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Constructal Theory, Constructal Law, and the Applications of Constructal Design to Mechanical Engineering

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INTRODUCTION

- The constructal design has been applied in a wide range of research fields, from engineering to biology, or even in the arts.

- What is the meaning of Constructal Theory, Constructal Law, and Constructal Design? Do they have the same meaning?

- Is the Constructal realm embraced by the researcher community?

- In which countries have these authors been publishing in this field?

- Where are these authors located in Brazil?

- What are the main applications in Mechanical Engineering?

CONSTRUCTAL THEORY

"**Constructal Theory** is the view that flow configuration (**geometry, design**) can be reasoned on the basis of a **principle of configuration generation and evolution** in time toward greater global flow access in **systems that are free to morph**. That principle is the **Constructal law**."

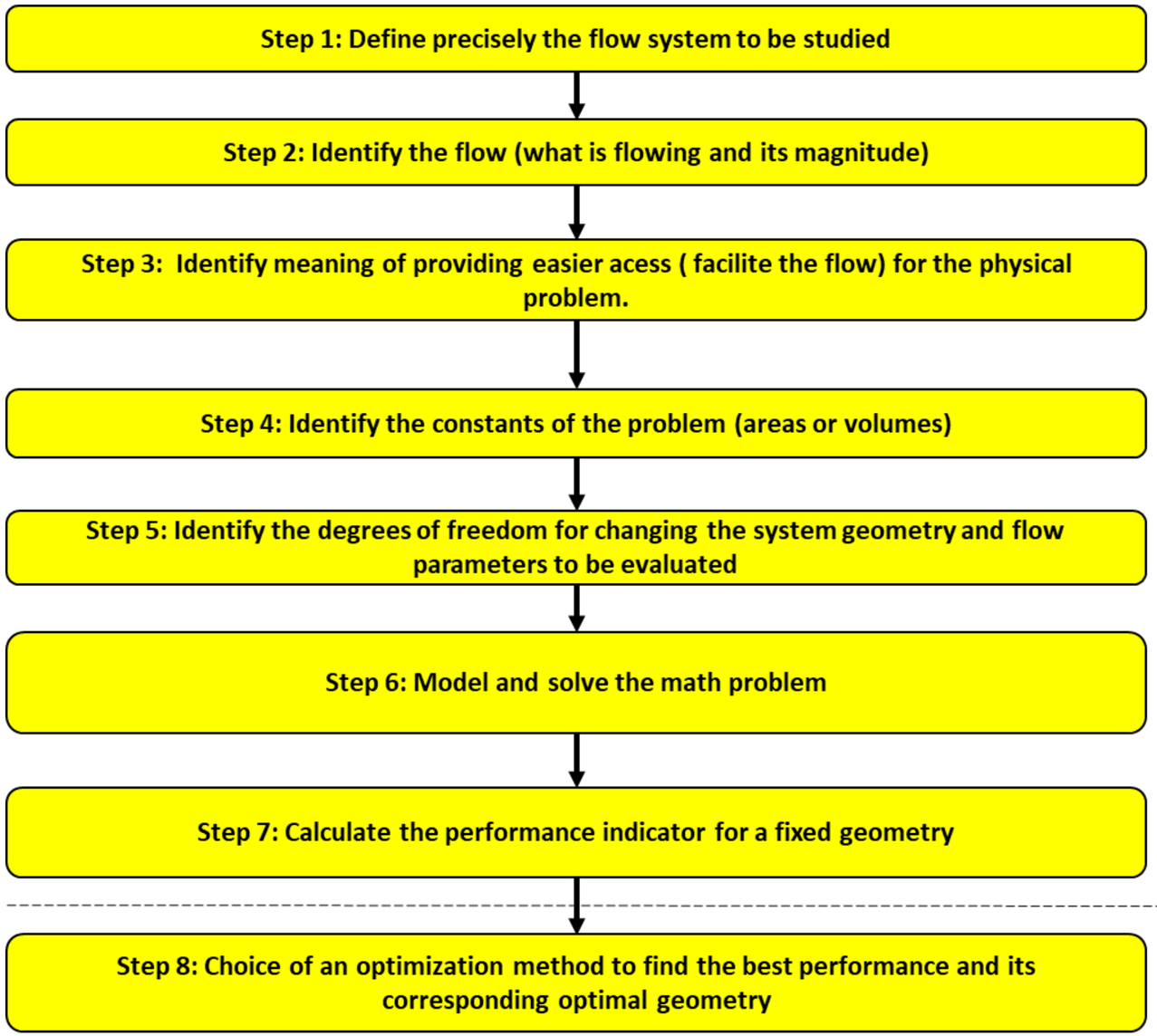
CONSTRUCTAL LAW

"For a **finite-size flow system** to persist in time (to live),

its **configuration** must evolve **freely** in such a way that provides

easier access to the currents that flow through it."

CONSTRUCTAL DESIGN



Constructal Design Method

Optimization

CONSTRUCTAL DESIGN

“There is no ‘best’ in evolutionary design. There is ‘better’ today, which turns out to be not as good tomorrow.”

“DCT is not a mathematical optimization method.”

“When the system has many degrees of freedom, the Constructal design method can be used in association with some **optimization methods**, for example, **exhaustive search or genetic algorithm**. This approach makes it possible to study **complex systems**, i.e., systems with a **larger number of degrees of freedom**.”

CL: SPREADING AND GROWTHING

a) 1996

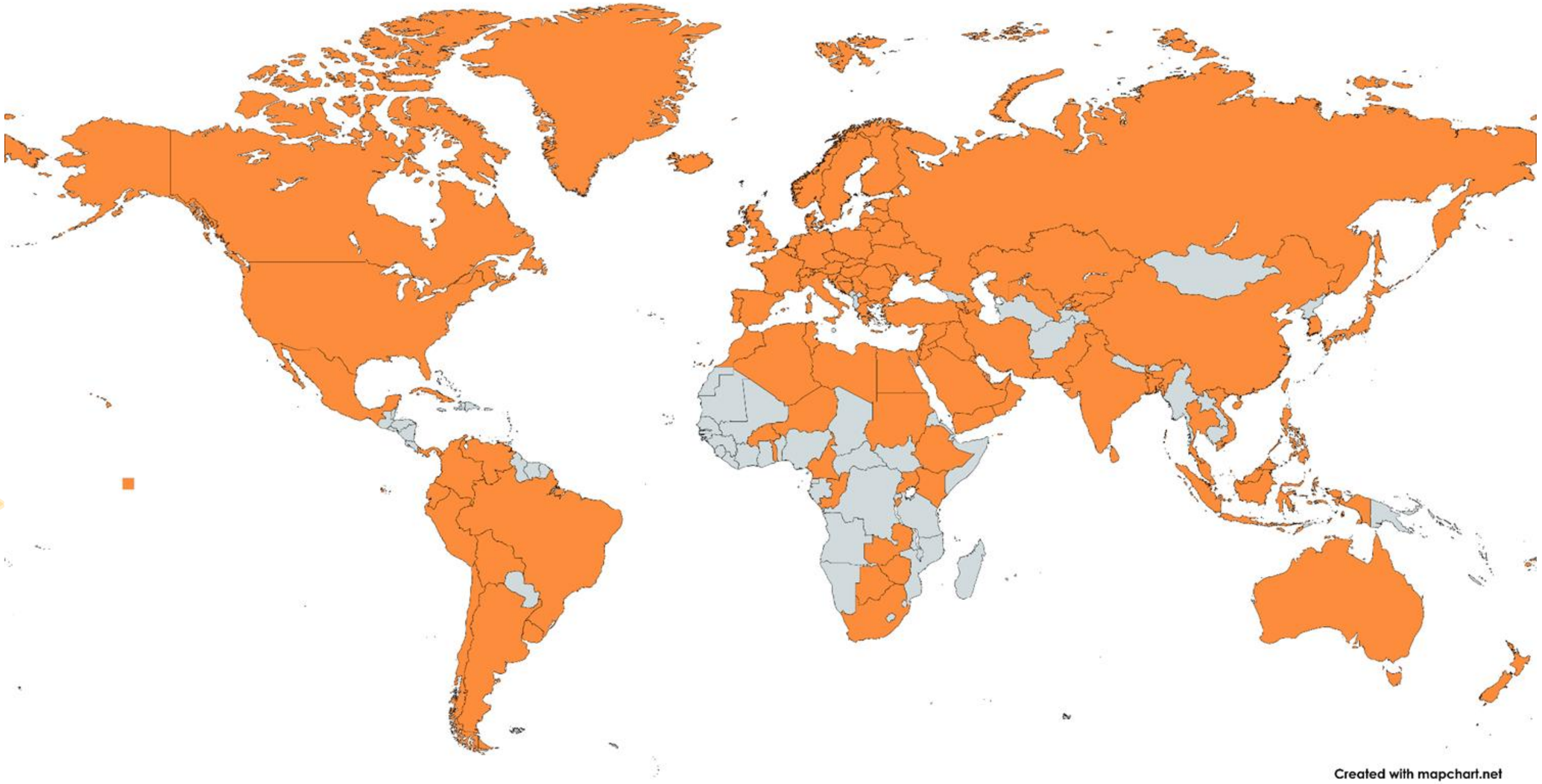
b) 2002

c) 2010

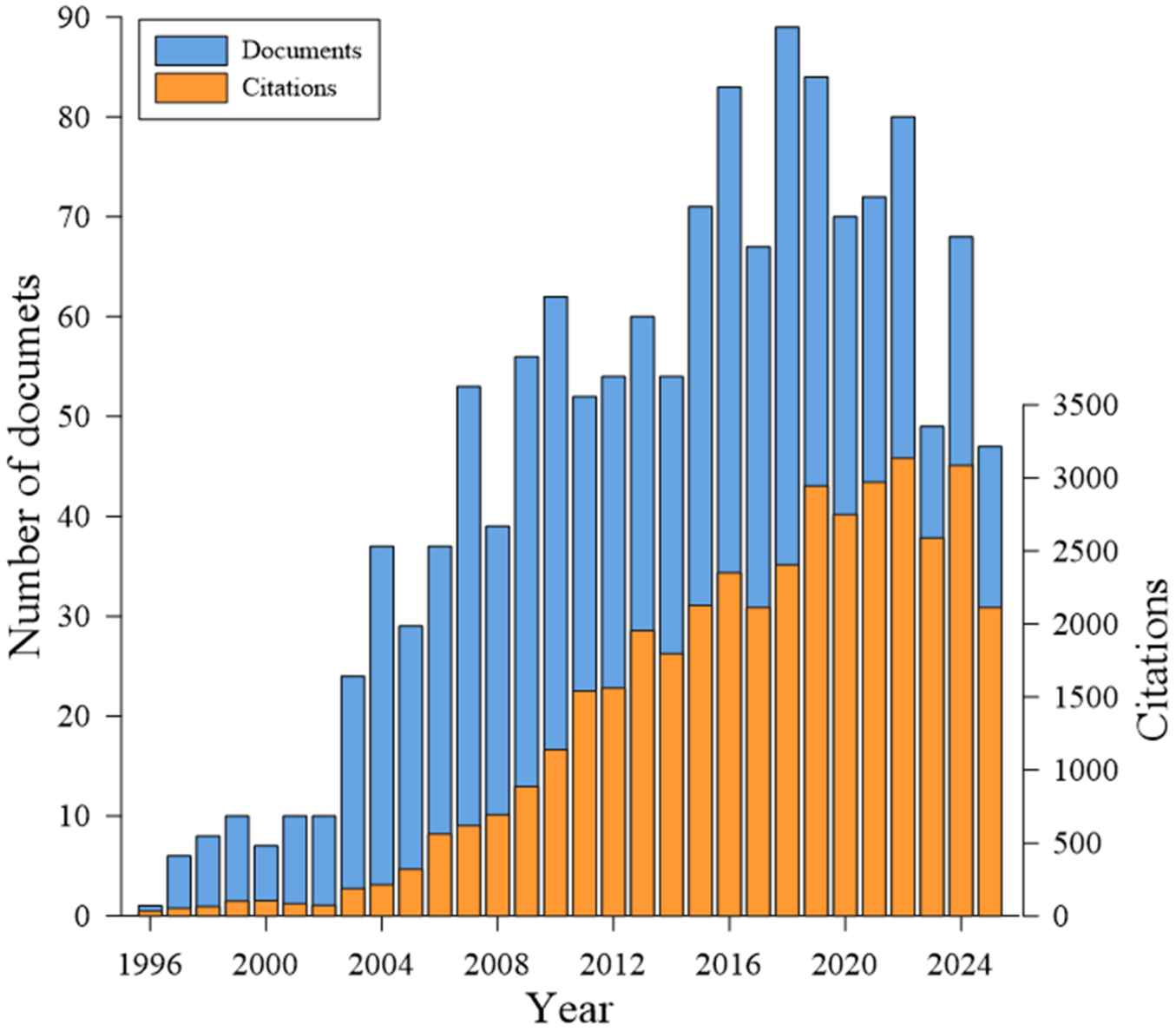
d) 2018

CL: SPREADING AND GROWTHING

2025



CL: SPREADING AND GROWTHING



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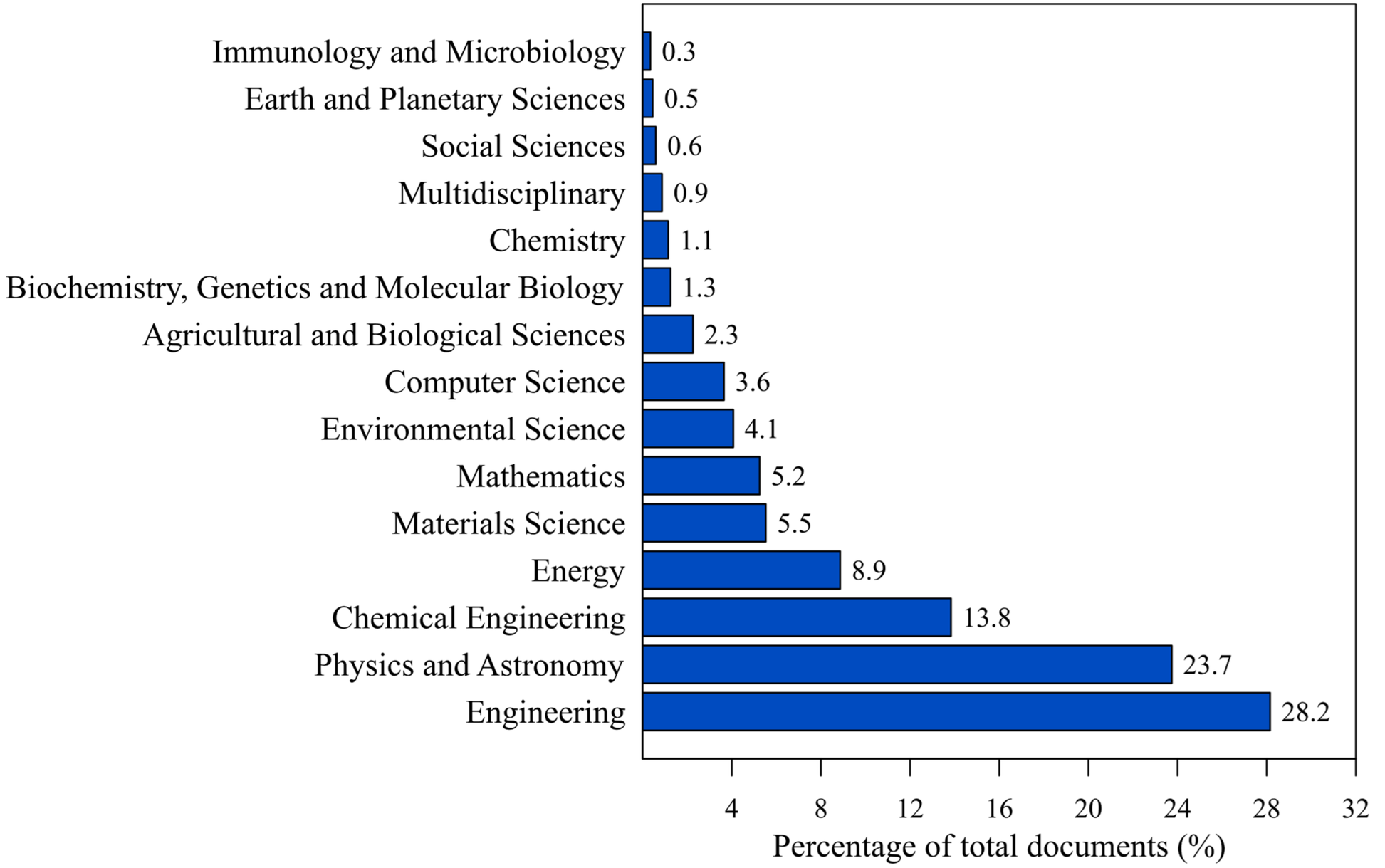

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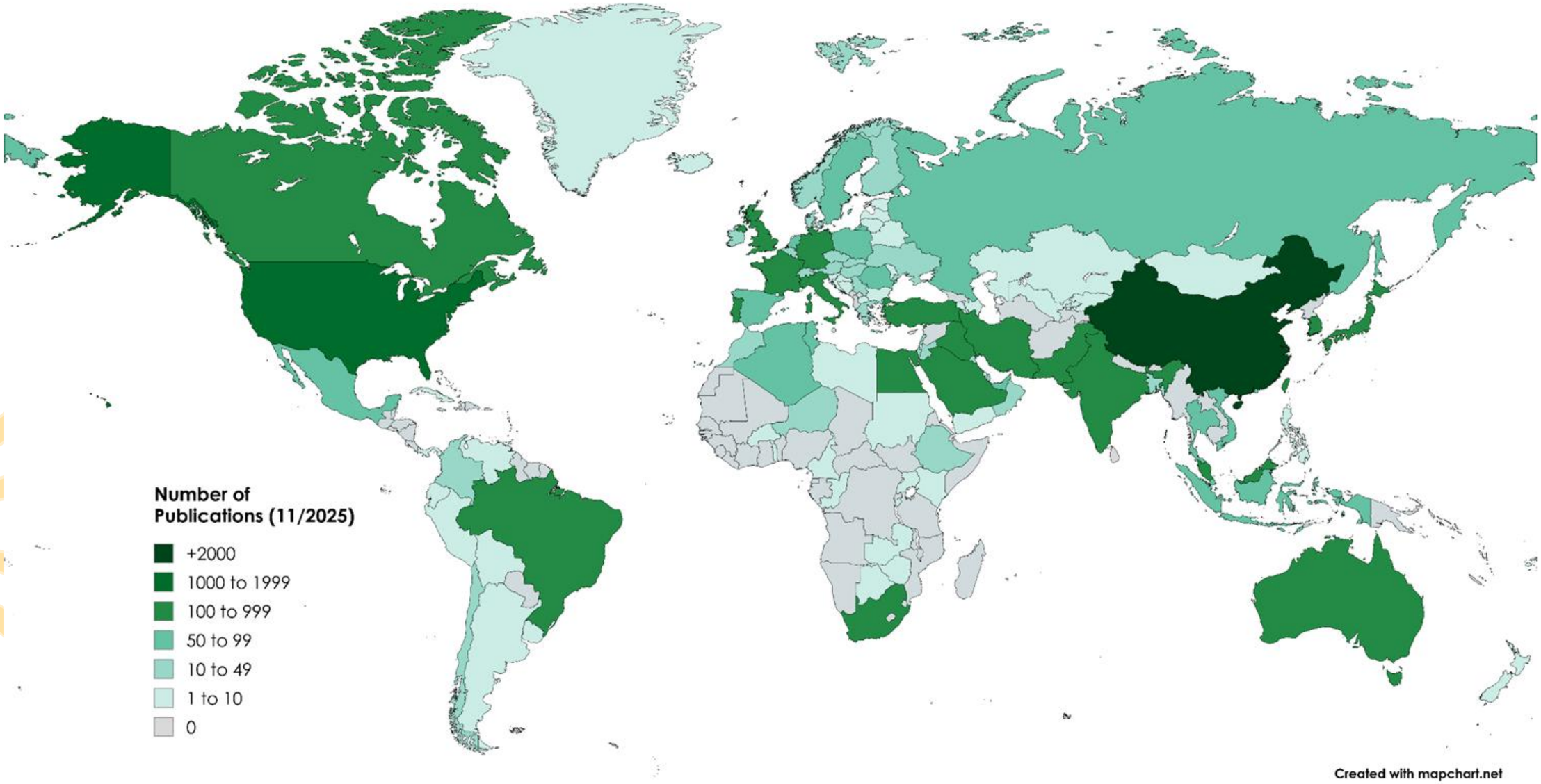
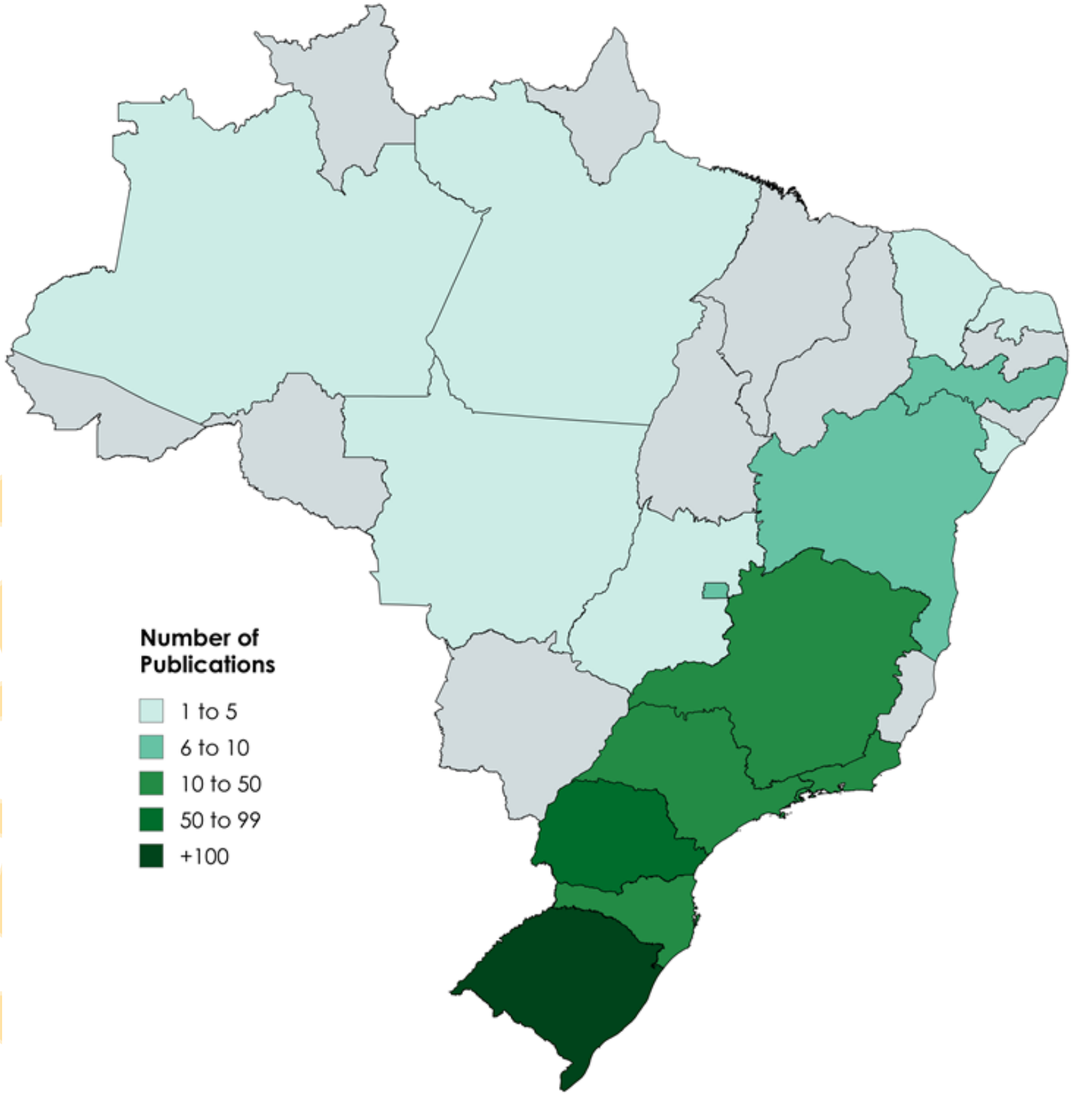
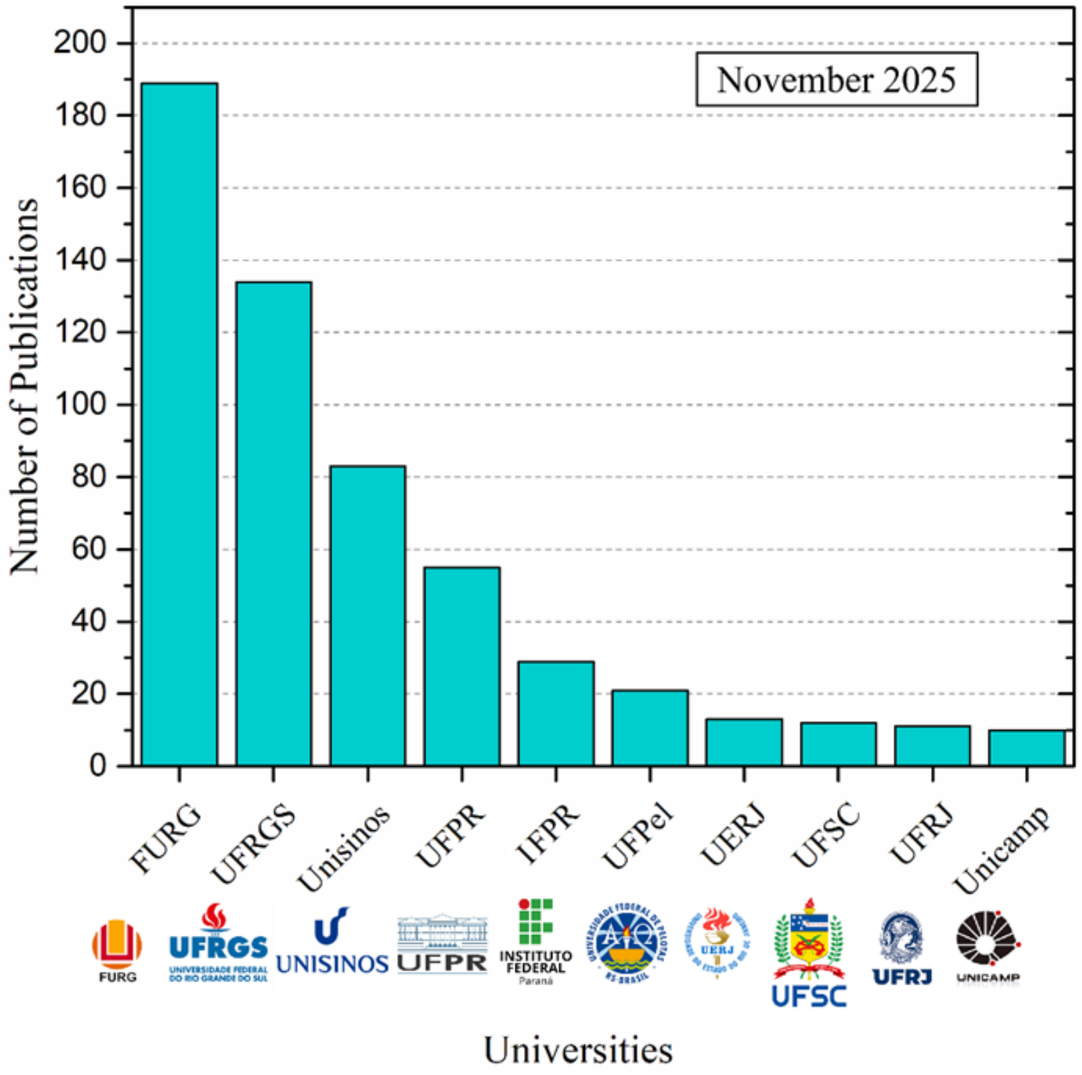


CL: SPREADING AND GROWTHING





ISOTHERMAL C-SHAPED CAVITY

The solid domain has constant thermal conductivity (k);

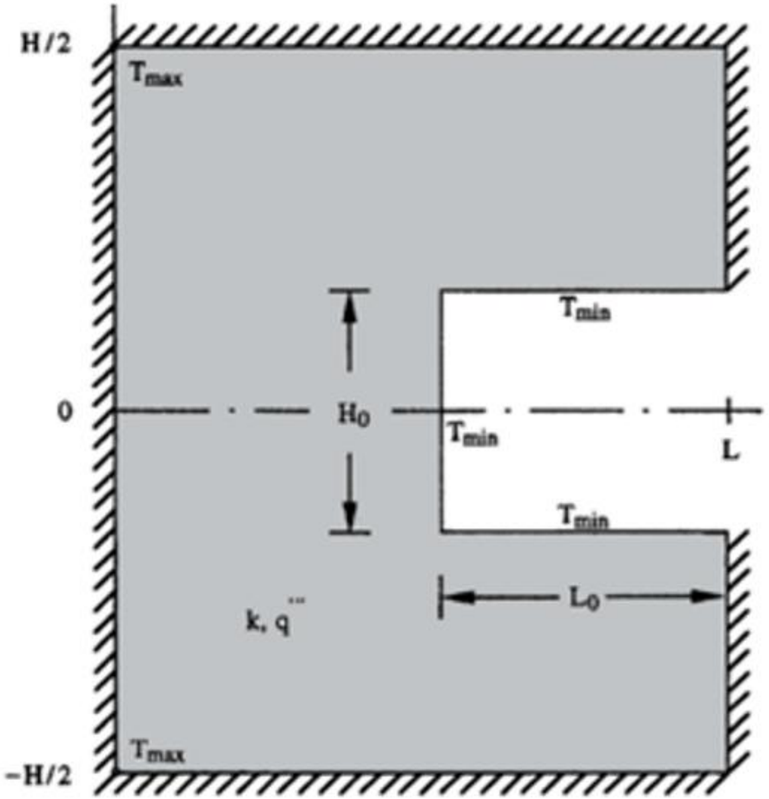
The cavity surfaces are isothermal (simulating fluid flow with a constant high coefficient h);

External surfaces of the solid domain are adiabatic;

The thermal field is in the steady state;

The magnitude of q‴ is uniform and constant;

The problem is modeled as two-dimensional.



(A) C-shaped

2004

ISOTHERMAL C-SHAPED CAVITY

- Total domain area:

$$A = HL$$

- Relation between total domain area and cavity area:

$$\varphi = \frac{A_c}{A} = \frac{Cavity\ area}{Total\ domain\ area} = \ 0.1; 0.2; 0.3 \ldots$$

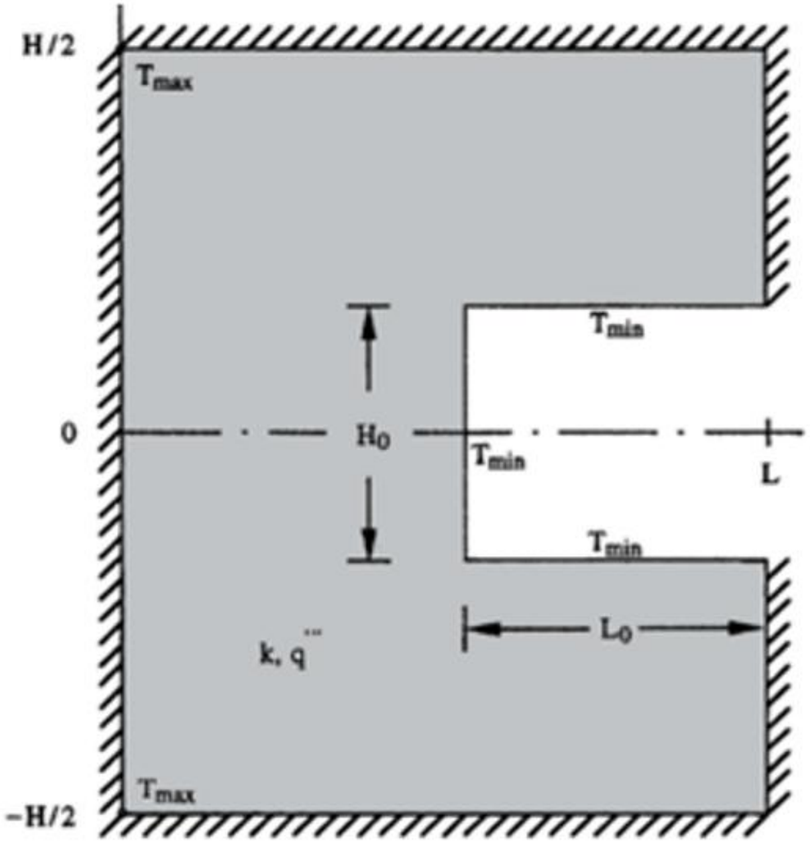
- The **performance indicator** to be minimized is the dimensionless maximum excess of temperature:

$$\theta_{max} = \frac{T_{max} - T_{min}}{q''' \frac{A}{k}}$$

$$\frac{\partial^2 \tilde{\theta}}{\partial^2 \tilde{x}} + \frac{\partial^2 \tilde{\theta}}{\partial^2 \tilde{y}} + 1 = 0$$

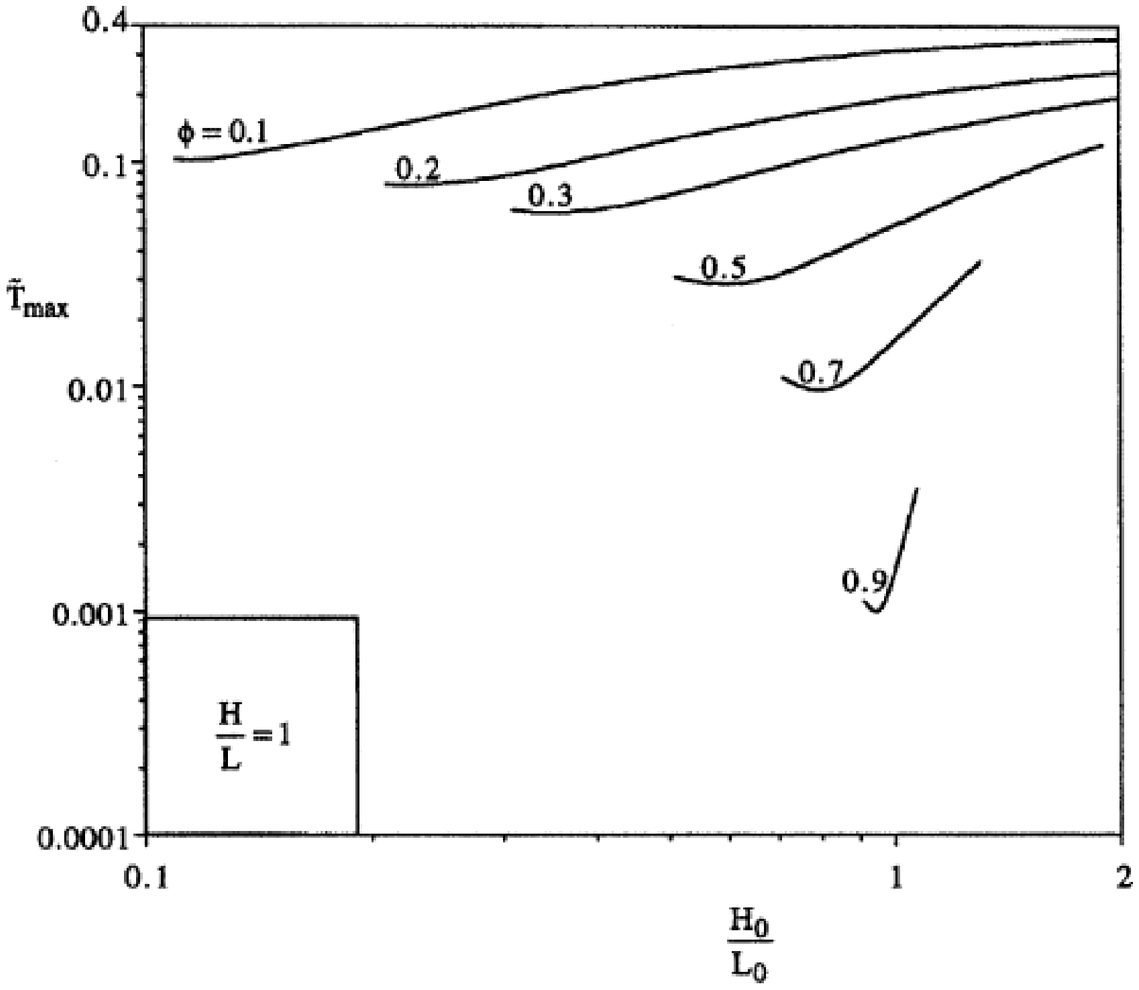
$$\theta = \frac{T - T_{min}}{q''' A/k}$$

$$\left(\tilde{x}, \tilde{y}, \tilde{H}, \tilde{L}, \tilde{H}_0, \tilde{L}_0\right) = \frac{(x, y, H, L, H_0, L_0)}{A^{1/2}}$$



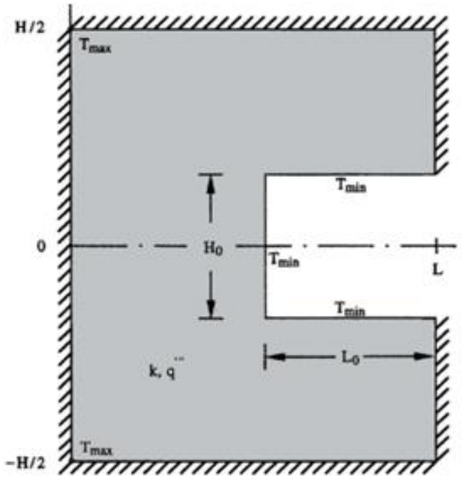
(A) C-shaped

2004

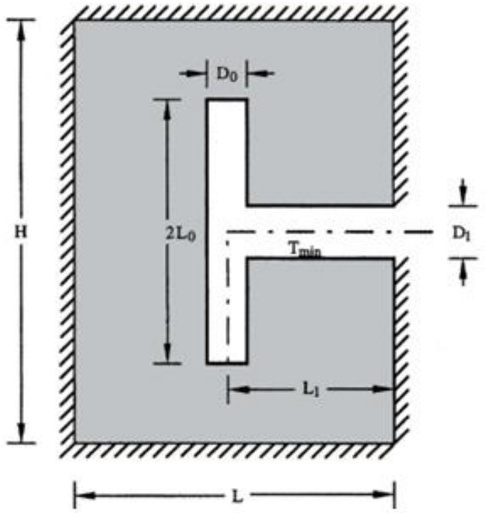


The minimization of the global thermal resistance when the external shape of the heat generating body is fixed.

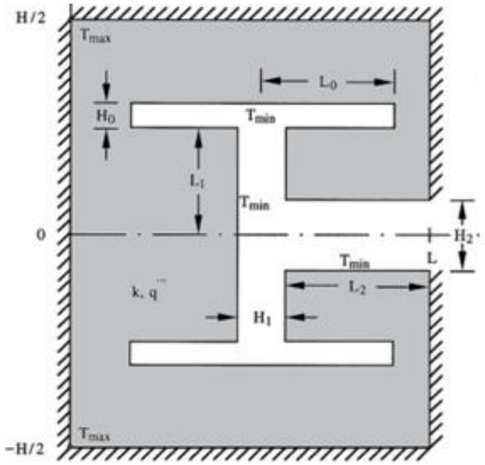
ISOTHERMAL CAVITIES



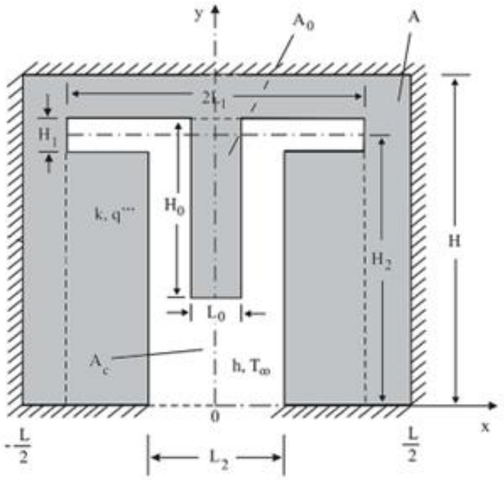
(A) C-shaped
2004



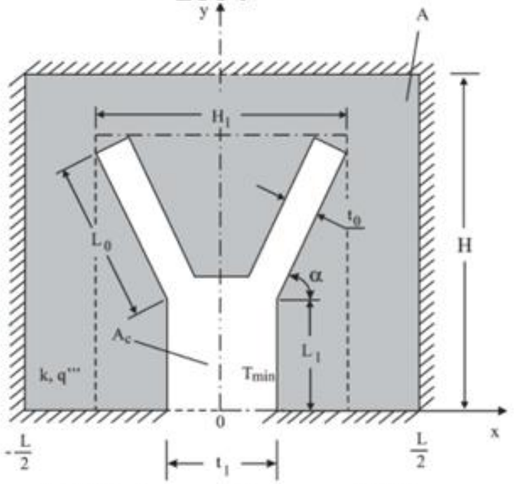
(B) T-shaped
2004



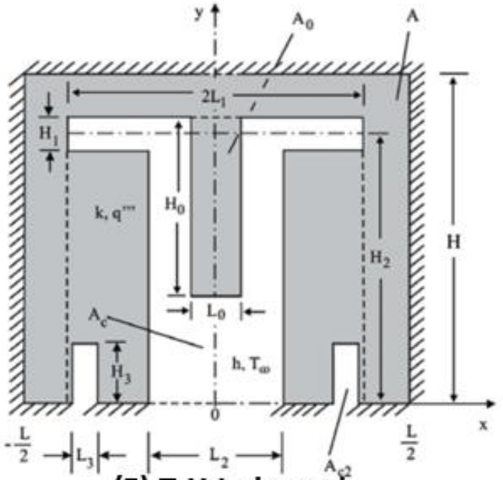
(C) H-shaped
2007



(D) T-Y-shaped
2009

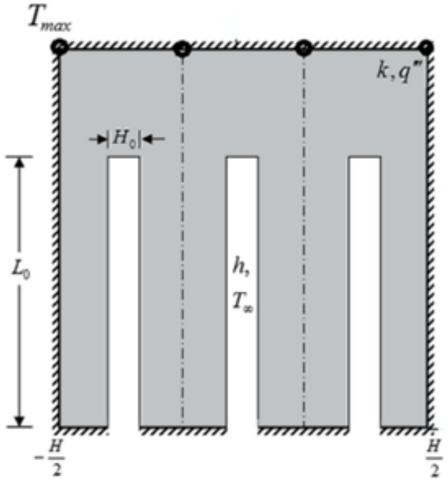


(E) Y-shaped Trapezoidal
2011

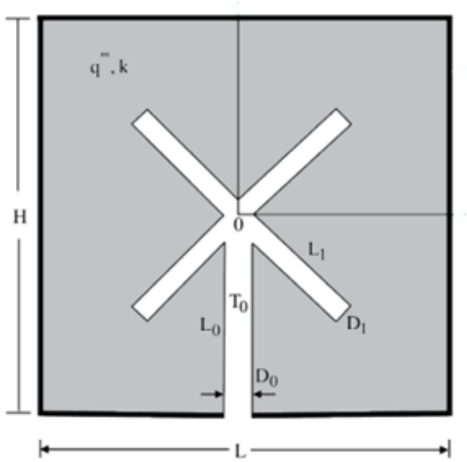


(F) T-Y-I-shaped
2012

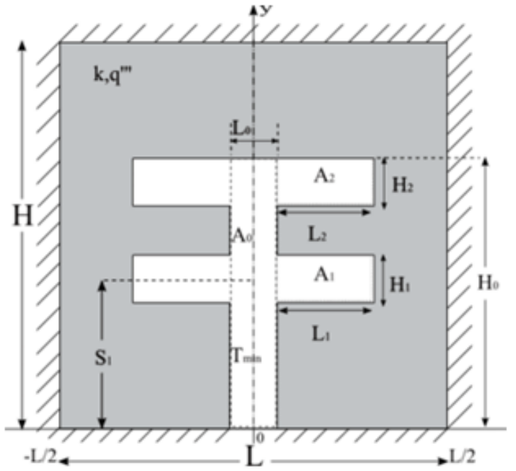
ISOTHERMAL CAVITIES



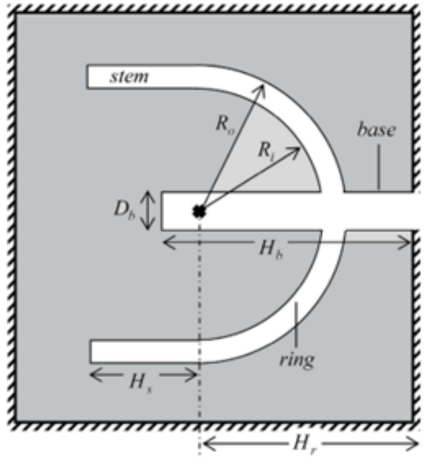
(G) I-shaped
2013



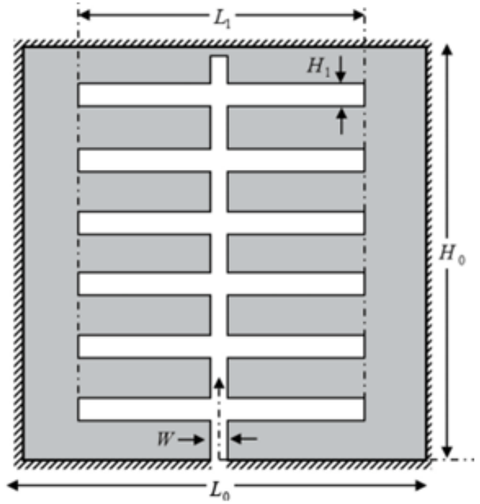
(H) X-shaped
2014



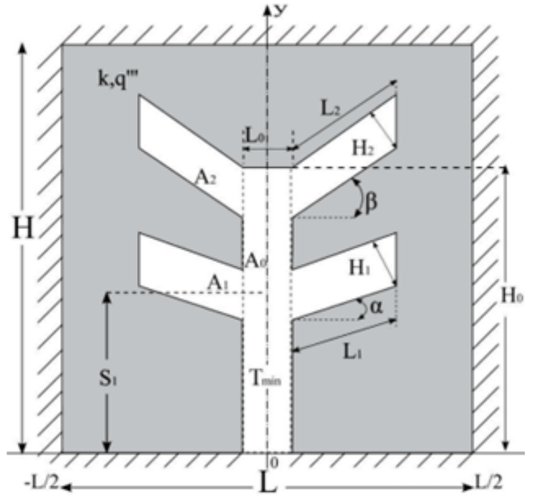
(I) Double T-shaped
2017



(J) Omega-shaped
2017

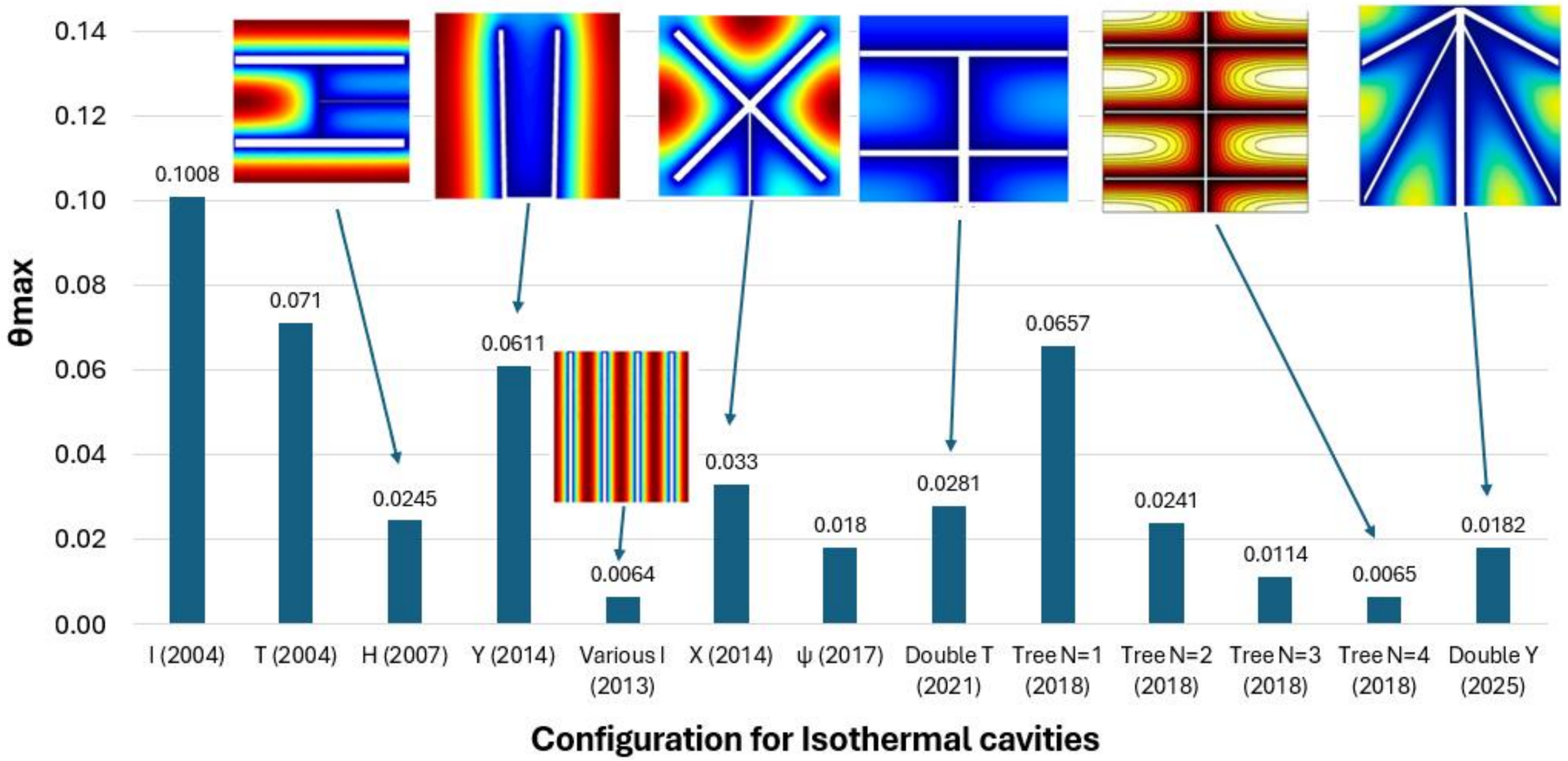


(K) Tree-shaped
2018

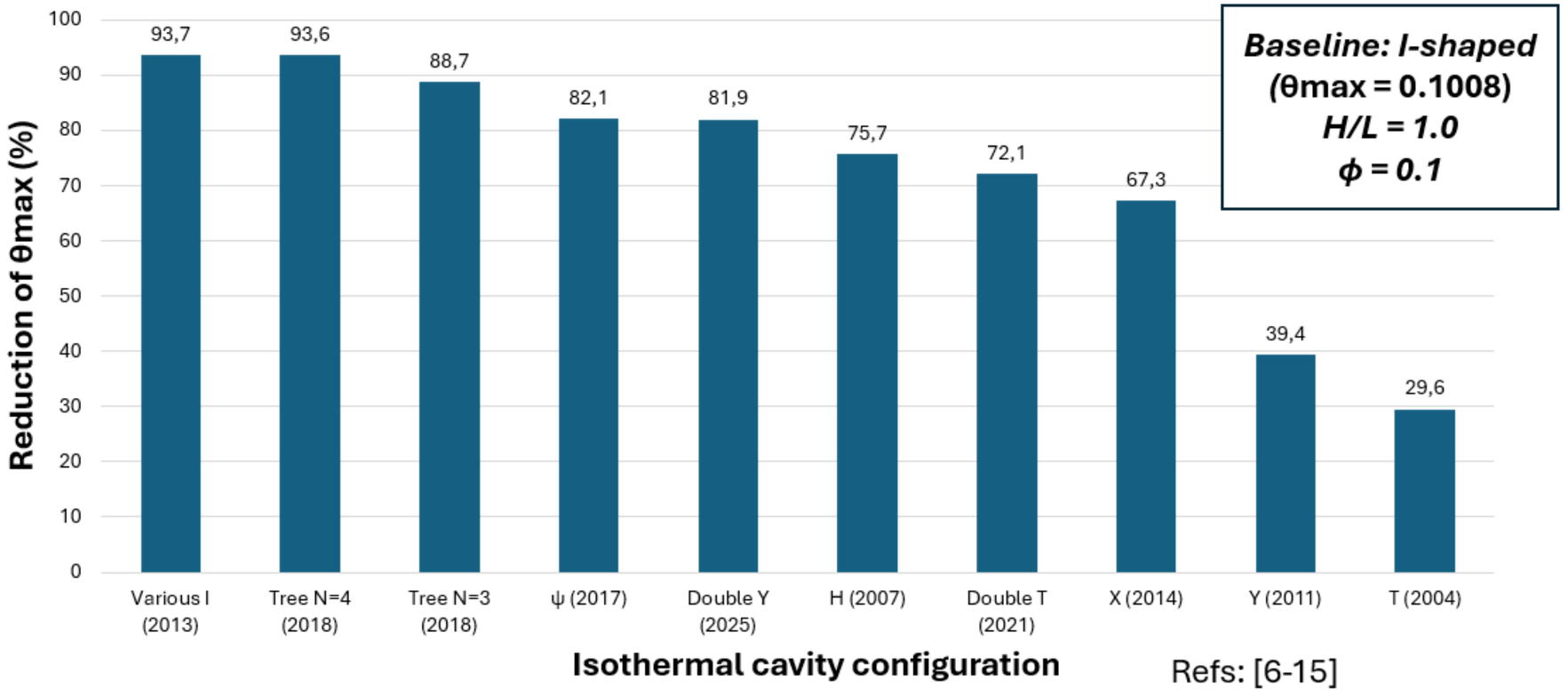


(L) Double Y-shaped
2023

ISOTHERMAL C-SHAPED CAVITIES



Results: design evolution over time in isothermal cavity problems

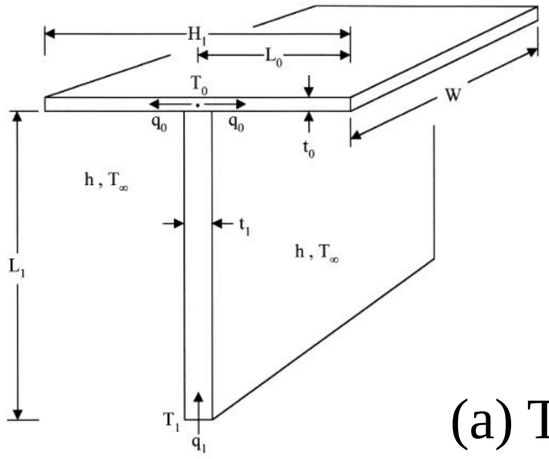


Refs: [6-15]

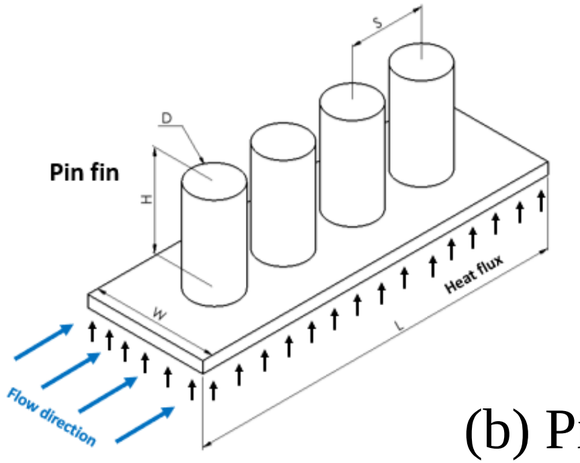
The evolution of the cavity's geometries has been studied over the years.

The freedom to morph facilitates access to the system's currents and improves its performance.

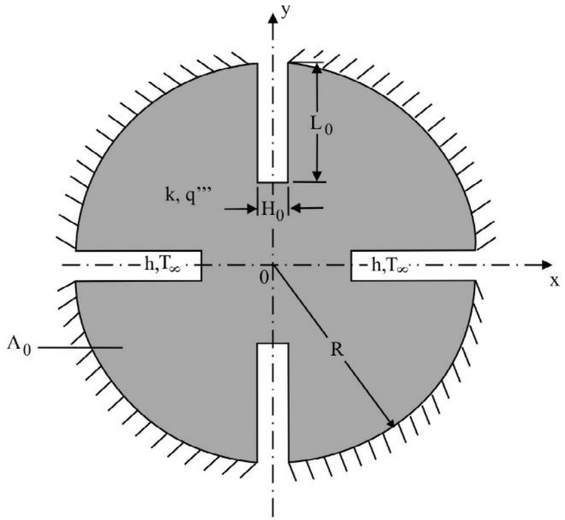
In this case, the elemental cavity has a global thermal resistance of 0.1008, which was reduced by 27 - 94% with a more complex cavity design.



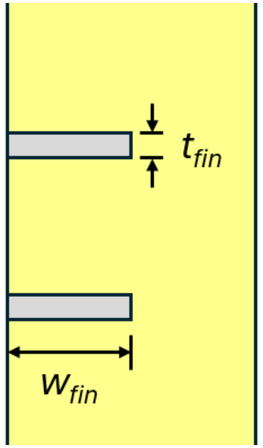
(a) T-shaped fin



(b) Pin fin

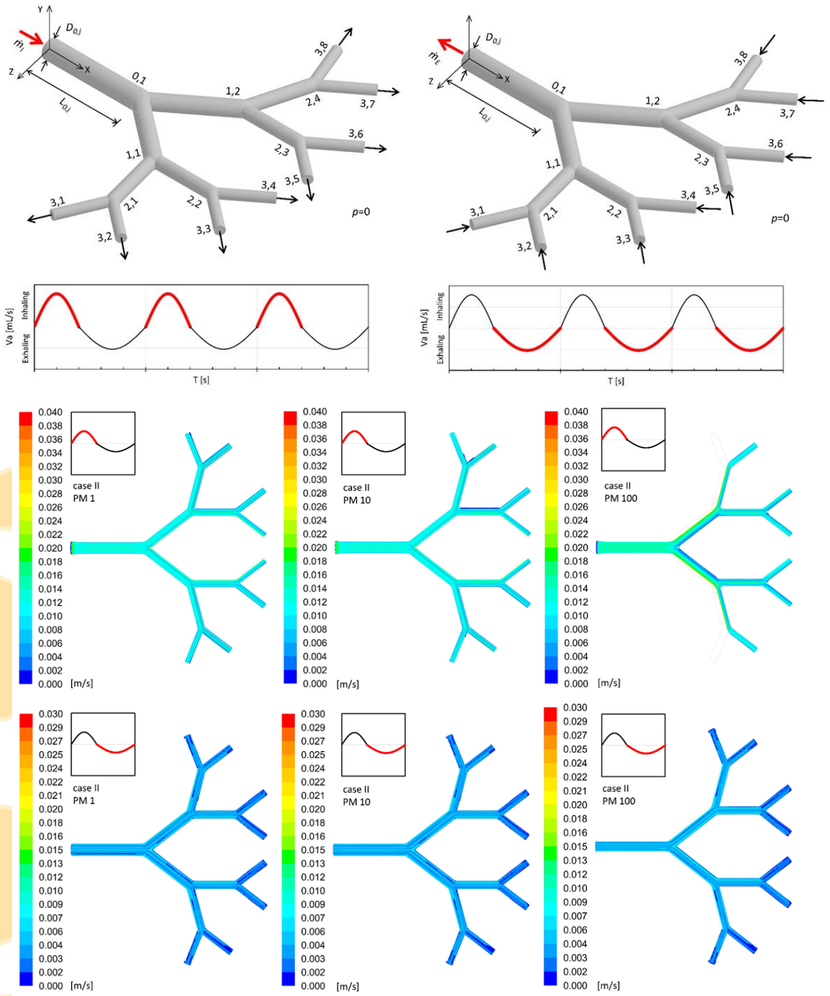


(c) circular cavity

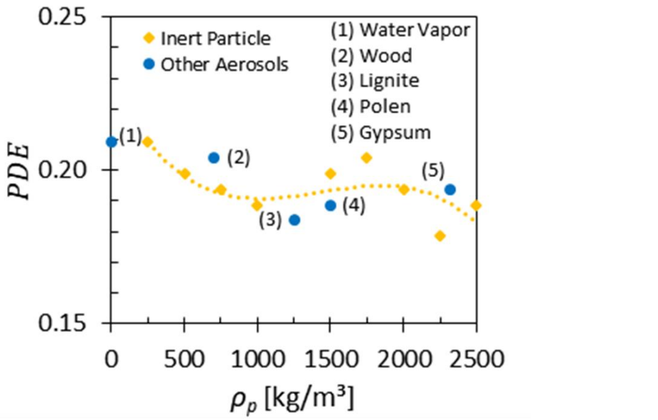


(d) PCM

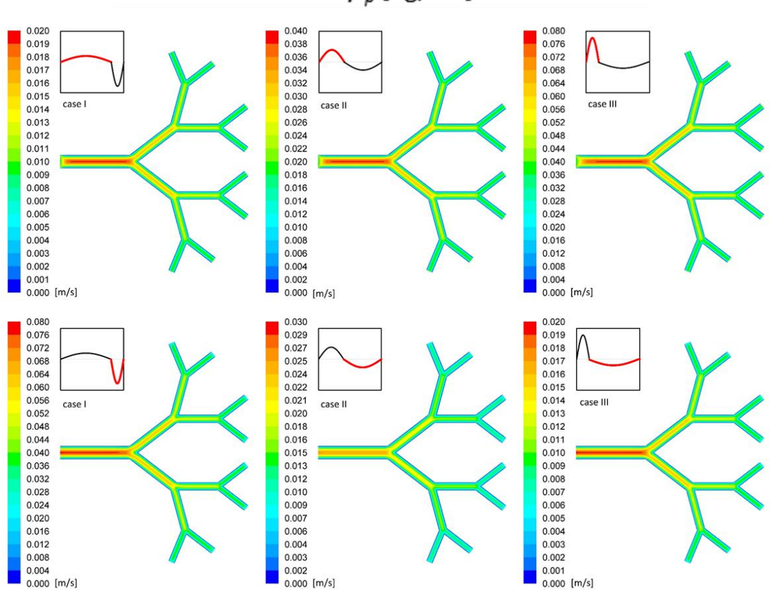
Pathway of Particle Dispersion in Children's Respiratory Dynamics



(a)



(b)



(c) (d)

(a) Children's respiratory tree and schematic of airflow structure;
(b) particle deposition efficiency;
(c) velocity magnitude contours at discrete phase (suspension flow) for uniform injection of particles with diameters from 1 to 100 μm;
(d) velocity magnitude contours at continuous phase.

DYNAMICS CONTRAST ULTRASOUD CALIBRATION

Temperature

- Inlet 1: Hot Water 100°C
- Inlet 2: Cold Water 0°C
- Pressure out: 0 bar
- Velocity inlet: 0.185 m/s

Particle

- Inlet 1: Water + Particle
- Inlet 2: Water
- Pressure out: 0 bar
- Velocity inlet: 0.185 m/s

Best Calibration

- Outlet 1: 100°C or 100%
- Outlet 2: 50°C or 50%
- Outlet 3: 0°C or 0%

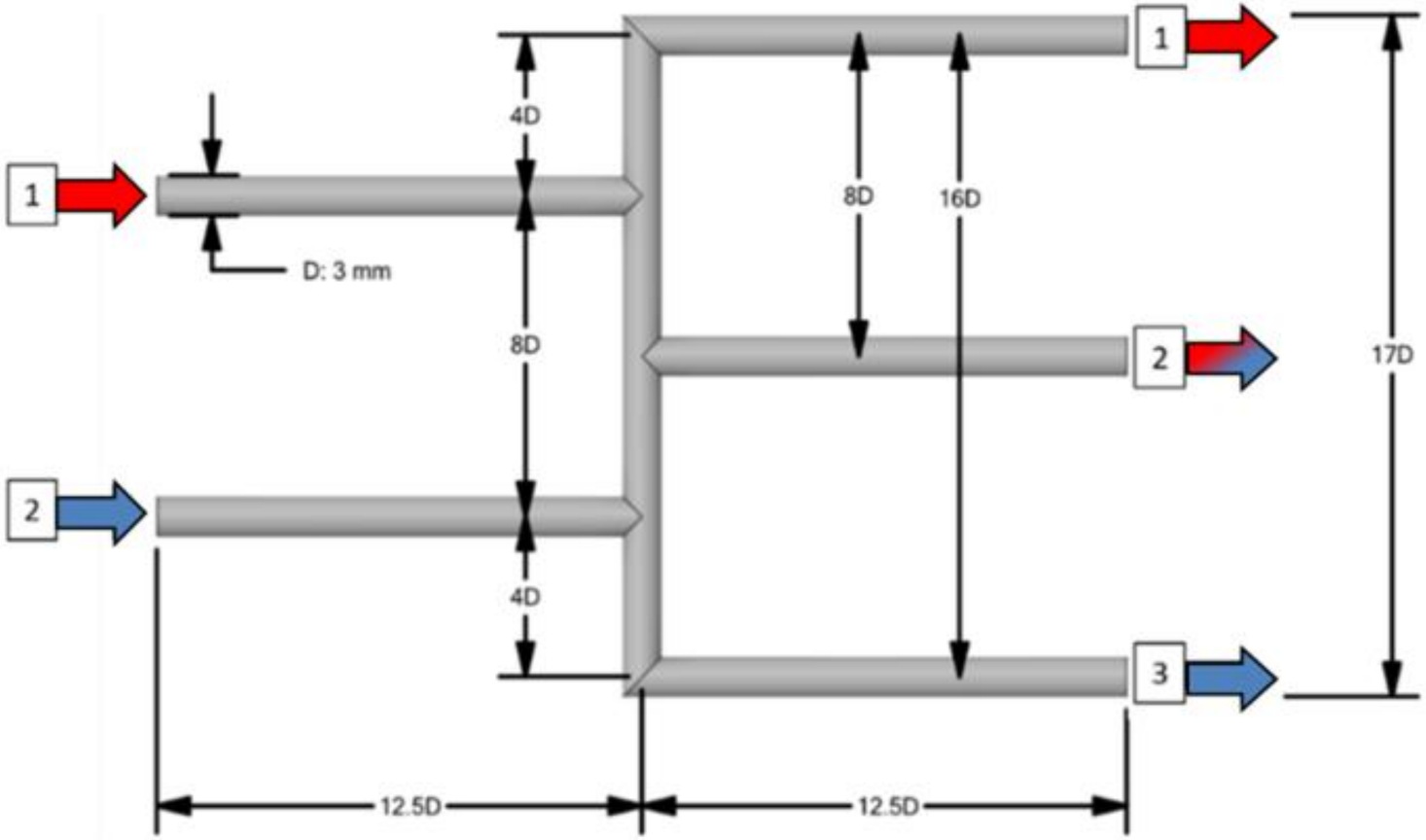


Figure 1. Geometric arrangement of a DCE-US based on a concentration divider.

Degrees of Freedom

- Vertical position of outlet 2 (3D – 11D)
- Velocity ratio between the inlets – ψ (0.2 – 1.2)

$$\psi = \frac{V_{in1}}{V_{in2}}$$

Global Constants

- Diameter - D
- Area
- Total volume

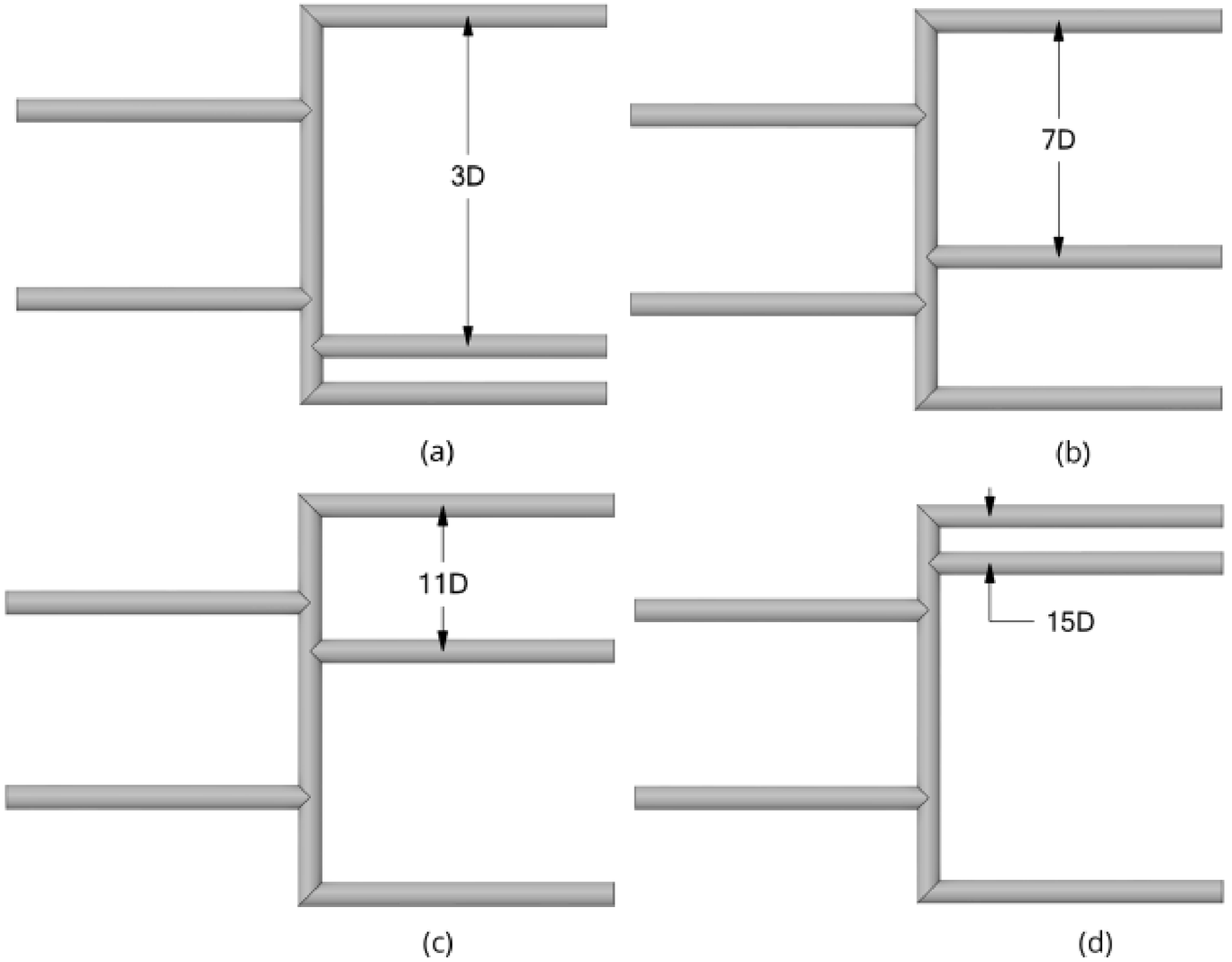
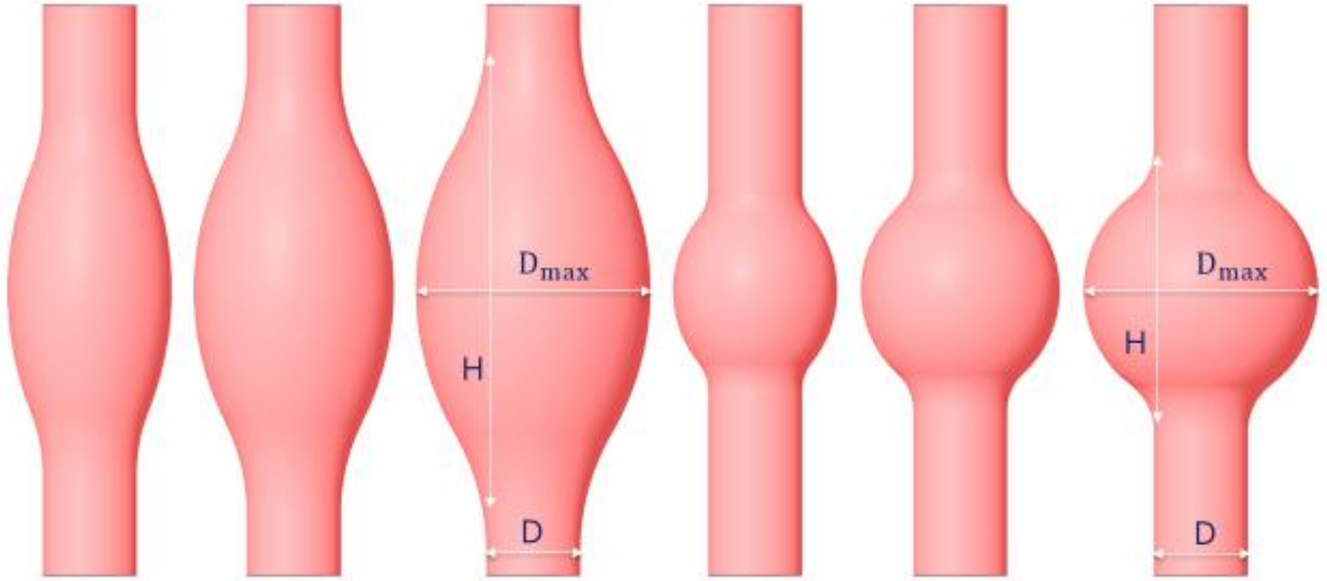


Figure 2. Geometric variation based on the vertical displacement of outlet tube 2 at positions (a) 3D, (b) 7D, (c) 11D, and (d) 15D.

Geometry Modeling

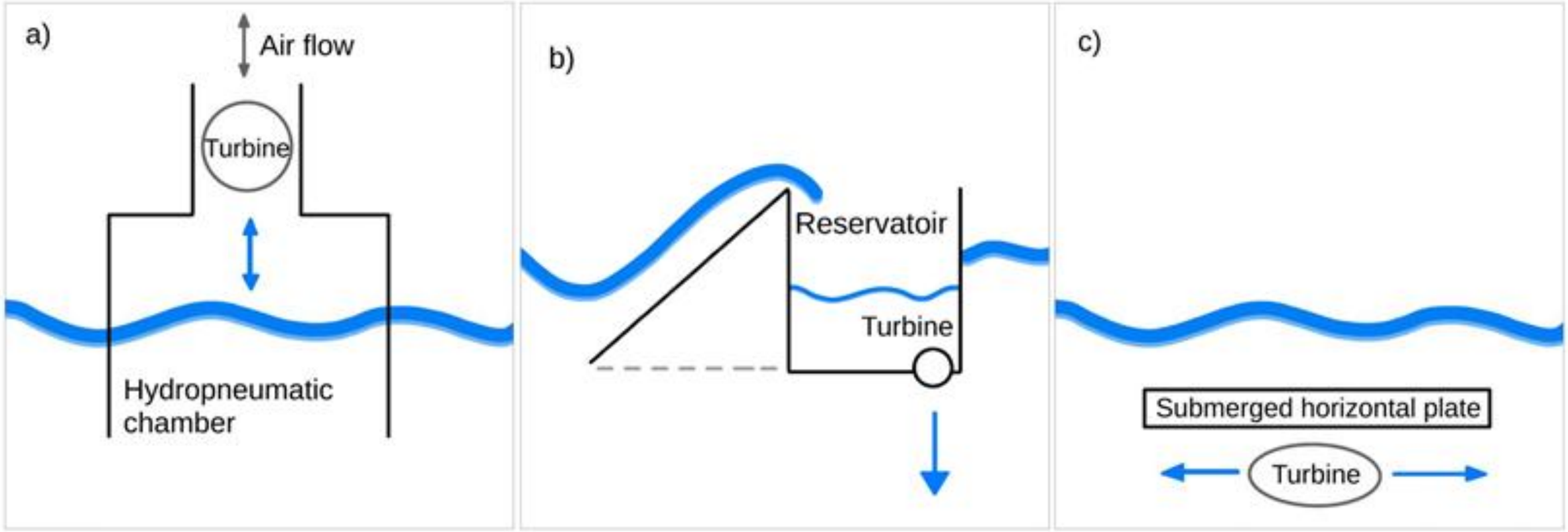
Idealized axisymmetric AAA geometry, constructed based on the model proposed by Philip et.al (2022).



$$DHr = \frac{D}{H}$$

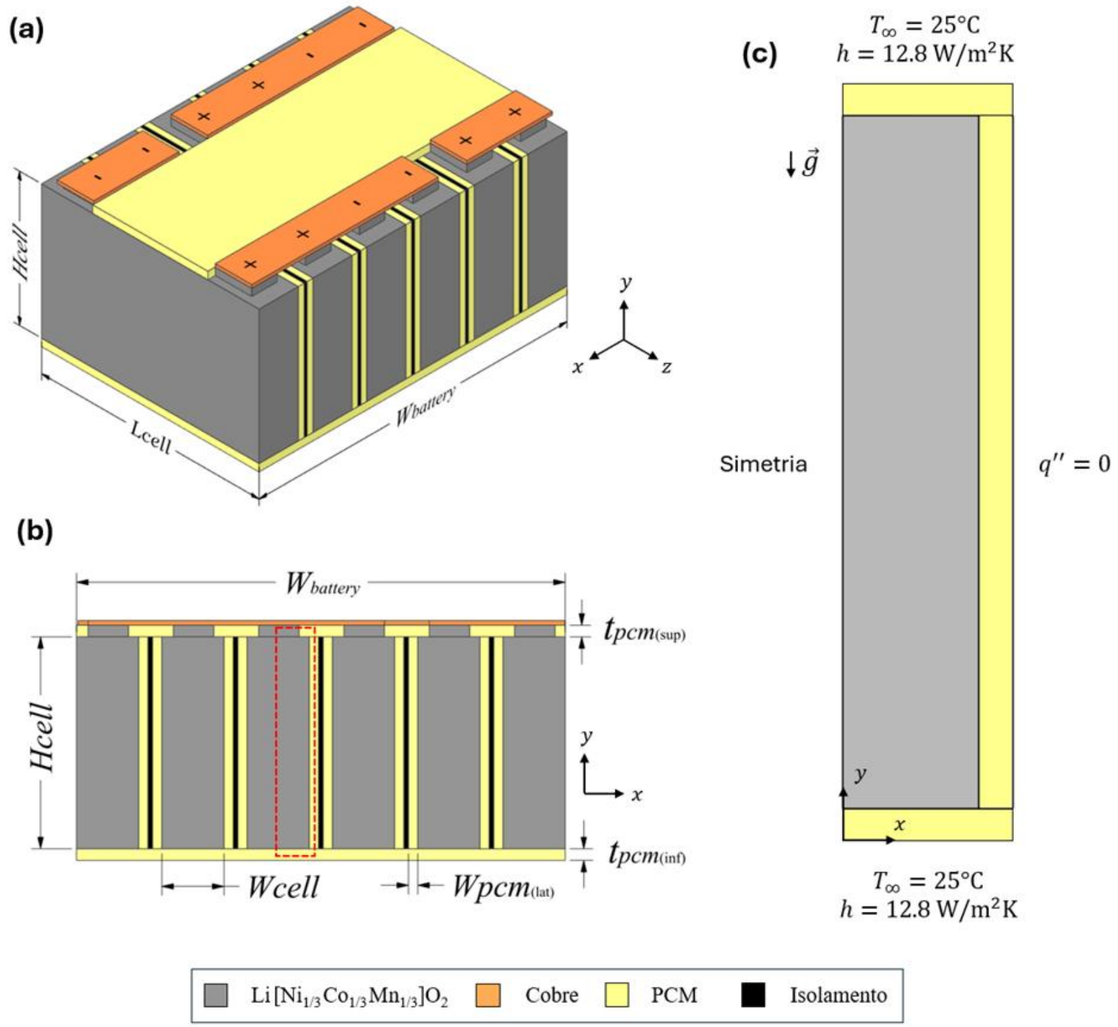
Model	AAA1a	AAA1b	AAA1c	AAA2a	AAA2b	AAA2c
D_{max}	35.0 mm	42.5 mm	50.0 mm	35.0 mm	42.5 mm	50.0 mm
DHr	0.45	0.45	0.45	0.83	0.83	0.83

Healthy artery diameter: D = 20 mm

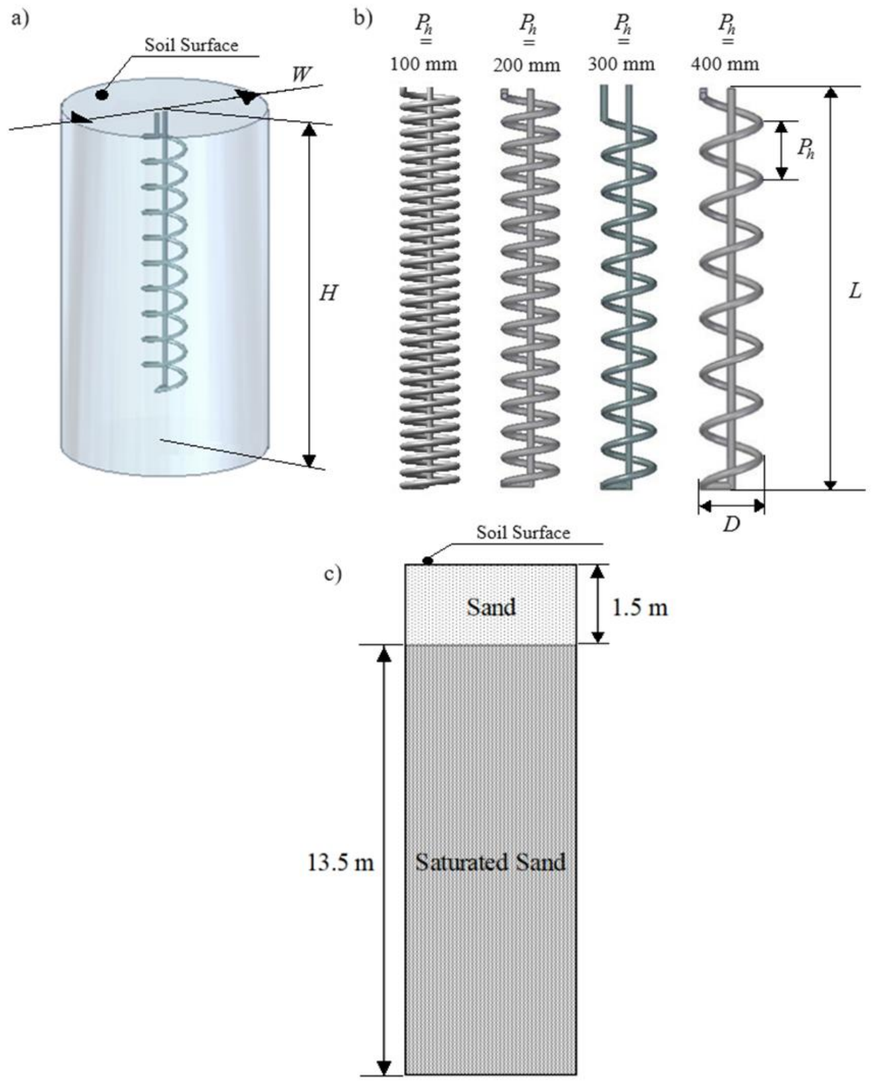


Wave energy converters: (a) oscillating water column, (b) overtopping, and (c) submerged horizontal plate.

LITHIUM-ION BATERIES COOLED BY PCM RESERVOIRS



Schematic representation of the battery pack analyzed, where (a) isometric view, (b) side view, and (c) computational domain.



EAHE-VH: a) computational domain; b) geometry of the helical duct, and c) geotechnical characteristics of the soil.

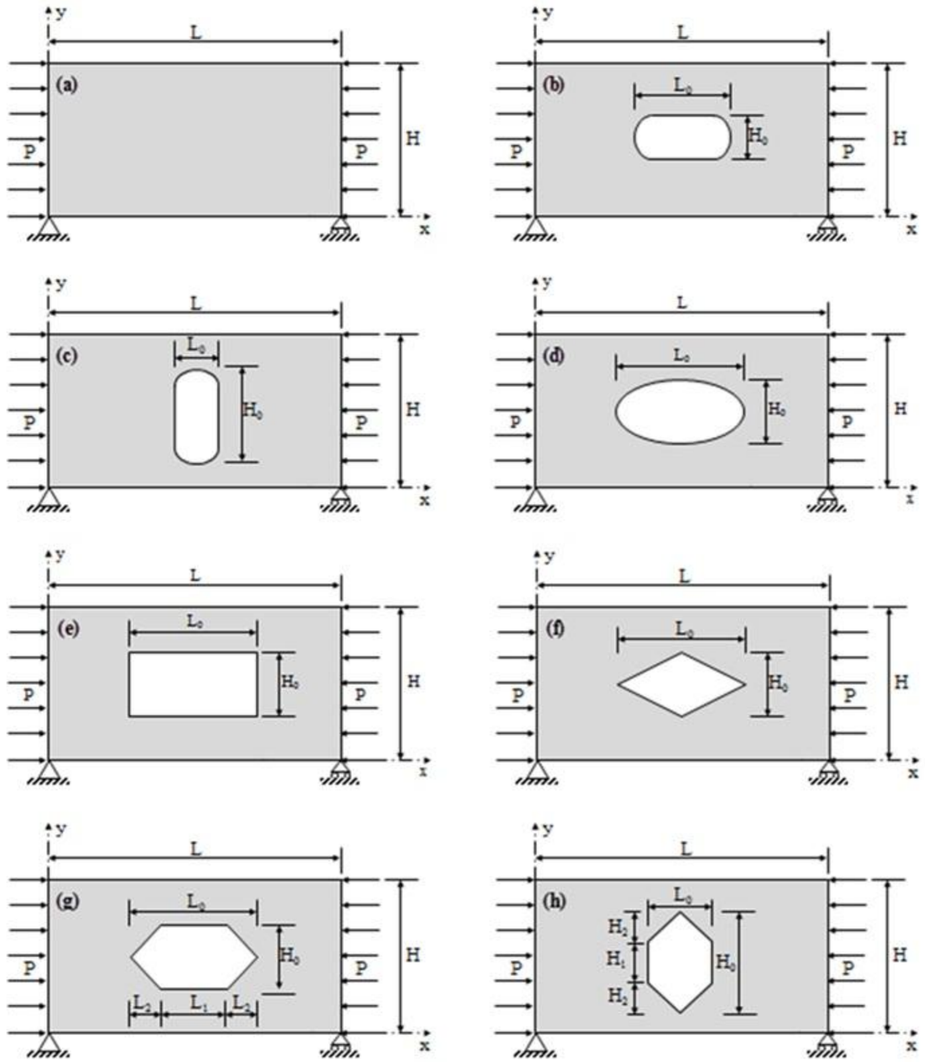
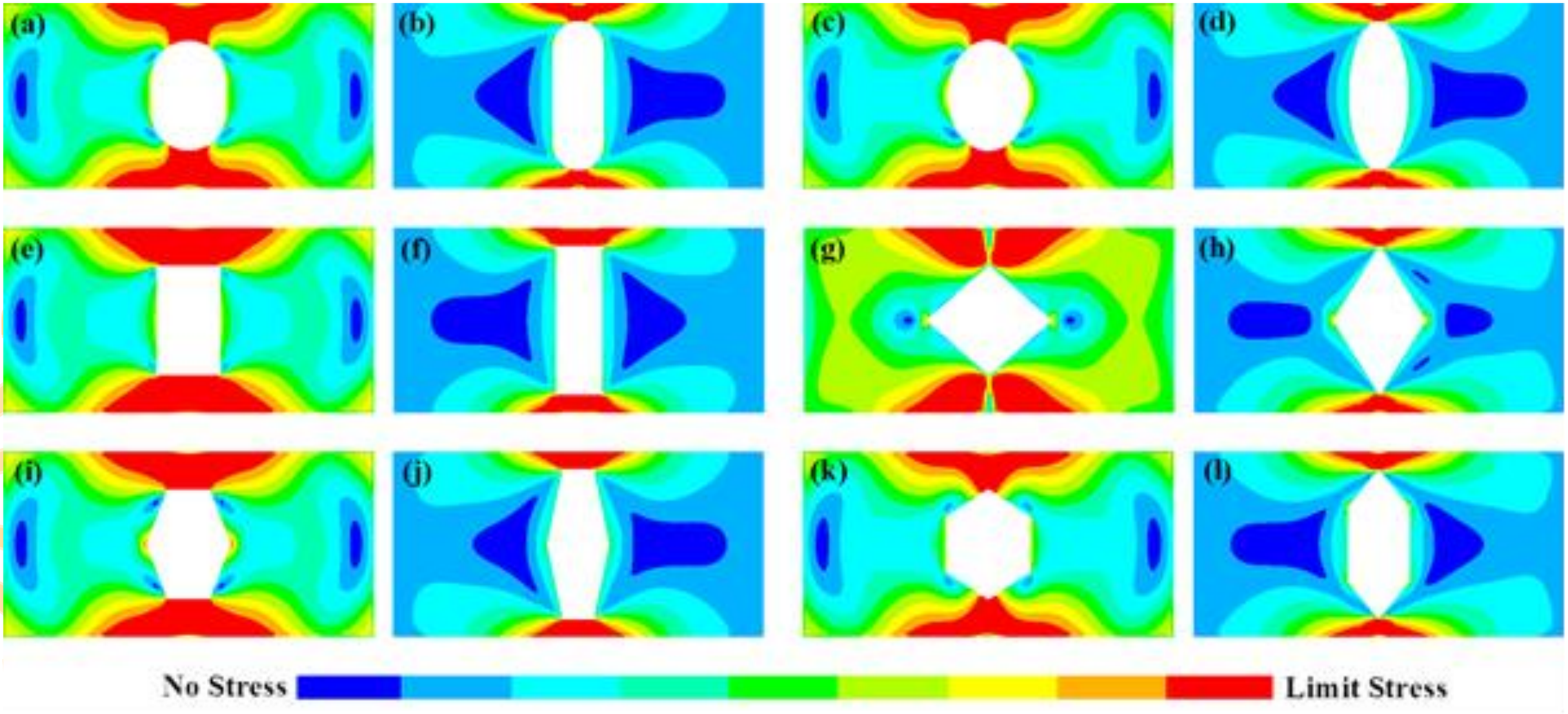


Plate with no hole (a) and plates with a centered opening of type: longitudinal oblong (b), transversal oblong (c), elliptical (d), rectangular (e), diamond (f), longitudinal hexagonal (g), and transversal hexagonal (h).



Distribution of the von Mises stress:
(a, c, e, g, i, k) best shapes, and (b, d, f, h, j, l) worst shapes.

CONCLUSIONS

The meaning of Constructal Theory, Constructal Law, and Constructal Design was discussed and clarified;

Most researchers worldwide are aware of the Constructal realm: 1,389 documents were published by 1,300 authors from 500 institutions, and 50 countries.

Only around 30% of the published articles are from the Engineering field;

The Constructal network is spreading and growing in Brazil;

Constructal Design is useful and effective to search for better designs as shown by its many applications;

“Geometry matters”

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Wilson dos Santos – PPGMC/FURG

"For actually the earth had no roads to begin with, but when many men pass one way, a road is made."

(Lu Xun, 1921)

THANK YOU VERY MUCH

Thank you very much

Muito obrigado

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