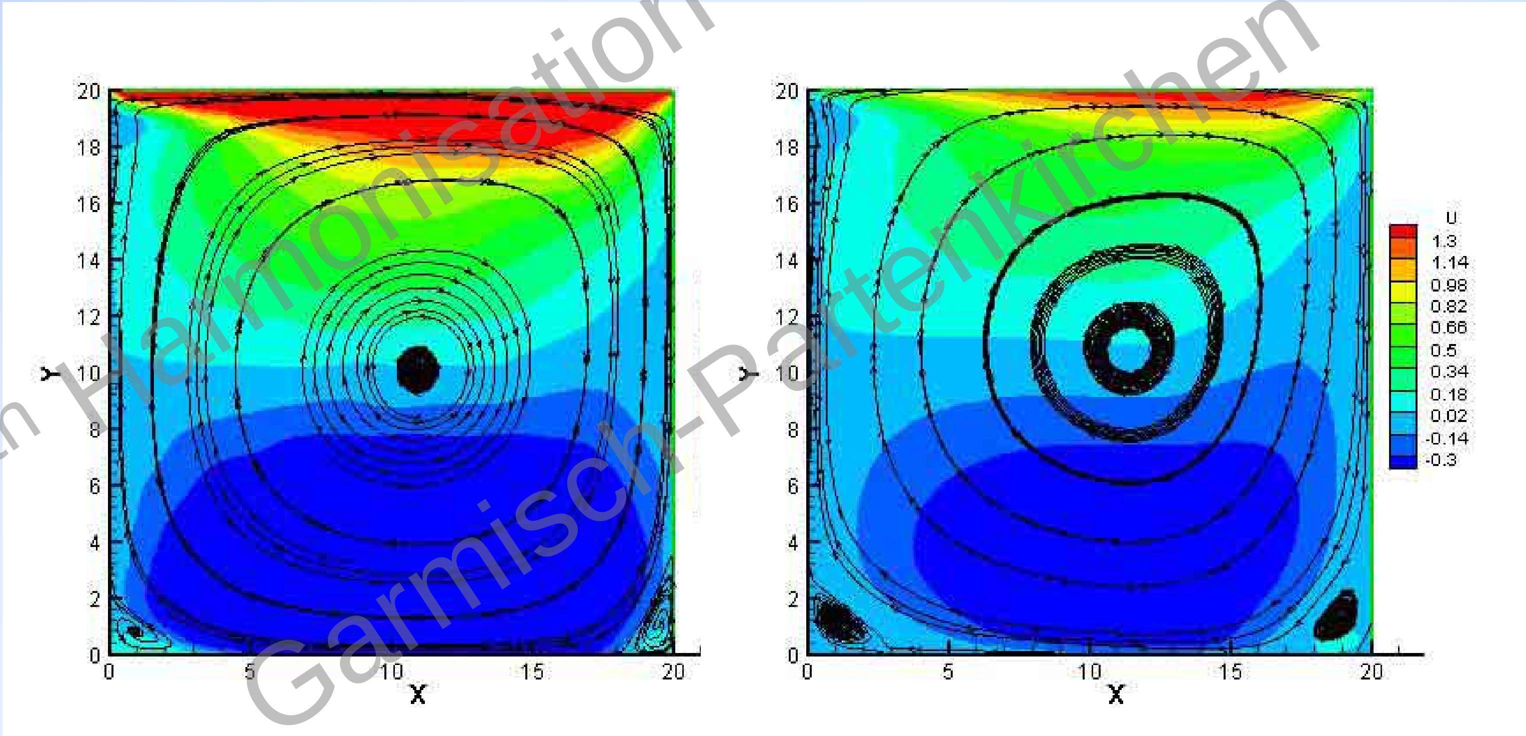
Flow field comparison for aspect ratio 1.0 for the isothermal case

(a) MIMO *(b) TASCflow*



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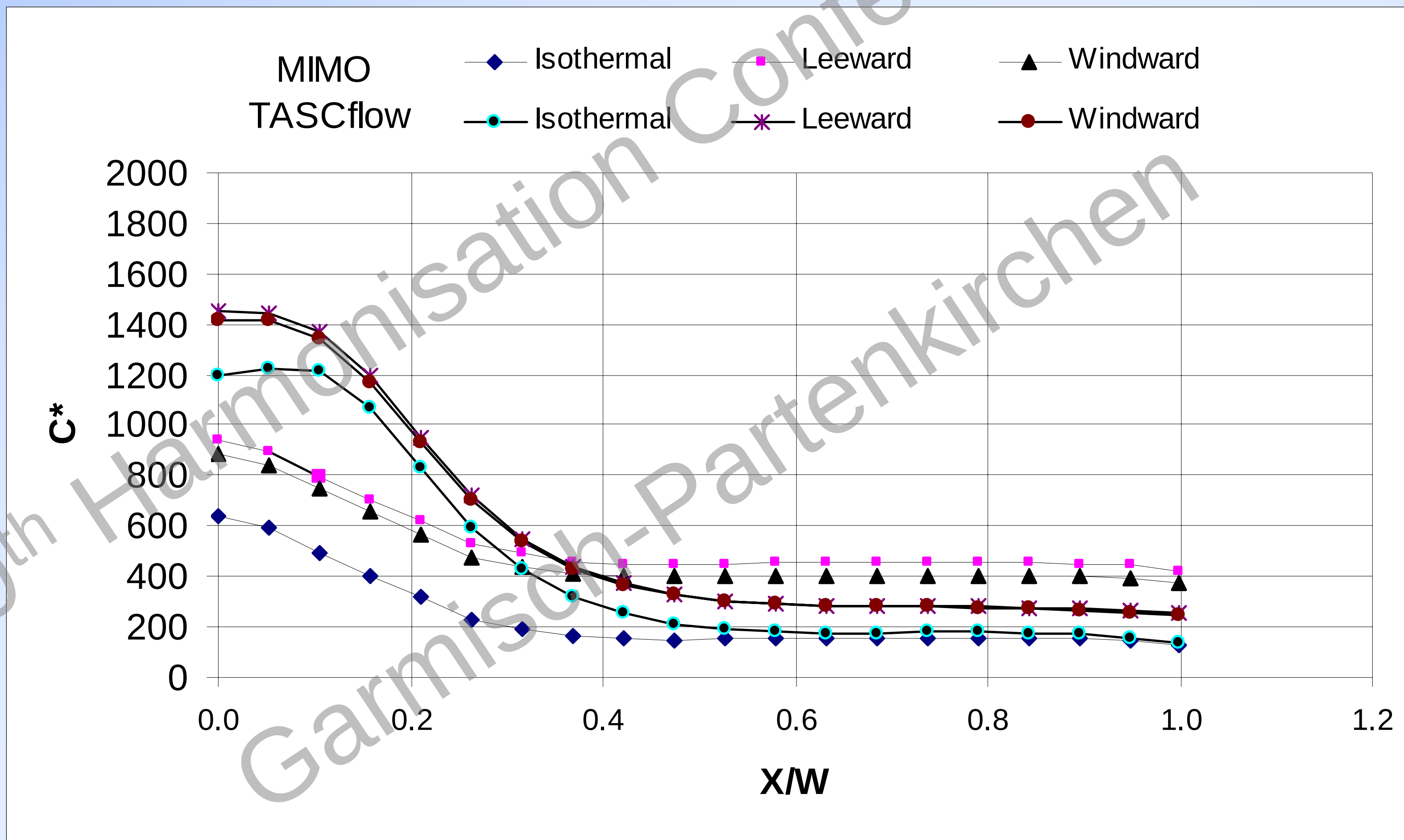
Calculated dimensionless concentration across the street canyon for aspect ratio 1.0

(a) Y/H=0.15



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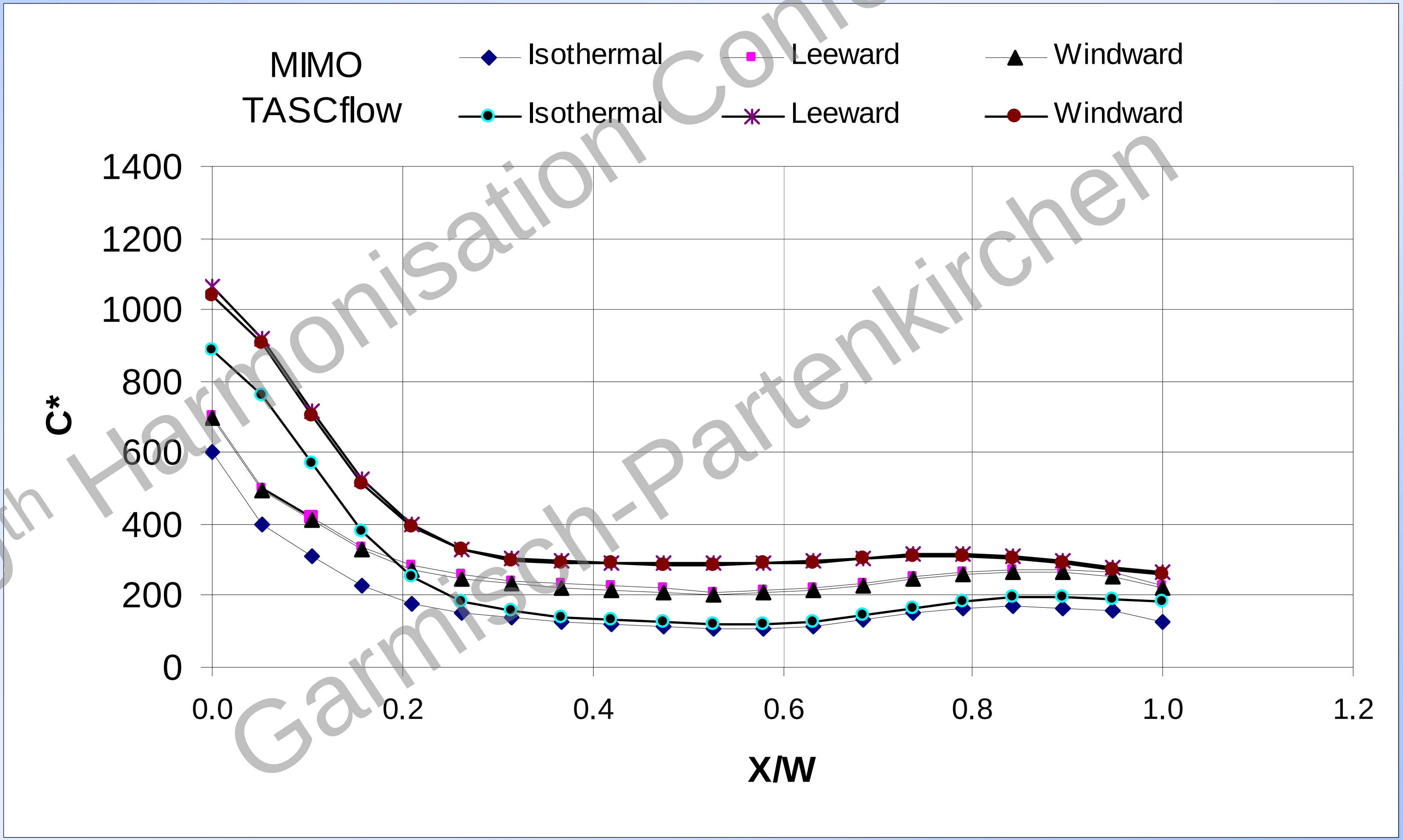
Calculated dimensionless concentration across the street canyon for aspect ratio 1.0

(b) Y/H=0.5



Calculated dimensionless concentration across the street canyon for aspect ratio 1.0

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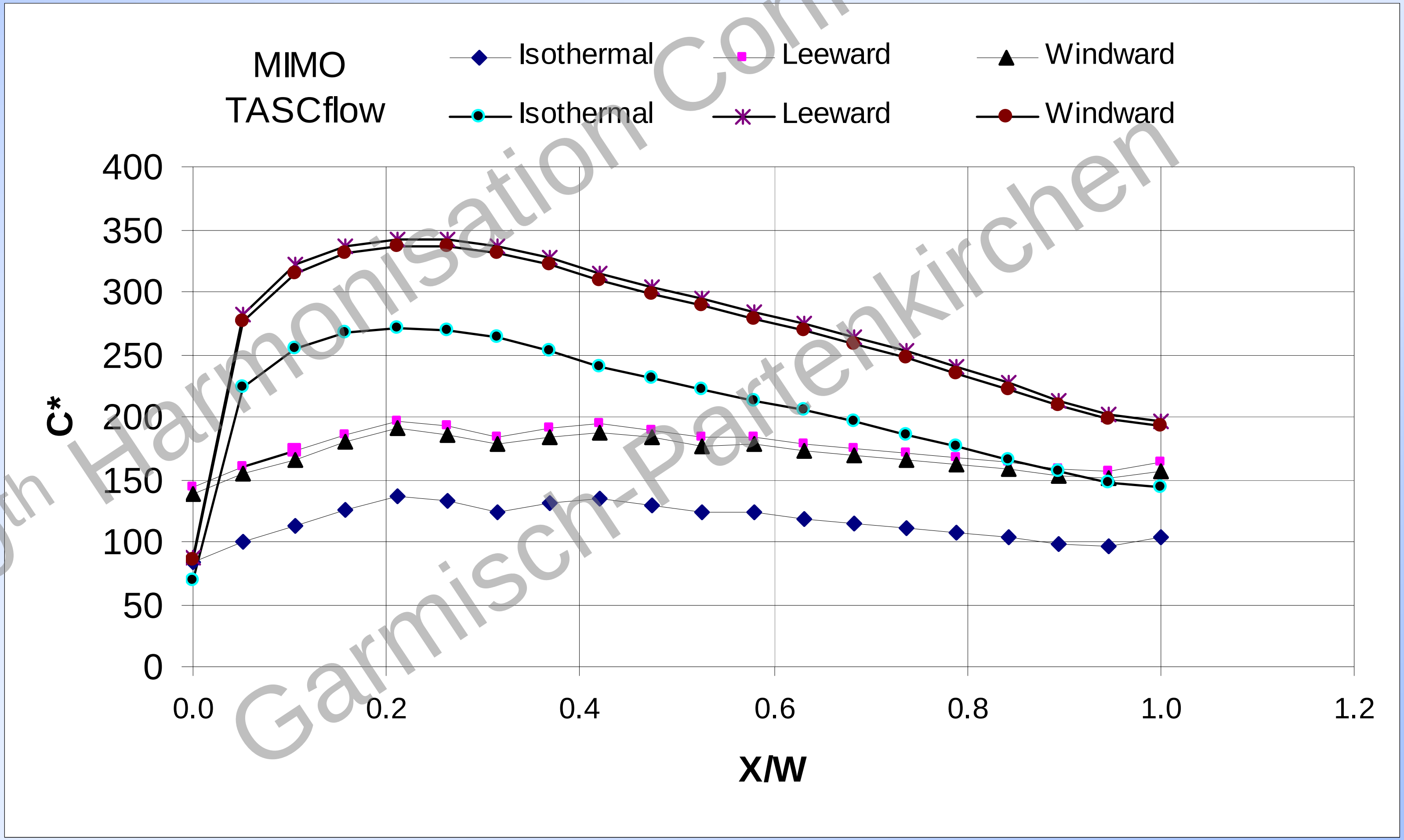
(c) Y/H=1.0



Aspect ratio 2.0

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⇨For aspect ratio 2.0 the flow fields predicted by both codes are in good agreement

- ➢One centrally located vortex
- ➢Two small ones at the street canyon ground level near each of the building walls

⇨TASCflow however, predicts a larger vortex near the leeward wall side than MIMO

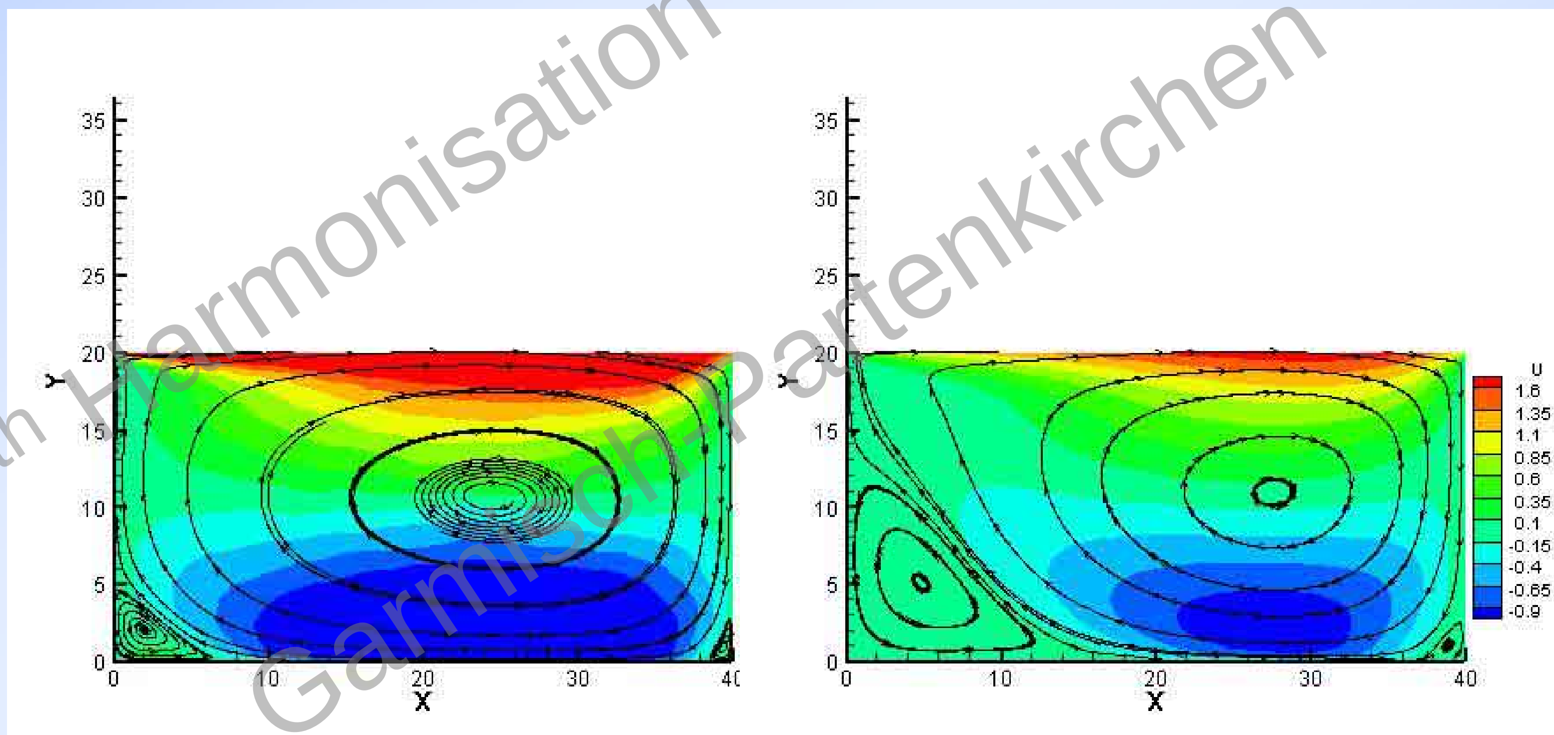
⇨As a result for Y/H≤ 0.5, for all cases MIMO predicts maximum concentrations near the leeward wall side at X/W ~0.1 while TASCflow at X/W ~0.3

⇨Heat transfer phenomena do not affect markedly the flow field

⇨Calculated concentrations increase when either the leeward or the windward wall is heated

Flow field comparison for aspect ratio 2.0 for the isothermal case

(a) MIMO *(b) TASCflow*



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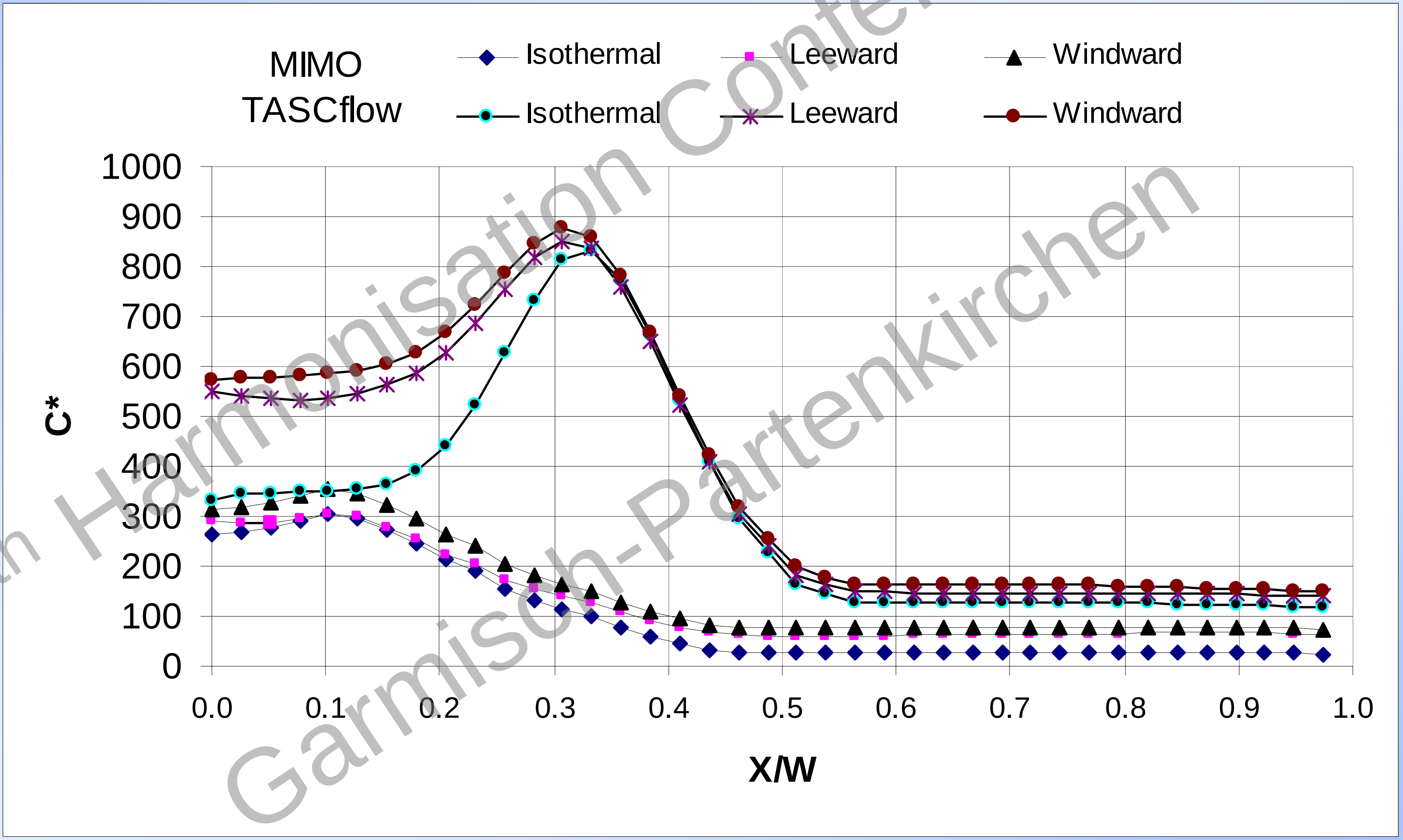
Calculated dimensionless concentration across the street canyon for aspect ratio 2.0

(a) **Y/H=0.15**



Calculated dimensionless concentration across the street canyon for aspect ratio 2.0

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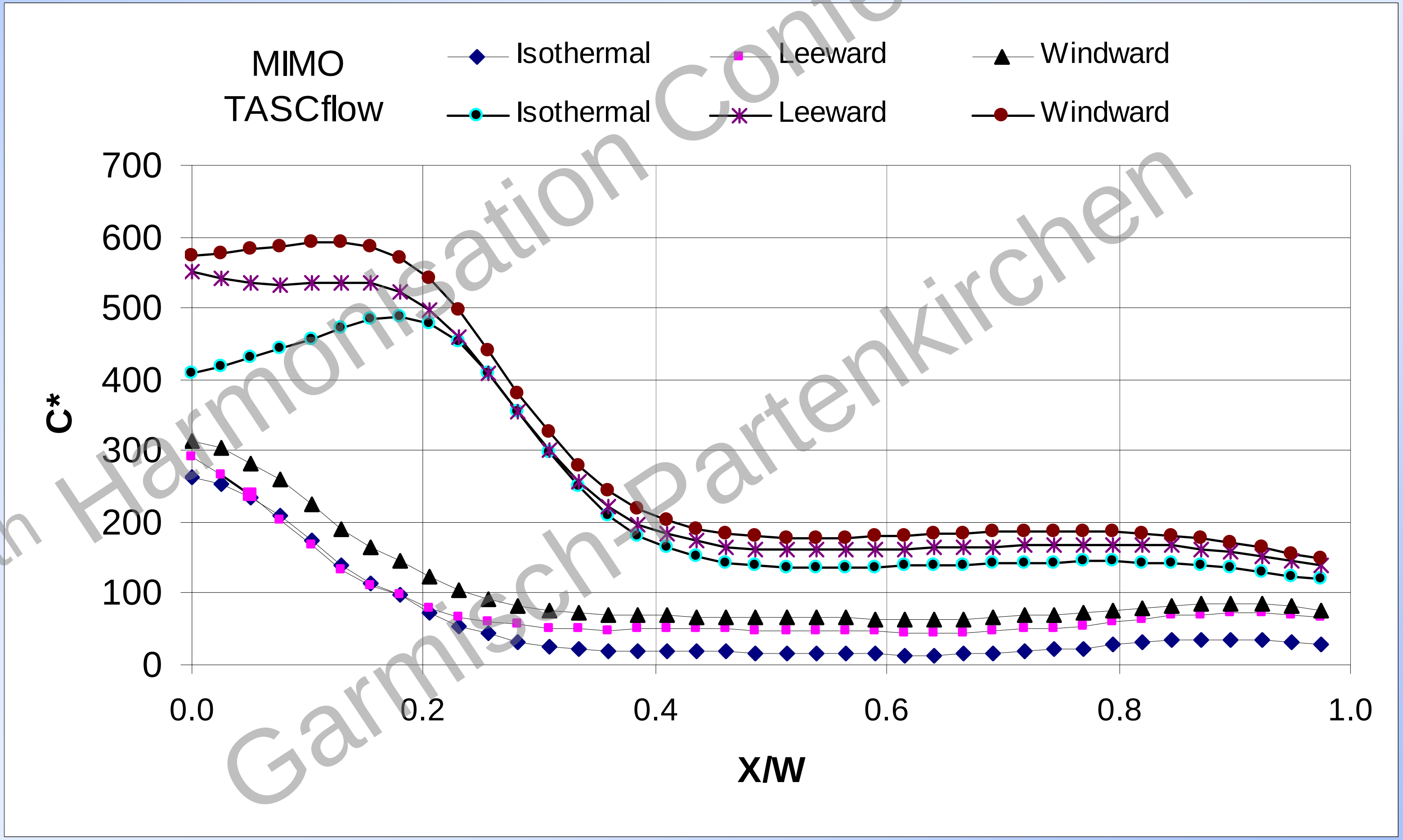
(b) **Y/H=0.5**



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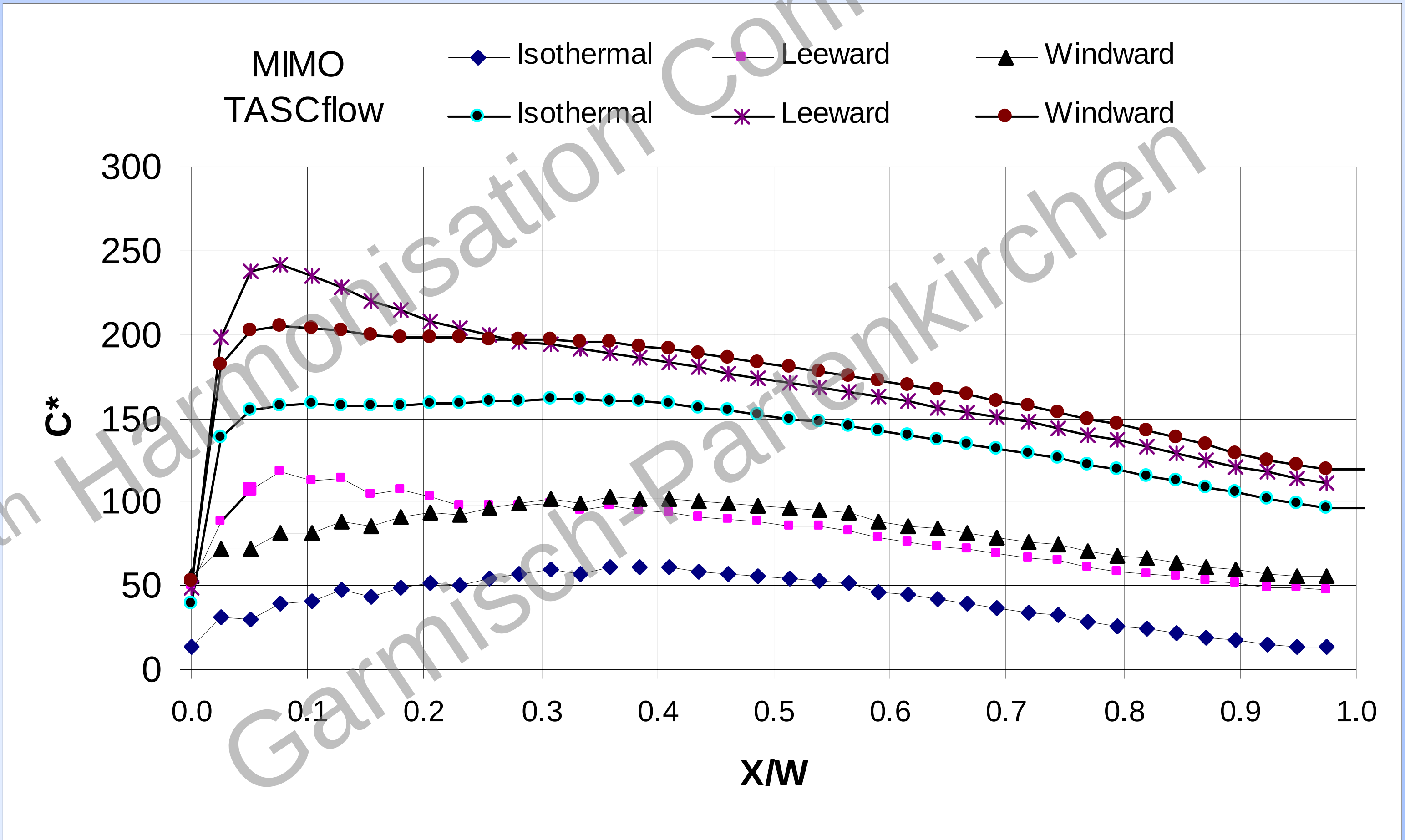
Calculated dimensionless concentration across the street canyon for aspect ratio 2.0

(c) Y/H=1.0



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Conclusions

Aspect ratios 1.0 and 2.0

⇨ **The flow field predicted by MIMO is similar to that obtained with TASCflow for all cases considered**

⇨ **Yet, MIMO predicts higher velocity components than TASCflow and therefore there is a strong disagreement between the corresponding concentration fields**

Aspect ratio 0.33

⇨ **Results show disagreement between the two codes in the predicted flow fields for all cases**

- **As a result, the two codes predict maximum concentrations at different regions near the building walls**

There is a need to study further how the selection of specific turbulence models - wall functions affects model performance.

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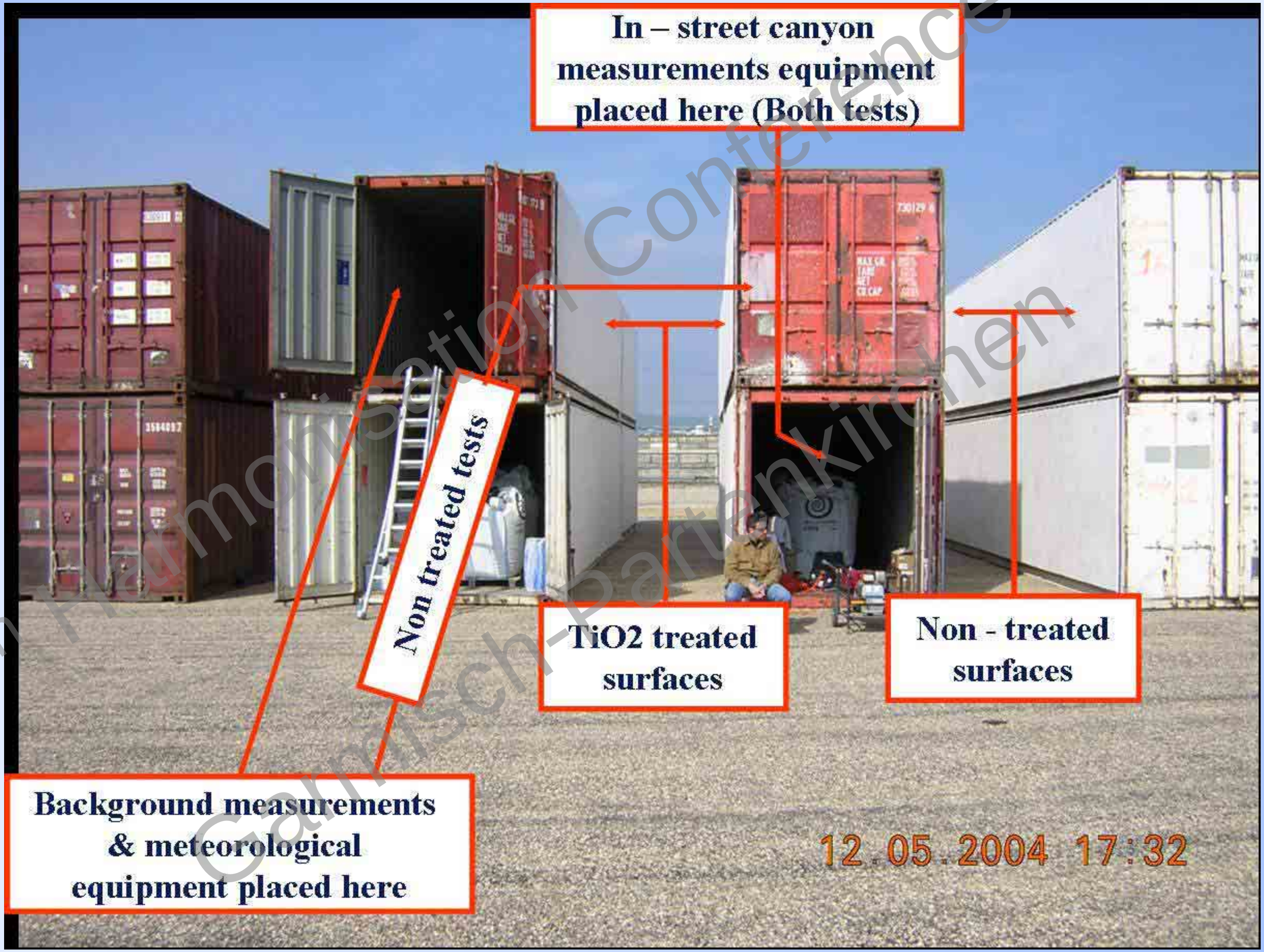
The Guerville street canyon experiment (PICADA project)



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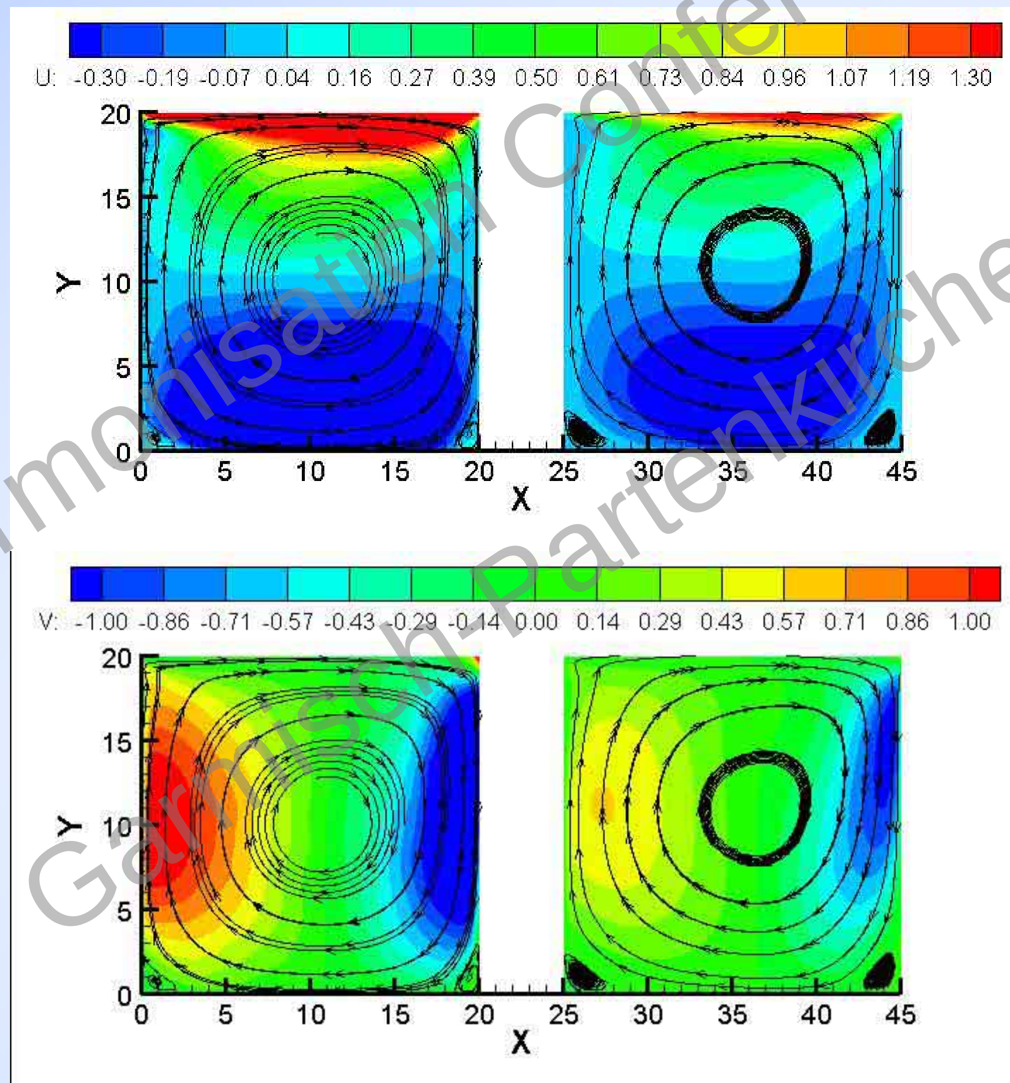
Comparison of u & v velocity component fields respectively for aspect ratio 1.0 for the isothermal case

MIMO TASCflow

u-component

v-component



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Comparison of u & v velocity component fields respectively for aspect ratio 2.0 for the isothermal case

MIMO **TASCflow**

u-component

v-component