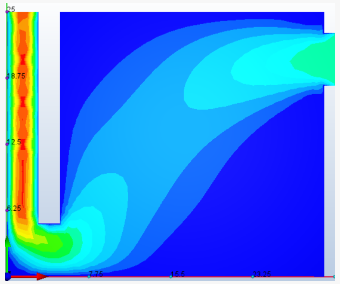
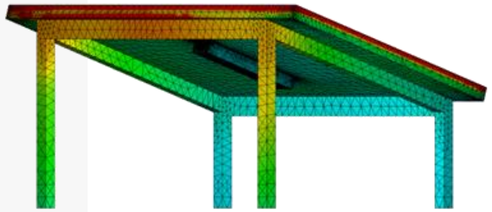
Universidad Juárez Autónoma de Tabasco
"Estudio en la duda. Acción en la fe"

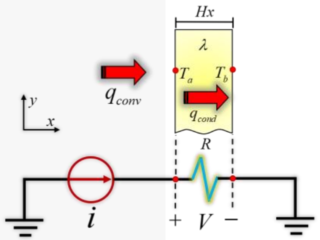
Facultad de Ingeniería
Universidad de la República Uruguay

JORNADAS URUGUAYAS DE CIENCIAS DE LA COMPUTACIÓN 2025

Modelado y evaluación de soluciones pasivas en edificaciones para ciudades sostenibles







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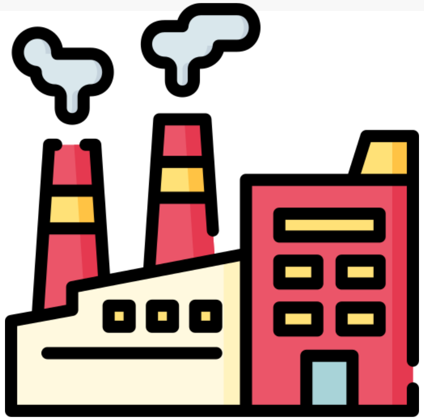
December 11th 2025

Global Challenge: Energy and Buildings

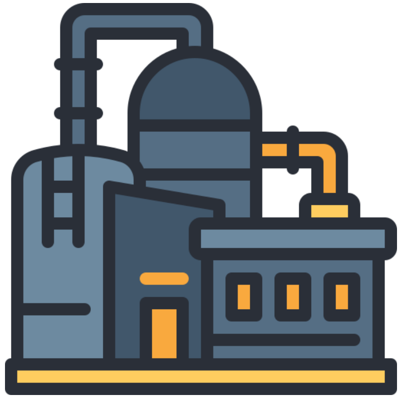
International
Energy Agency

2025

Global energy demand has increased 20% since 2010*



Total global energy demand continues to increase, rising by 2% in 2024 to more than 650 exajoules (EJ). Fossil fuels accounted for nearly four-fifths of total energy demand – a share that has decreased only marginally since 2000.*



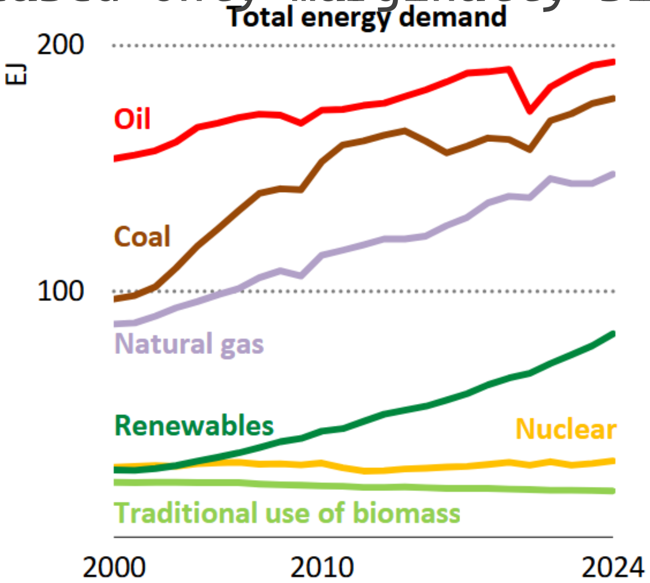
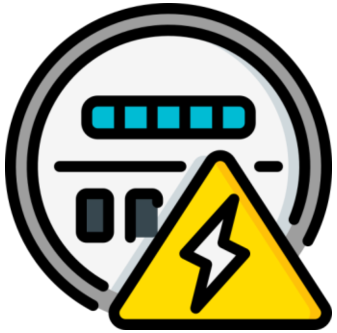


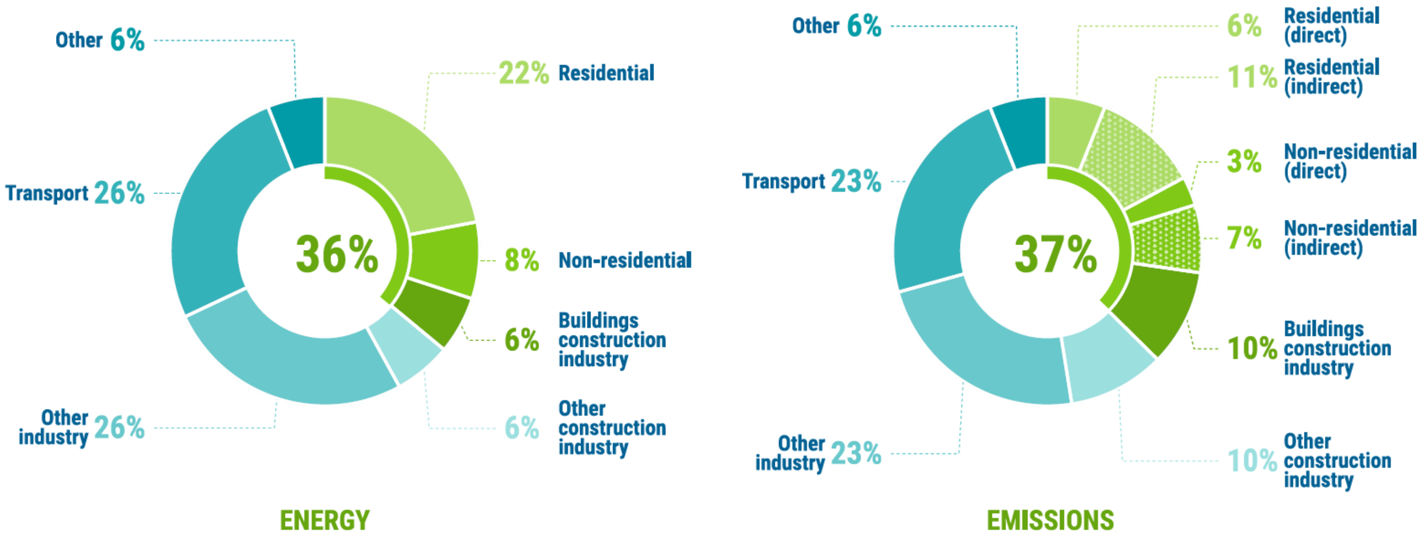
Figure Global energy demand by fuel, 2000-2024*

* “World Energy Outlook 2025”, International Energy Agency

Global Challenge: Energy and Buildings

2020–2024





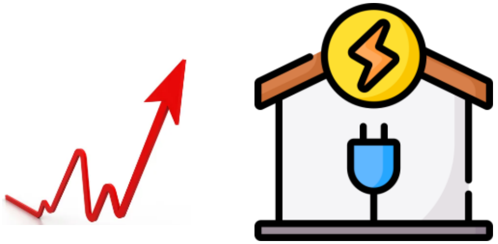
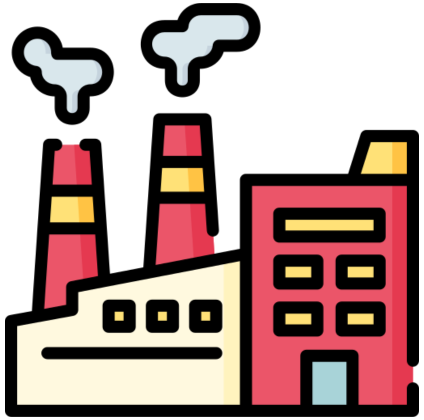


Figure. Buildings and construction's share of global final energy and energy-related CO2 emissions, 2020 *

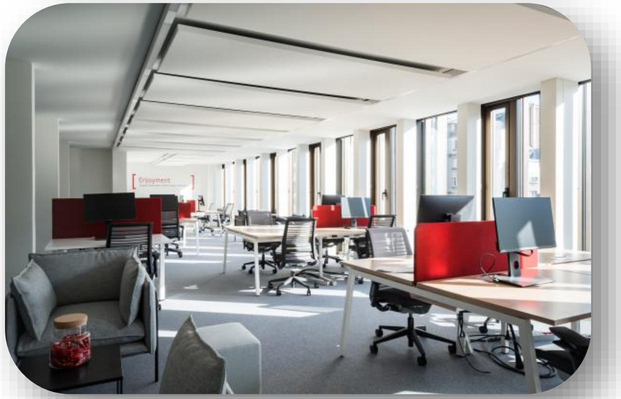
* "Tracking Clean Energy Progress", IEA 2021

Global Challenge: Energy and Buildings

2020–2024



Buildings consume approximately one-third of the world's energy, highlighting their importance for energy efficiency improvements. This sector is also responsible for a similar percentage of energy-related CO_2 emissions, which ranges from 26% to 37%, according to the IEA and the IPCC.

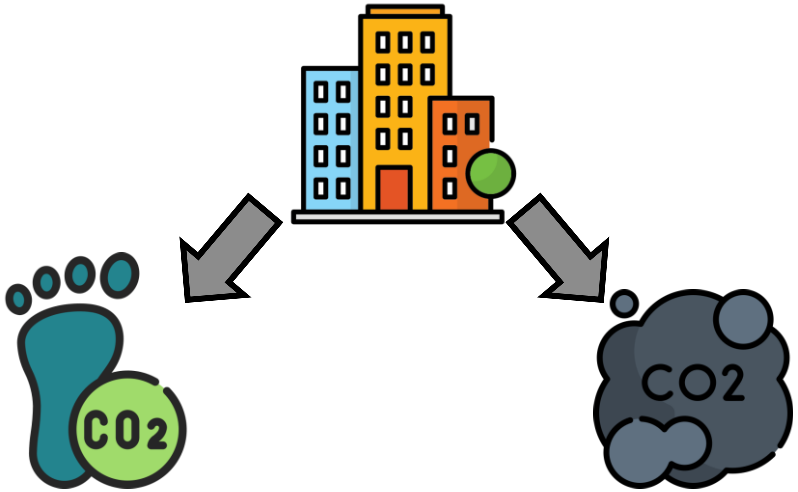


Global Challenge: Energy and Buildings

UN environment programme

June 2024

Energy-related carbon dioxide emissions from building operations and construction reached a new high, rising to 10 gigatonnes, according to a recent report from the UNEP. This represents 37 percent of global carbon dioxide emissions.



Most popular types of energy

Fossil Fuels (Oil & Gas Sector)

- Crude oil and derivatives (gasoline, diesel, kerosene)
- Natural gas (processing, transport, and power generation)
- Coal

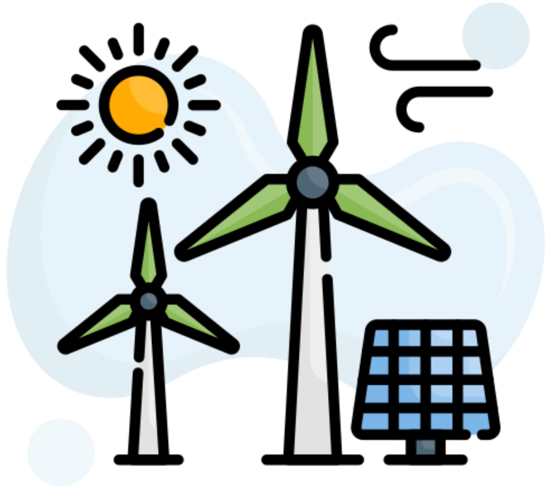
Conventional Power Generation

- Thermal power (plants burning fossil fuels)
- Nuclear energy

Renewable Energies

- Wind power
- Solar energy
- Hydropower
- Biomass and biogas
- Geothermal energy

Some applications: Passive Strategies



- Sun
- Wind
- Geothermal

…

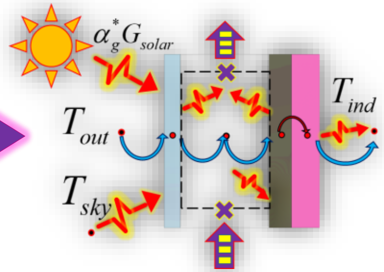


Fig. Solar Chimney with PCM
(Torres-Aguilar et al., 2025)

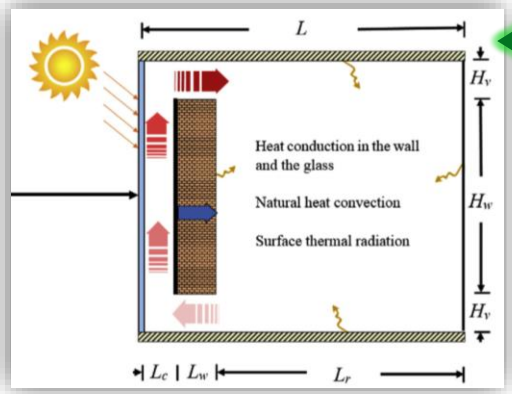


Fig. Trombe Wall
(Hernández-López et al., 2016)

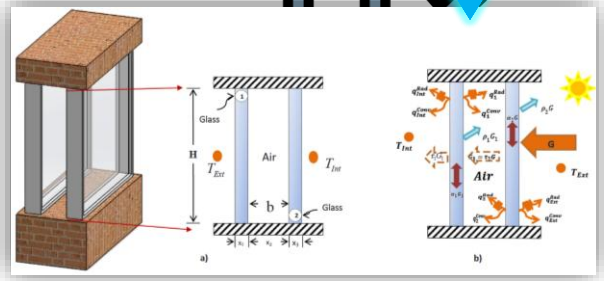


Fig. Double-glazed window
(González-Julián et al., 2018)

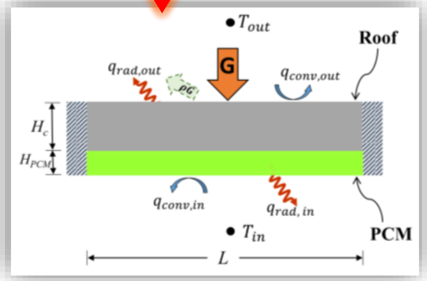
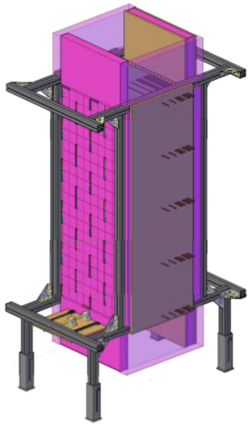


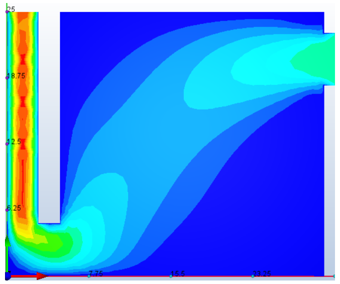
Fig. PCM Ceiling
(Xamán et al., 2019)

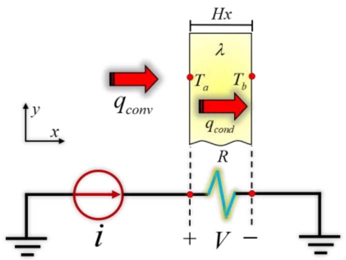
Fig. PV-PCM
(Tariq et al., 2020)

Renewable Energy and Simulation: Passive Strategies

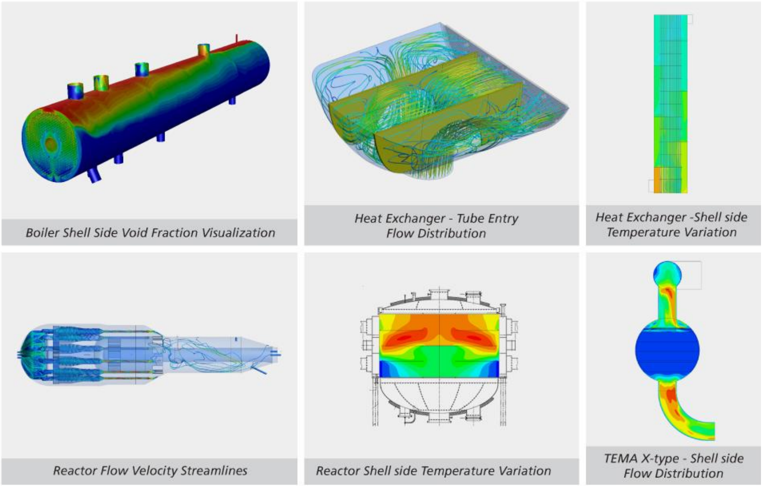
- Energy analysis
  - Experimental
    - Outdoor conditions
    - Controlled conditions
  - Theoretical
    - Analytical
    - Numerical
      - CFD
      - GEB

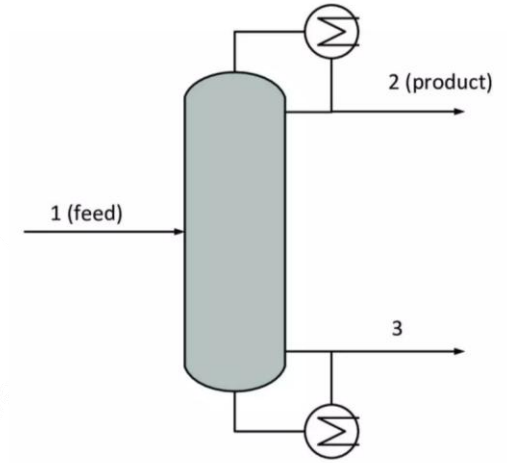


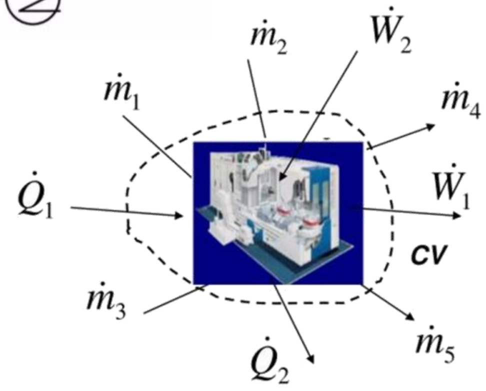




CFD vs GEB


Boiler Shell Side Void Fraction Visualization
Heat Exchanger - Tube Entry Flow Distribution
Heat Exchanger -Shell side Temperature Variation
Reactor Flow Velocity Streamlines
Reactor Shell side Temperature Variation
TEMA X-type - Shell side Flow Distribution


2 (product)
1 (feed)
3


$\dot{m}_2$
$\dot{W}_2$
$\dot{m}_1$
$\dot{m}_4$
$\dot{Q}_1$
$\dot{W}_1$
CV
$\dot{m}_3$
$\dot{Q}_2$
$\dot{m}_5$

Energy and mass balance vs CFD

Navier–Stokes Equations

$$\underbrace{\frac{\partial(\rho\phi)}{\partial t}}_{Transient}+\underbrace{\frac{\partial(\rho u\cdot\phi)}{\partial x}+\frac{\partial(\rho v\cdot\phi)}{\partial y}+\frac{\partial(\rho w\cdot\phi)}{\partial z}}_{Convective}=\underbrace{\frac{\partial}{\partial x}\left(\Gamma\frac{\partial\phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma\frac{\partial\phi}{\partial y}\right)+\frac{\partial}{\partial z}\left(\Gamma\frac{\partial\phi}{\partial z}\right)}_{Diffusive}+\underset{Source}{S}$$

$$\frac{\partial(\rho)}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}=0$$

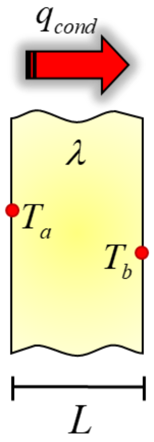
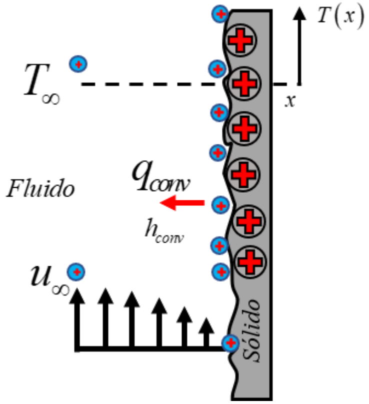
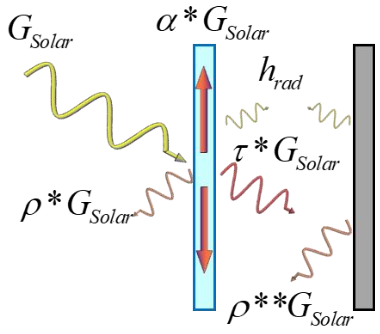
$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u\cdot u)}{\partial x}+\frac{\partial(\rho v\cdot u)}{\partial y}=\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)-\frac{\partial P}{\partial x}+\rho g_x\beta(T-T_\infty)$$

$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho u\cdot v)}{\partial x}+\frac{\partial(\rho v\cdot v)}{\partial y}=\frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)-\frac{\partial P}{\partial y}+\rho g_y\beta(T-T_\infty)$$

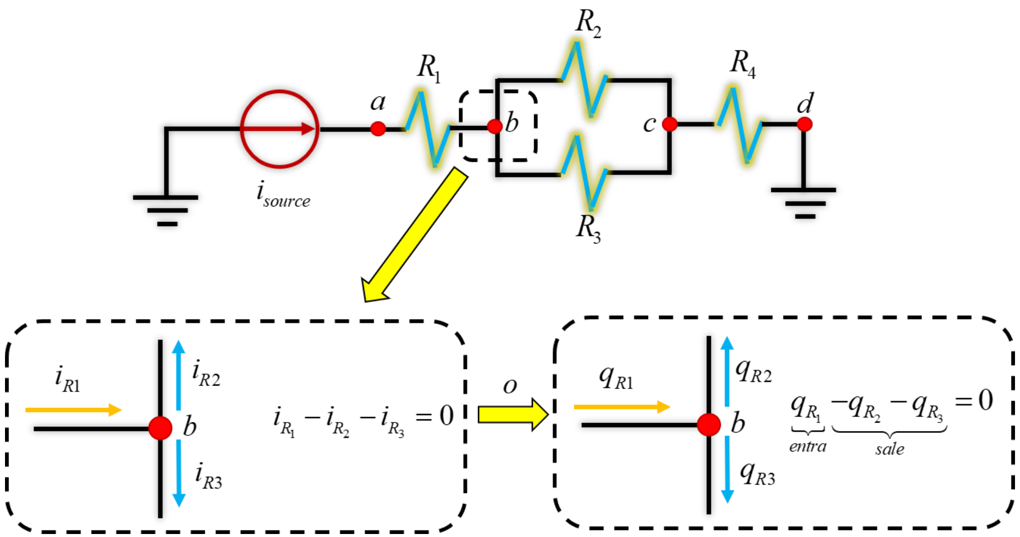
$$\frac{\partial(\rho T)}{\partial t}+\frac{\partial(\rho u\cdot T)}{\partial x}+\frac{\partial(\rho v\cdot T)}{\partial y}=\frac{\partial}{\partial x}\left(\frac{\lambda}{C_p}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\lambda}{C_p}\frac{\partial T}{\partial y}\right)$$

Γ	S	ϕ
0	0	1
μ		u
μ		v
$\frac{\lambda}{C_p}$	0	T

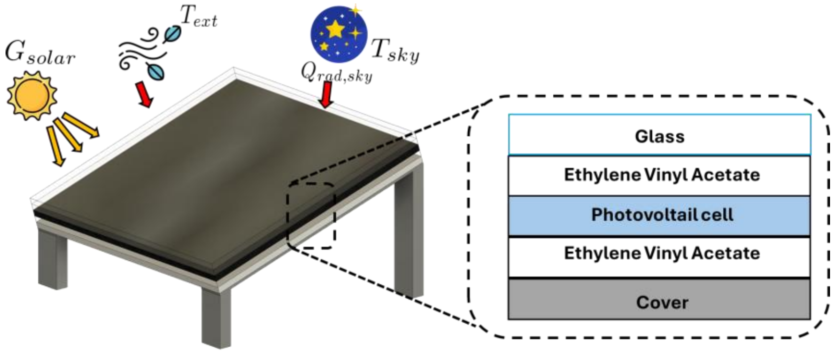
Global Energy balance

Conduction	Convection	Radiation
		
Fourier's law $q_{cond} = \lambda \frac{(T_a - T_b)}{L}$	Newton's law of cooling $q_{conv} = h_{conv}(T - T_\infty)$	Stefan-Boltzmann law $q_{rad} = \sigma\varepsilon(T_{sky}^4 - T^4) = h_{rad}(T_{sky} - T)$
$I = q_{cond}$, $V = (T_a - T_b)$, $R = \frac{L}{\lambda}$	$I = q_{conv}$, $V = (T - T_\infty)$, $R = \frac{1}{h_{conv}}$	$I = q_{rad}$, $V = (T_{sky} - T)$, $R = \frac{1}{h_{rad}}$

Electric circuits analogy



Study Case: Photovoltaic panel



CFD

- Language: C++
- Steady-state (average boundary conditions)
- Turbulence (k-ε)
- Three-dimensional
- Computational time: 72 hours

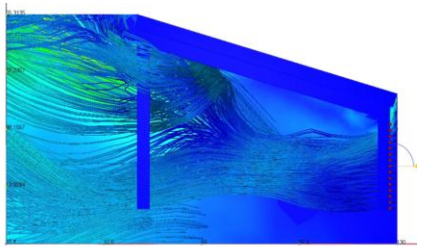


Fig. Air Flow distributi on

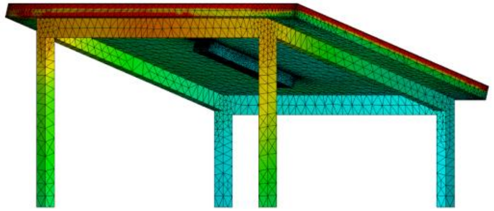


Fig. Temperature of photovoltaic panel and structure

GEB

- Language: Python 3.12.7
- Unsteady-state (boundary conditions based on weather data of one day)
- Turbulence correlations for convective coefficients
- Computational time: 10 seconds

Processor: 13th Gen Intel Core i9-13900HK
RAM: 32 GB
Operative System: Windows 11

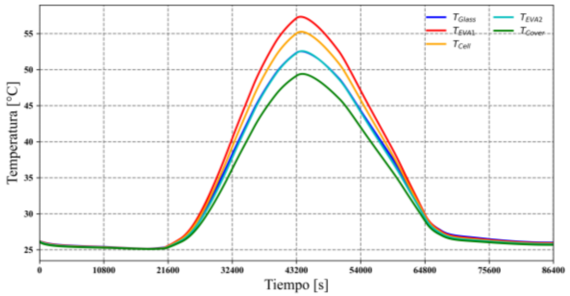


Fig. Temperature of the PV components

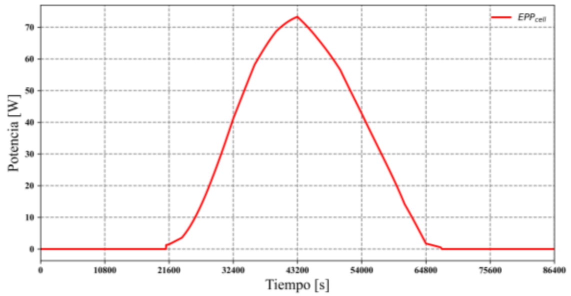
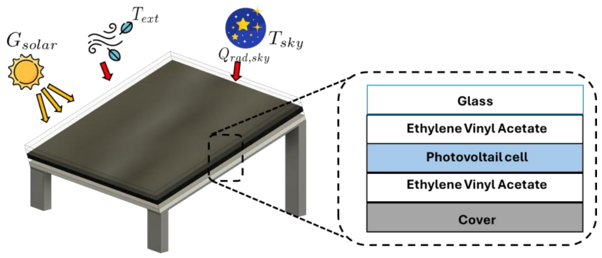
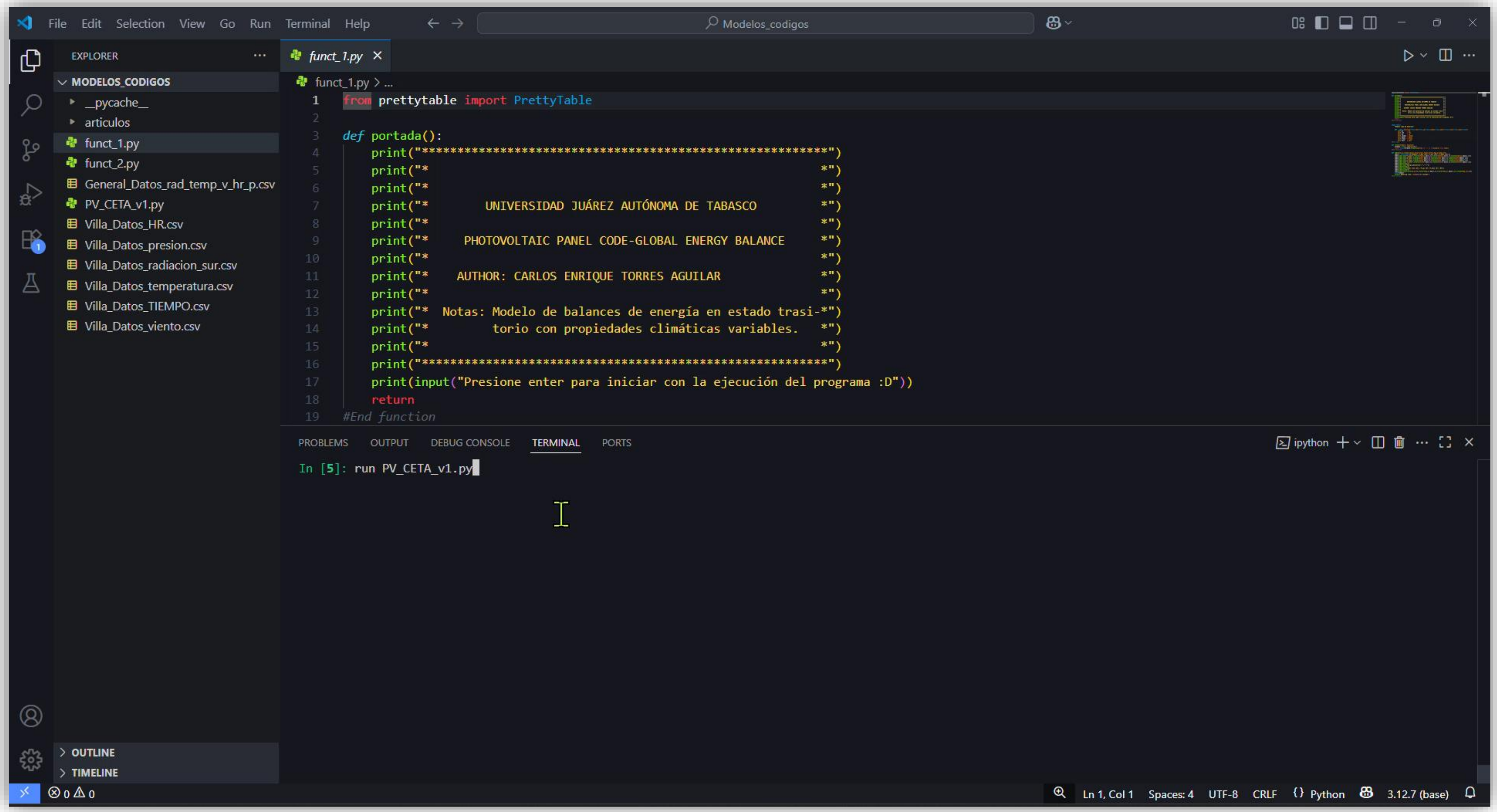


Fig. Energy produced by the PV

CFD application: Photovoltaic panel performance

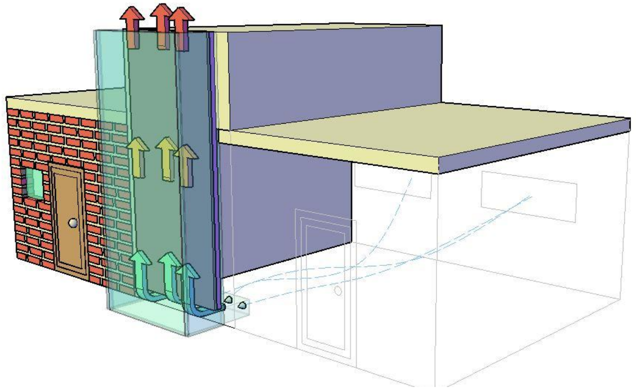
Computational time GEB approach

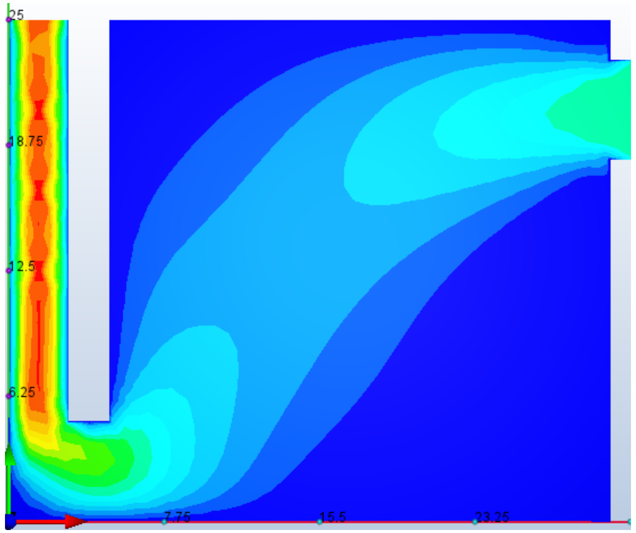




Study Case: Solar Chimney

Solar Chimney connected to a room



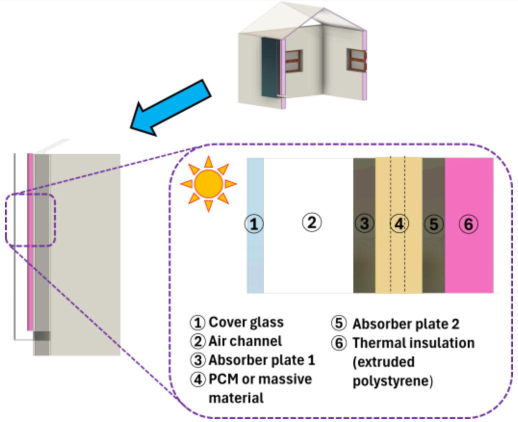


– High computational demand

– Field of temperature, pressure, velocity, and other scalar variables.

– Developed on any computational platform. However, a low-level computational language is recommended.

CFD application: Solar Chimney



CFD

- Language: C++
- Steady-state (average boundary conditions)
- Turbulence (k-ε)
- Two-dimensional
- Computational time: 20 hours

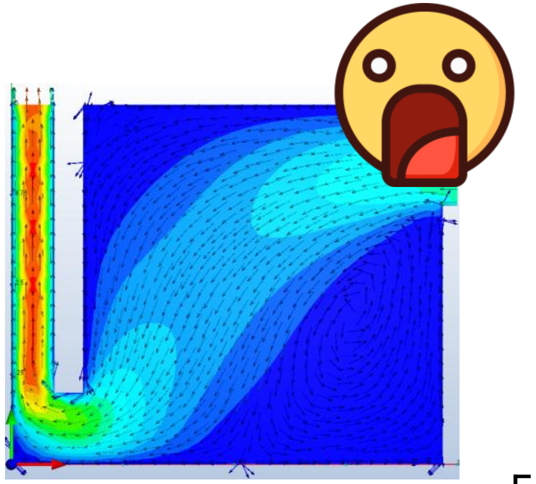


Fig. Velocity magnitude

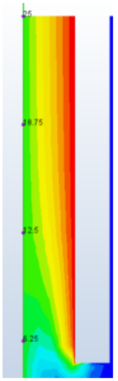


Fig. Temperature contours of channel

Processor: 13th Gen Intel Core i9-13900HK
RAM: 32 GB
Operative System: Ubuntu 22.04.5

GEB

- Language: C++
- Unsteady-state (boundary conditions based on weather data of one year)
- Turbulence correlations for convective coefficients
- Computational time: 30 minutes

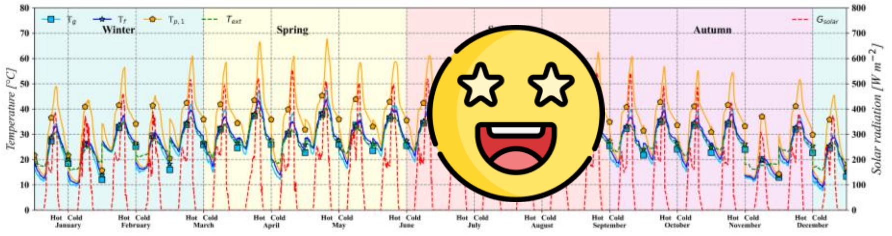


Fig. Temperature of solar chimney elements (one year)

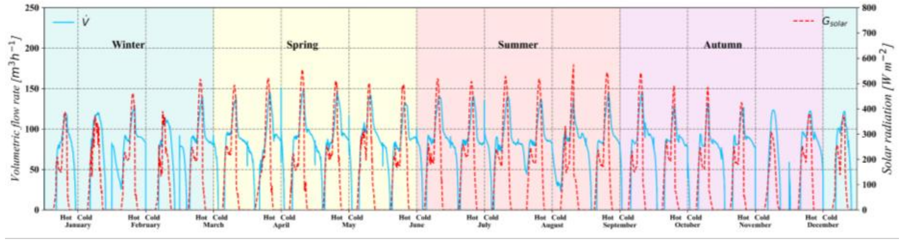
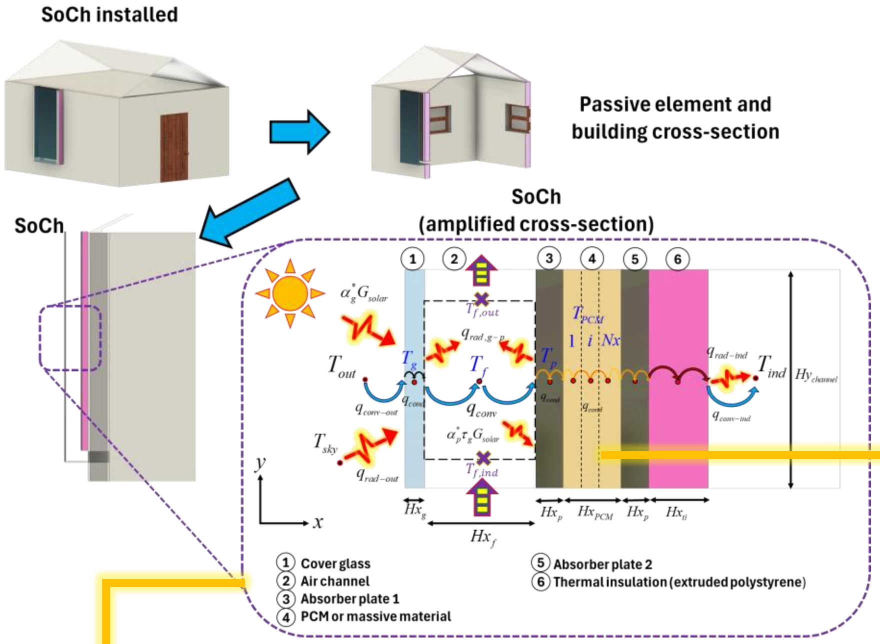
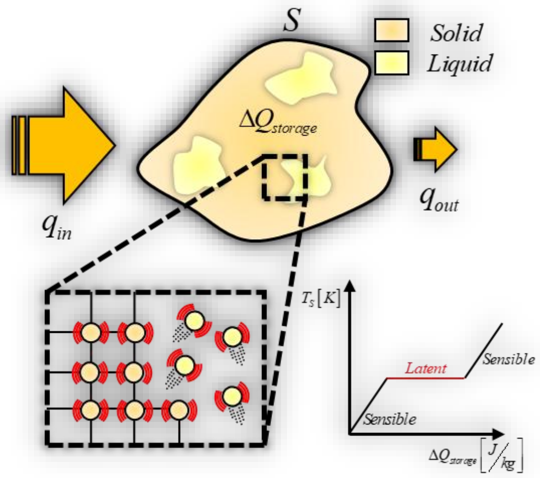


Fig. Volumetric Flow rate induced by solar chimney (one year)

Future work: Hybrid Approach





PCM: Effective heat capacity method

$$\rho\left[\underbrace{C_P+\frac{h_{liq-sol}}{\Delta T}}_{C_{P-effect}}\right]\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right)+g$$

$$C_{P-effect}=\begin{cases} C_{P-sol} & T<T_{sol} \\ \dfrac{C_{P-sol}+C_{P-liq}}{2}+\dfrac{h_{ls}}{\Delta T} & T_{sol}\le T\le T_{liq} \\ C_{P-liq} & T>T_{liq} \end{cases}$$

GEB Model

$$\rho C_P\frac{\partial T}{\partial t}=\sum q_{inputs}-\sum q_{outputs}$$

+

CFD: Finite Volume Method

$$\int_V\frac{\partial}{\partial x}\left(\Gamma\frac{\partial\phi}{\partial x}\right)dV+\int_V\frac{\partial}{\partial y}\left(\Gamma\frac{\partial\phi}{\partial y}\right)dV+\int_V SdV=0$$

$$\left[\left(\Gamma\Delta y\frac{\partial\phi}{\partial x}\right)_e-\left(\Gamma\Delta y\frac{\partial\phi}{\partial x}\right)_w\right]+\left[\left(\Gamma\Delta x\frac{\partial\phi}{\partial y}\right)_n-\left(\Gamma\Delta x\frac{\partial\phi}{\partial y}\right)_s\right]$$
$$+\bar{S}\Delta x\Delta y=0$$

=

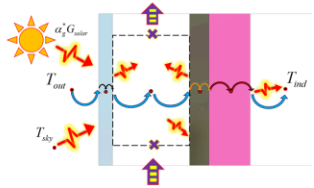
Hybrid Approach

- Two and three-dimensional effects
- Conservation and transportivity during the discretization process.
- Scalability with other techniques such as the Enthalpy Method.

Future work: Hybrid Approach

Linear regression example

Parameters evaluated



$Hy_f, Hx_f, Hx_g, \alpha_p^*, \alpha_p$

SoCh GEB model

$$\rho C_p \frac{\partial T}{\partial t} = \sum q_{inputs} - \sum q_{outputs}$$

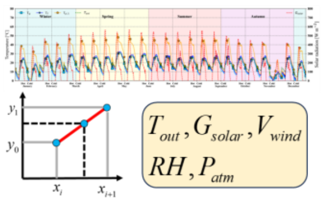
C++ code

Results:

$\dot{m}, \mathrm{ACH}, \mathrm{kgCO_2}, \mathrm{kWh}$

Meteorological data

`interpolate_climate(ambient_temperature,…)`



$T_{out}, G_{solar}, V_{wind}$
RH, P_{atm}

GEB model:
Computational time: 30 minutes

Linear Regression model:
Computational time: 3 seconds

Best metrics:
RMSE = 0.002
R2 = 0.952

Worst metrics:
RMSE = 0.432
R2 = 0.527

Data arrangement (Results)

Python code

Hy_f, α_p, $\dot{m}$, ACH

Numpy library

$\mathbf{X} = Hy_f, Hx_f, Hx_g, \alpha_p^*, \alpha_p$

$\mathbf{Y} = \dot{m}, \mathrm{ACH}, \mathrm{kgCO_2}, \mathrm{kWh},$

Scikit-Learn library

```
train_test_split
(X,Y,test_size=0.33,
random_state=33)
```

[X_training, Y_training]

[X_test, Y_test]

Linear Regression

Scikit-Learn library

Python code

```
LinearRegression()
Fit(X_training,
Y_training)
```

$$\dot{m} = \beta_{0,\dot{m}} + \beta_{1,\dot{m}} Hy_f + \beta_{2,\dot{m}} Hx_f + \beta_{3,\dot{m}} Hx_g + \beta_{4,\dot{m}} \alpha_p^* + \beta_{5,\dot{m}} \alpha_p$$

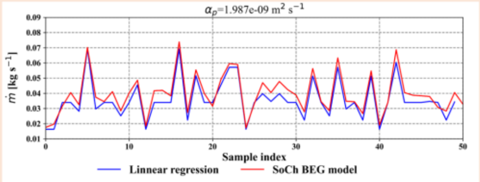
$$\mathrm{ACH} = \beta_{0,\mathrm{ACH}} + \beta_{1,\mathrm{ACH}} Hy_f + \beta_{2,\mathrm{ACH}} Hx_f + \beta_{3,\mathrm{ACH}} Hx_g + \beta_{4,\mathrm{ACH}} \alpha_p^* + \beta_{5,\mathrm{ACH}} \alpha_p$$

$$\mathrm{kgCO_2} = \beta_{0,\mathrm{kgCO_2}} + \beta_{1,\mathrm{kgCO_2}} Hy_f + \beta_{2,\mathrm{kgCO_2}} Hx_f + \beta_{3,\mathrm{kgCO_2}} Hx_g + \beta_{4,\mathrm{kgCO_2}} \alpha_p^* + \beta_{5,\mathrm{kgCO_2}} \alpha_p$$

$$\mathrm{kWh} = \beta_{0,\mathrm{kWh}} + \beta_{1,\mathrm{kWh}} Hy_f + \beta_{2,\mathrm{kWh}} Hx_f + \beta_{3,\mathrm{kWh}} Hx_g + \beta_{4,\mathrm{kWh}} \alpha_p^* + \beta_{5,\mathrm{kWh}} \alpha_p$$

```
Rmse(Y_training, Y_predicted)
R2(X_training,Y_predicted)
```

[X_test,Y_test]



Universidad Juárez Autónoma de Tabasco

"Estudio en la duda. Acción en la fe"

Thank you!

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