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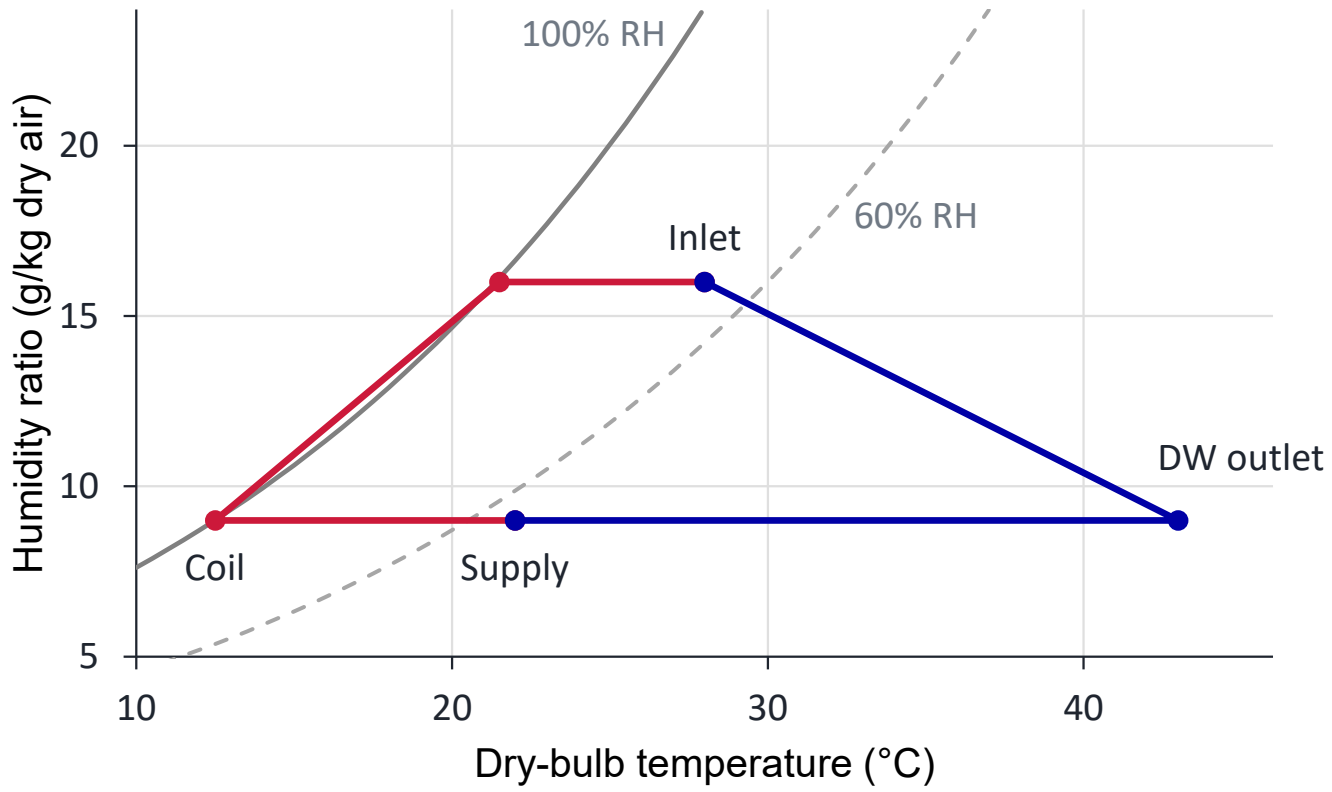
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A Unified Multi-Fidelity Modelica Library for Desiccant Wheel Simulation

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Dehumidification



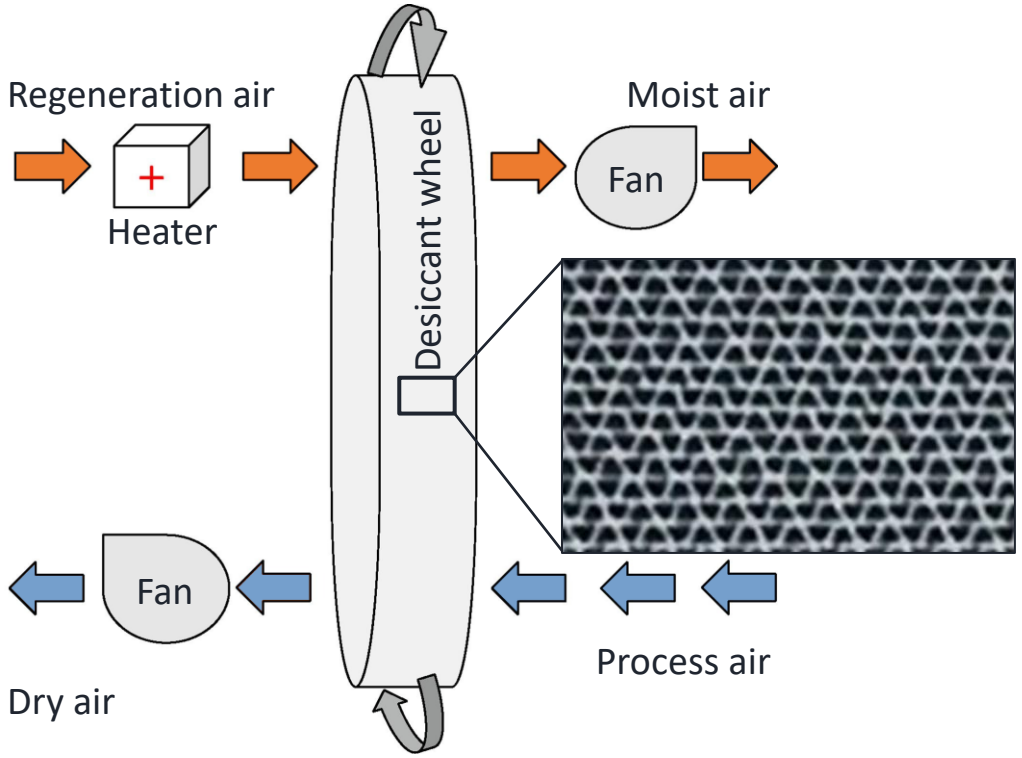
Illustrative paths at 101.3 kPa. Process comparison: ASHRAE Handbook (2025), Ch. 32.

Cooling coil + reheat
Cool below the dew point to condense water. Reheat to the supply temperature.

DW + sensible cooling
Adsorption lowers humidity while warming the process air. Sensible cooling sets the supply temperature.

Regeneration requires heat. Savings depend on its source and the operating conditions.

Wheel Operation

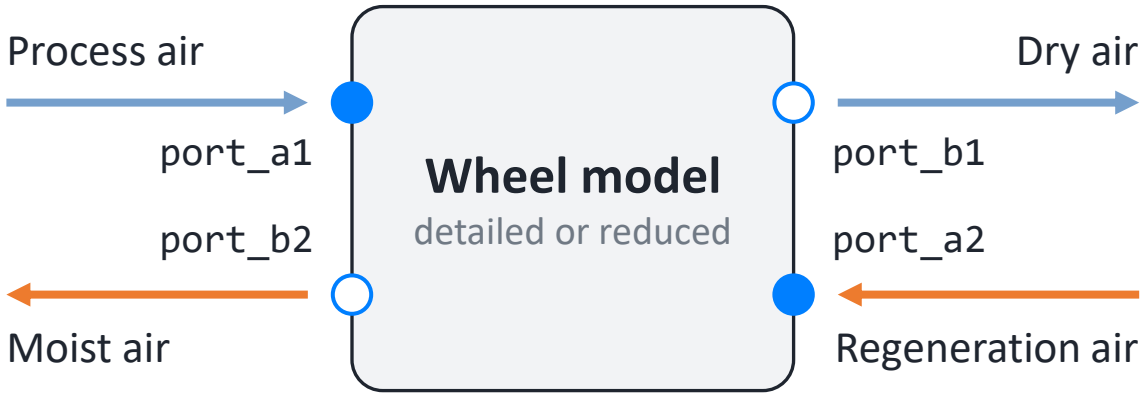


1. A rotating honeycomb matrix carries a desiccant coating.
2. **Process air** passes through one sector. Water vapor adsorbs on the desiccant, drying the air.
3. Heated **regeneration air** passes through the other sector. It removes stored moisture.
4. Rotation carries the material state between the two sectors.

Figure adapted from Ortis and Khatiwada (2023); close-up from Yang and Kim (2025). Both CC BY 4.0.

The wheel exchanges both moisture and heat with two air streams at the same time.

Modeling Needs



A system model sees only these four fluid states, all at the same simulation time.

Component design

How do material and geometry change performance?

Needs resolved channel physics.

System study

What model cost can a long simulation afford?

Needs low computational cost.

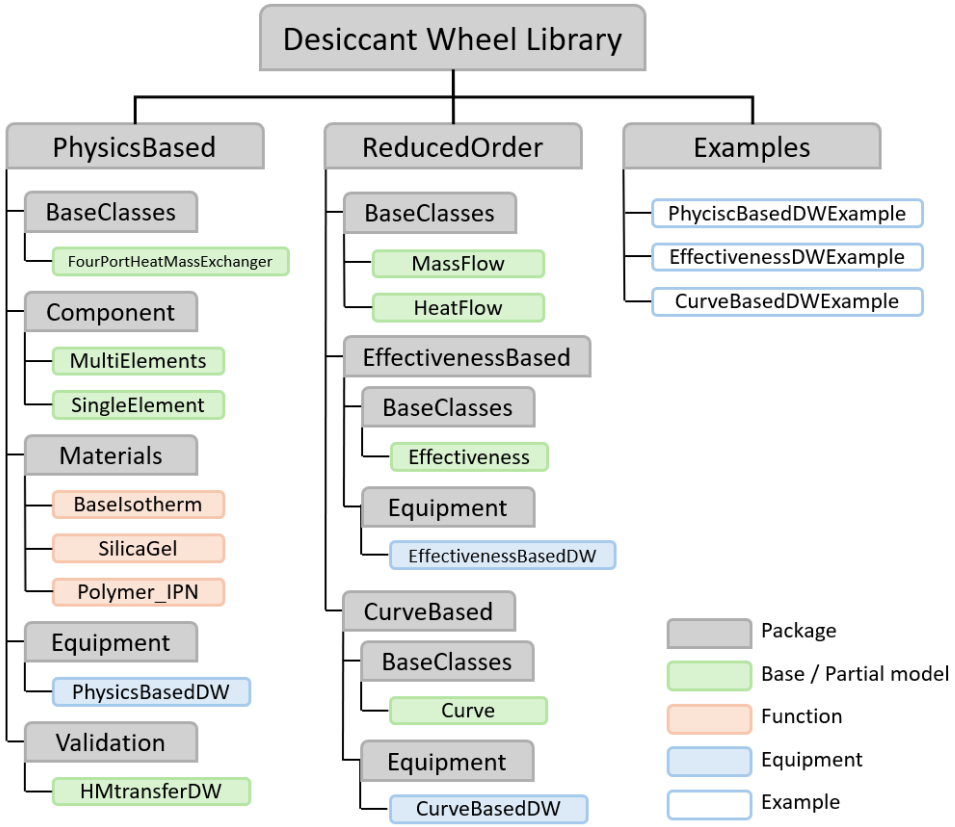
One model resolution cannot answer both questions at the same computational cost.

Modeling Gap

Existing approach	Useful capability	Gap for Modelica systems
Single representative channel	Resolves cyclic heat and moisture transfer	Reports the outlet of whichever sector the channel currently occupies
Standalone detailed implementation	Supports component analysis	Often lacks a reusable four-port Modelica component
Steady-state correlation	Runs quickly in long simulations	Cannot directly explore new material or channel geometry

This work: a library with a full-wheel, multi-element physics model and two reduced-order alternatives. All expose the same four fluid ports.

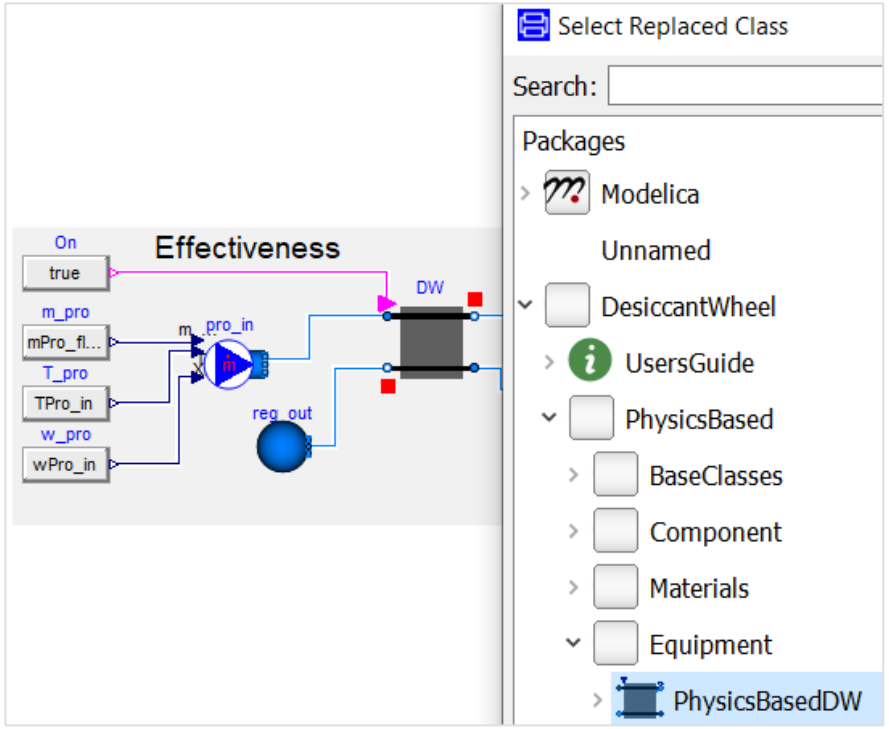
Library Architecture



- **PhysicsBased**: `SingleElement` resolves channel heat and moisture transfer; `MultiElements` assembles the rotating wheel.
- **ReducedOrder**: effectiveness and performance curves calculate steady-state outlet conditions.
- **Examples**: connect each model family to system boundary conditions.

The two families provide different internal models of the same two-stream device.

Unified Model Structure

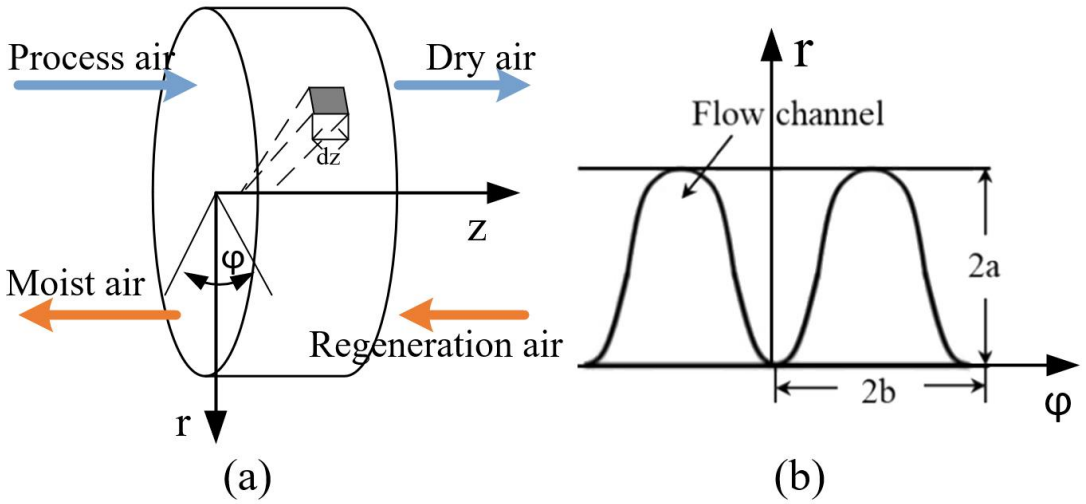


Swapping the DW class keeps the fluid connections.

Implementation	Internal calculation	Additional connector
Physics-based	Dynamic channel and full-wheel model	Speed *N* (RealInput); motor power (RealOutput)
Effectiveness-based	Characteristic potentials	On/off *u* (BooleanInput)
Curve-based	Polynomial performance correlation	On/off *u* (BooleanInput)

The fluid ports are shared; model changes may require adapting the control signal.

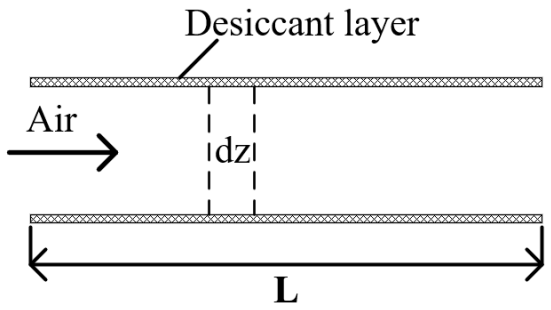
Physics-Based Assumptions



- **Identical channels**: one representative channel is resolved along *z* (a).
- **One-dimensional flow**: axial air flow, no radial gradients.
- **Channel cross-section**: half height *a* and half width *b* set Nu, Sh, and the transfer coefficients (b).
- **Neglected effects**: axial conduction and diffusion, carry-over, leakage, pressure drop.

All channels are identical, so the physics model resolves one representative channel.

Physics-Based Equations



Representative channel: axial air flow exchanges heat and water vapor with a desiccant-coated wall.

Moisture: air and desiccant

$$A\rho_a(\partial_t Y_a + u\partial_z Y_a) = K_y P(Y_d - Y_a)$$
$$^1/_2\, f_d \partial_t W = K_y P(Y_a - Y_d)$$

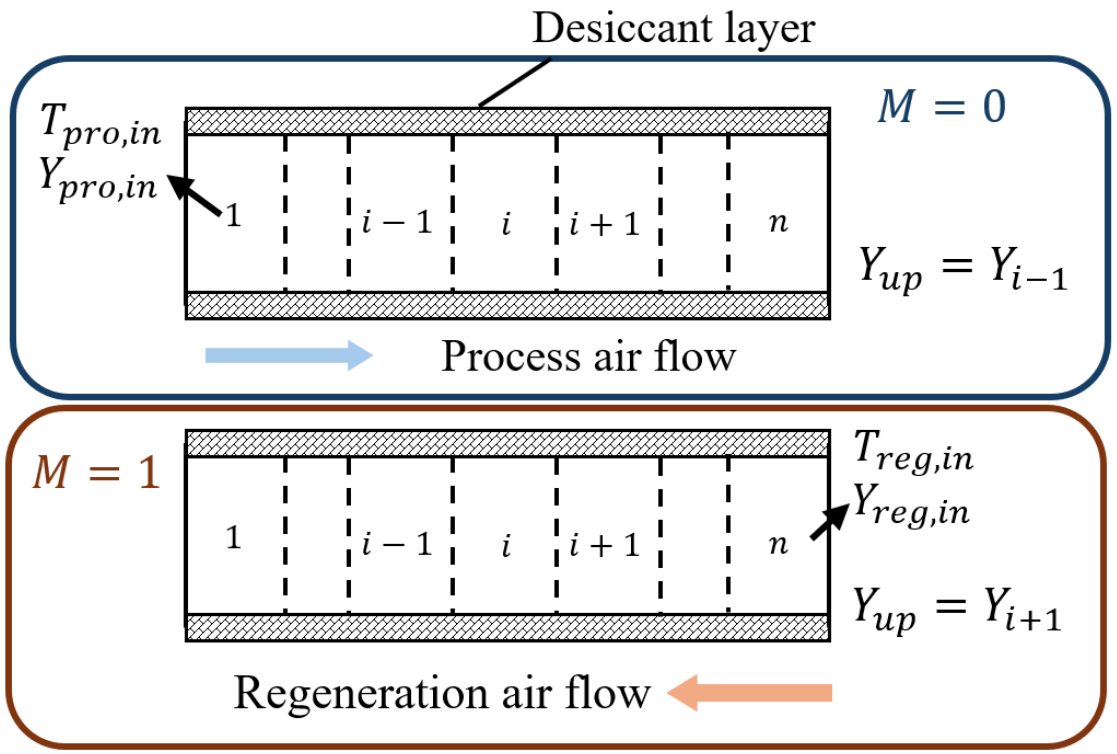
Energy: air and desiccant

$$A\rho_a\left(c_{pa} + Y_a c_{pv}\right)(\partial_t T_a + u\partial_z T_a) = hP(T_d - T_a) + K_y P c_{pv}(Y_d - Y_a)(T_d - T_a)$$
$$\left[^1/_2\, f_d\left(c_{pd} + W c_{pl}\right) + f_{sp} c_{psp}\right]\partial_t T_d = hP(T_a - T_d) + K_y P(Y_a - Y_d) q_{st} + K_y P c_{pv}(Y_a - Y_d)(T_a - T_d)$$

Terms: ∂_t: storage; $u\partial_z$: air advection; $K_y P\Delta Y$: vapor transfer; $hP\Delta T$: sensible heat; c_{pv} terms: heat carried with vapor; q_{st}: adsorption heat.

Symbols: Y_a,Y_d: air/equilibrium humidity (Y_d from isotherm); W: water loading; T_a,T_d: temperatures; u: air speed; A,P: channel area/perimeter; ρ_a: air density; K_y,h: transfer coefficients; f_d,f_{sp}: solid mass per length; c_p: specific heats.

Physics-Based Discretization



Axial finite volumes

Divide channel length L into n cells, $\Delta z = L/n$.

Mode-dependent first-order upwind

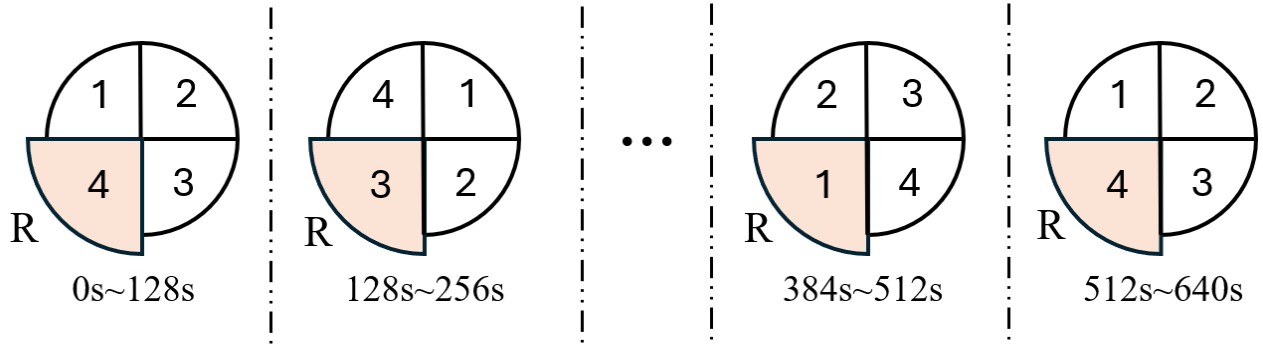
For interior cell i,

$$Y_{\mathrm{up,i}} = \begin{cases} Y_{a,i-1}, & M = 0 \quad \text{(process)}, \\ Y_{a,i+1}, & M = 1 \quad \text{(regeneration)}. \end{cases}$$

$T_{\mathrm{up},i}$ follows the same selection. Boundary cells use process inlet at $z = 0$ or regeneration inlet at $z = L$.

The channel retains its thermal and moisture states when its mode changes.

Physics-Based Full Wheel



Rotation and sector assignment

n_{Ele} channel elements represent the wheel; n_{PEle} occupy the process sector. At speed N rev/h, the logical positions shift every

$$\Delta t_{\text{sw}} = \frac{3600}{N n_{\text{Ele}}}$$

Each element retains its internal state as its mode changes.

Outlet aggregation

Average the elements currently in each sector. For process temperature,

$$T_{\text{out,pro}} = \frac{\sum_i w_{\text{pro},i} T_{\text{out},i}}{n_{\text{PEle}}}.$$

$w_{\text{pro},i}$ = 1 in the process sector and 0 otherwise. The same rule gives the regeneration outlet and both humidity ratios at each time.

Reduced-Order Models

	Effectiveness model	Performance curve
Basis	Jurinak characteristic potentials $F_1(T,Y)$ and $F_2(T,Y)$	EnergyPlus polynomial correlations
Parameters	Two calibrated effectiveness factors	Regression coefficients and valid input ranges
Primary calculation	Solve process outlet T and Y from inlet states	Calculate regeneration outlet T and Y from inlet states
Strength	Physical thermodynamic analogy	Very low computation cost
Limitation	Factors depend on calibration	Limited extrapolation and material insight

Both are steady-state alternatives to the dynamic channel model.

Reduced-Order Coupling

Moisture source term

$$\dot{m}_w = \frac{\dot{m}}{1 + Y_{\text{in}}}(Y_{\text{out}} - Y_{\text{in}})$$

The opposite air path receives $-\dot{m}_w$.

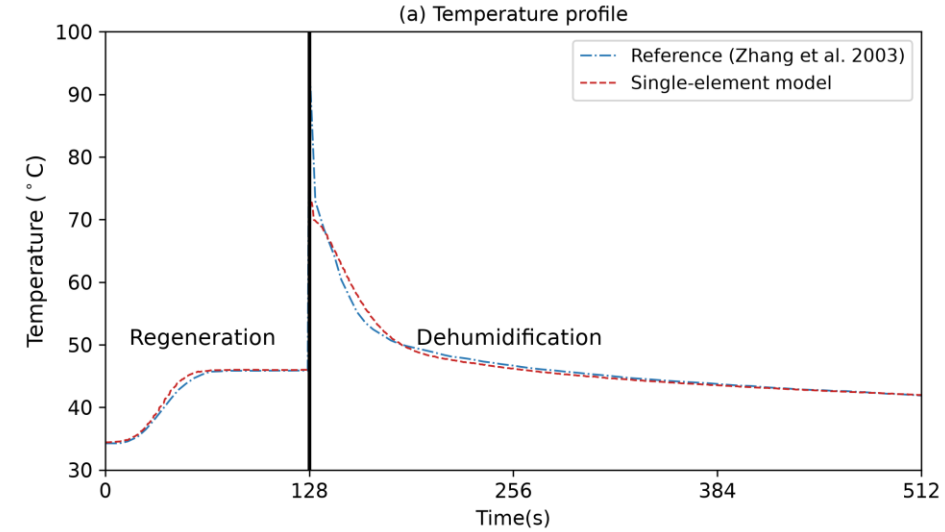
Heat source term

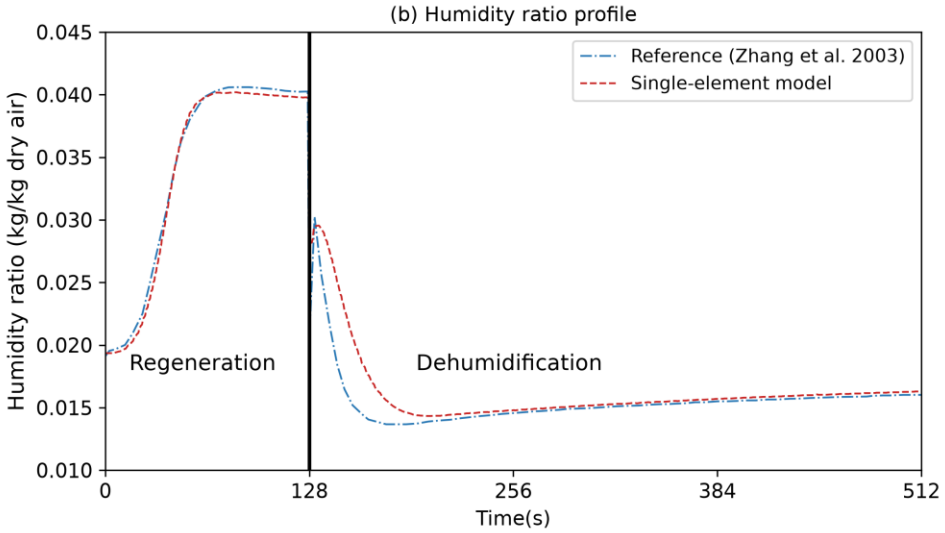
$$\dot{Q} = (h_{\text{in}} - h_{\text{out}})\dot{m}$$

The opposite path receives $-\dot{Q}$.

- A predicted outlet state becomes heat and moisture exchange in two fluid volumes.
- Both sides conserve transferred heat and moisture within the modeled component.
- Boolean input *u* sets the exchange terms to zero when the wheel is off.
- The four fluid port names match the physics model; the control input differs (*u* versus *N*).

Validation of Physics Models





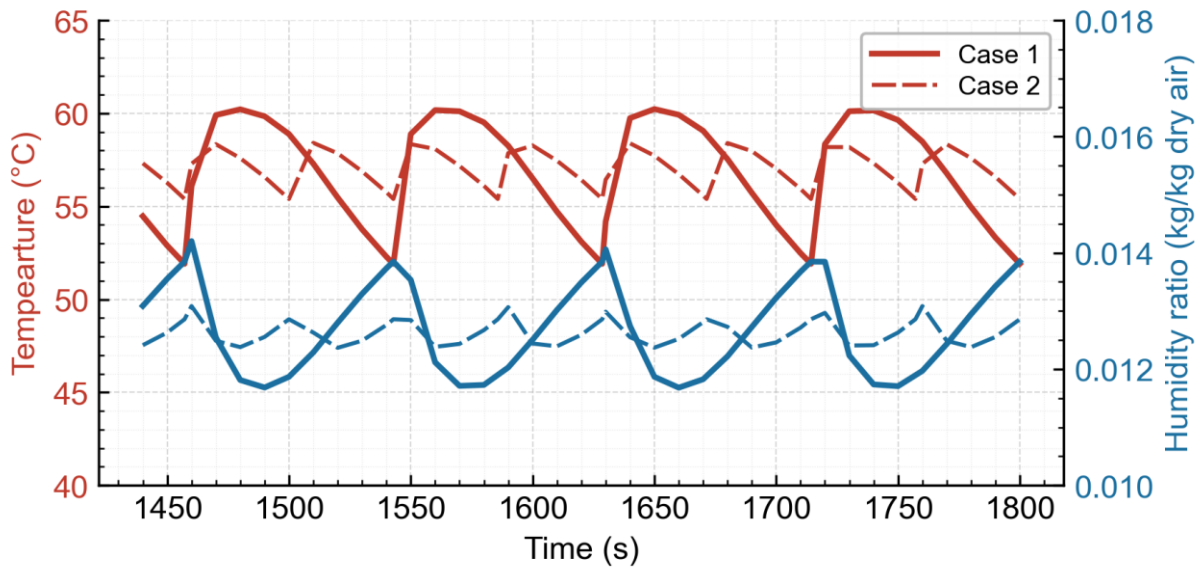
Reference case

Zhang et al. (2003), one 512 s rotation cycle; process inlet 34.3 °C, regeneration inlet 100 °C.

	Agreement
T RMSE	0.76 °C
T R^2	0.991
Y RMSE	0.0016 kg/kg_d
Y R^2	0.972

Single element: matches Zhang et al. (2003).
Full wheel: validated in Guan et al. (2026).

Circumferential Resolution

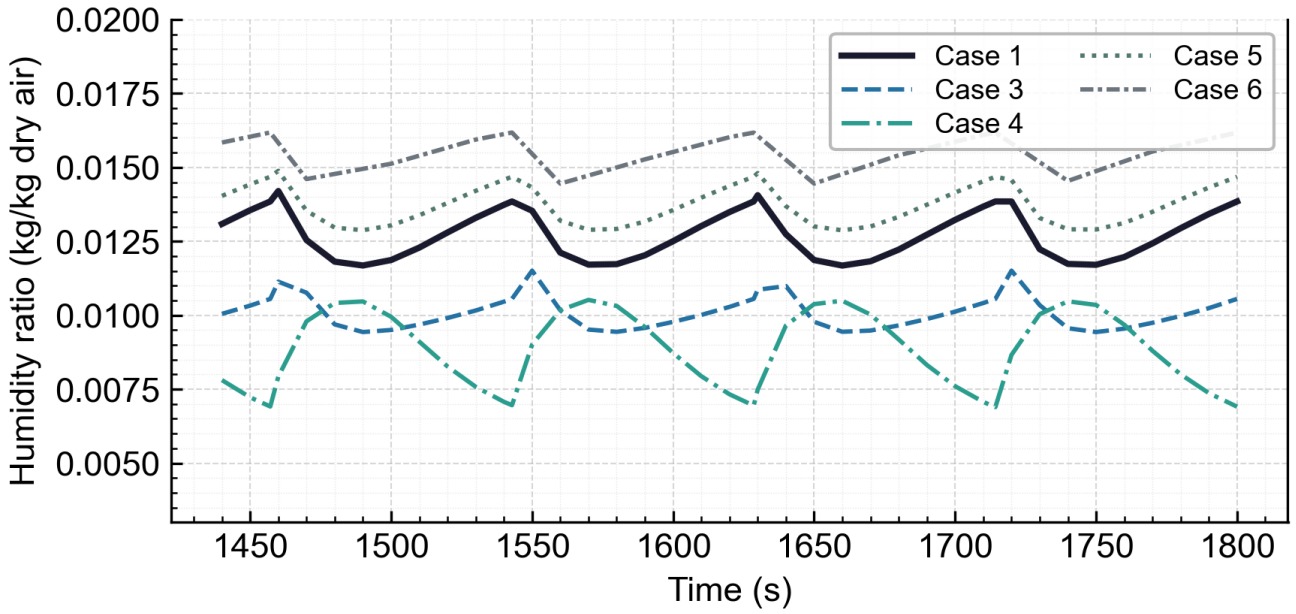


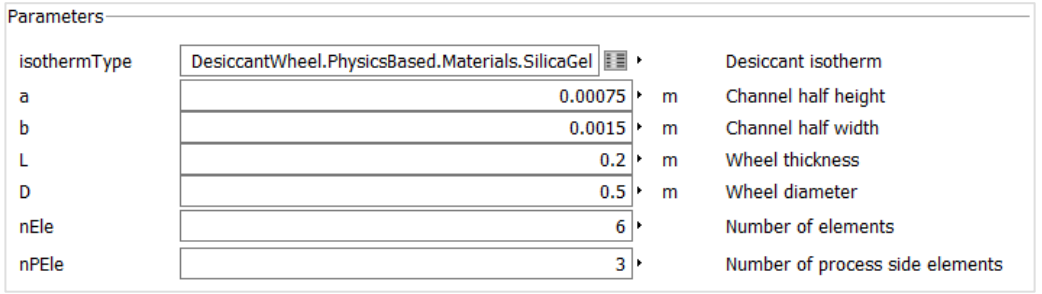
Cases 1 and 2

Both represent a complete wheel under the same boundary conditions.

- 6 versus 12 circumferential elements.
- Twelve elements resolve switching at a finer angular interval.
- Six elements give smoother periodic outlet profiles.

Geometry and Materials





Dymola parameter dialog, Case 3 settings

Changes relative to Case 1

Case 3: channel half height 0.0015 → 0.00075 m.

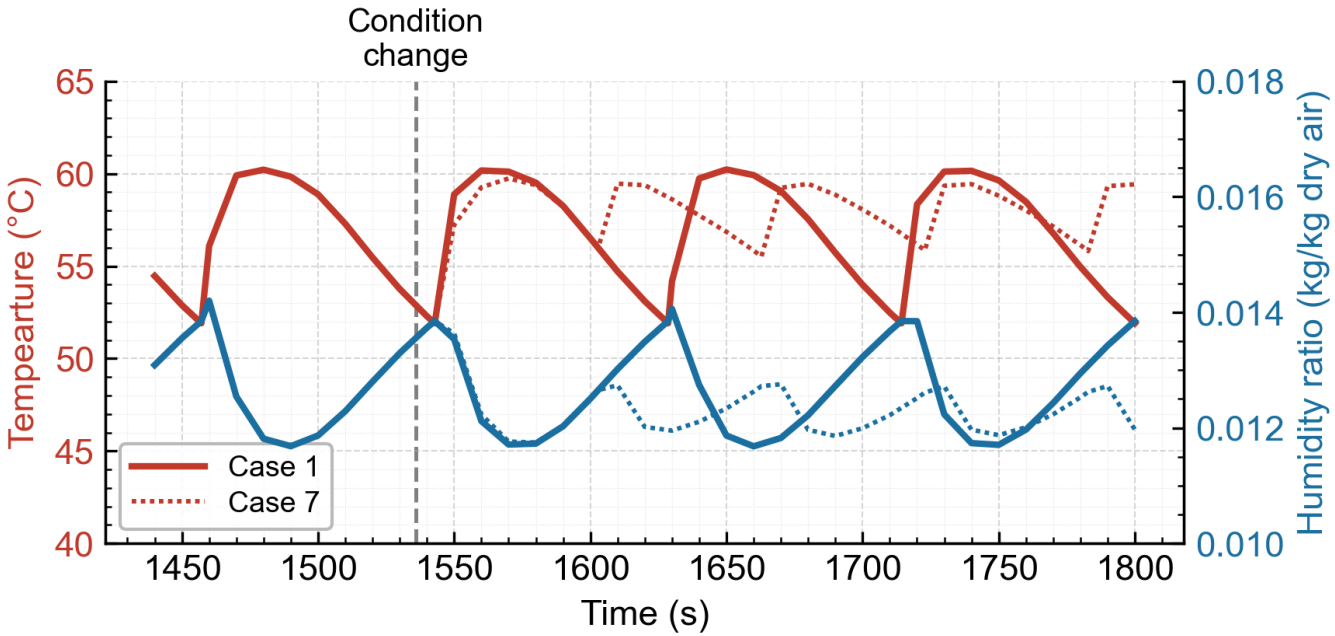
Case 4: wheel thickness 0.2 → 0.5 m and diameter 0.5 → 0.7 m.

Case 5: process/regeneration area ratio 1 → 2.

Case 6: silica gel → polymer desiccant.

All four cases change parameters without changing the model structure; outlet humidity responds to the changes.

Transient Response



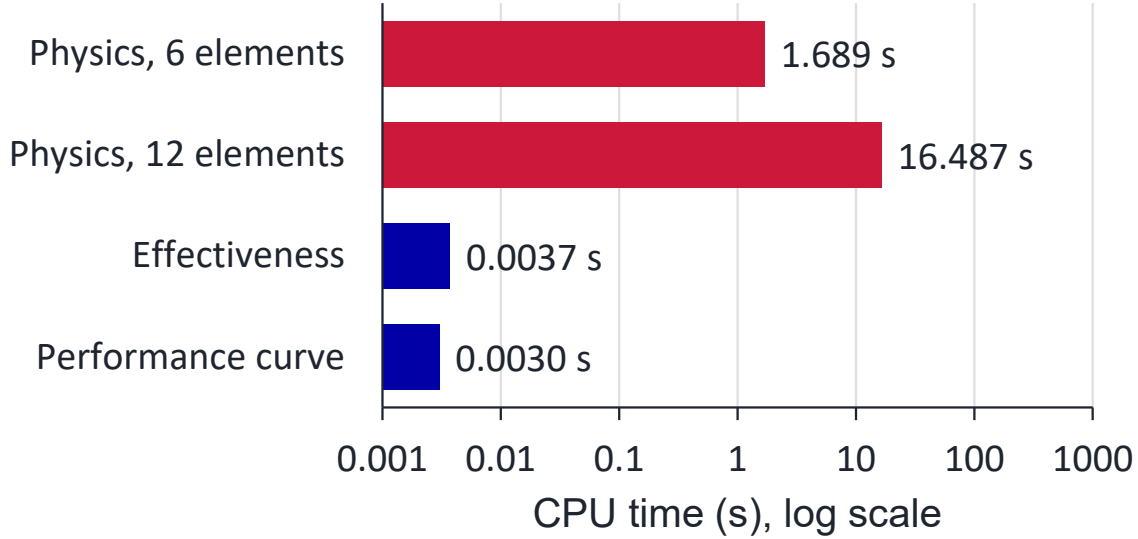
Case 7 at t = 1536 s

Wheel speed increases from 7 to 10 rev/h. Regeneration inlet temperature decreases from 100 to 80 °C.

Compared with the fixed-condition baseline, outlet temperature and humidity ratio shift in both mean level and cycle amplitude.

The multi-element model retains transient response to operating inputs.

Computational Cost



Use the physics model for
geometry, materials, cyclic states, and transient controls.

Use the reduced models for
long system runs within the range represented by their calibrated parameters.

3600 s simulated; Dymola on Intel Core i7-12700, 32 GB RAM.

For this case, doubling element count costs about 9.8 times more CPU time.

Transfer to Energy Recovery Wheels

Same rotary two-stream exchanger: ERWs rotate faster and need no external regeneration heat.

Library component	Total energy recovery wheel	Sensible heat recovery wheel
Four-port fluid interface	Reused	Reused
Rotation and element assembly	Reused	Reused
Channel energy balance	Reused	Reused
Moisture balance and sorption	Reused	Removed
Operating inputs	Higher *N*; exhaust air inlet	Higher *N*; exhaust air inlet
Reduced-order models	Recalibrated	Latent off; recalibrated

Total ERWs reuse all model equations; sensible wheels drop only the moisture equations.

ERW operating differences: Nóbrega and Brum (2009).

Conclusions

1. **Unified interface**: physics-based and reduced-order models share four fluid ports; swapping them changes only the control input.
2. **Full-wheel physics**: validated at channel and full-wheel level; gives both outlets at once and responds to material and geometry changes.
3. **Multi-fidelity choice**: reduced-order models run over 400 times faster (0.0037 s vs. 1.689 s); use the physics model for design and reduced models for long system runs.
4. **Beyond desiccant wheels**: total energy recovery wheels reuse all equations; sensible wheels drop only the moisture equations.

Next: experimental validation across materials and operating conditions.

Open-source library: https://github.com/BE-HVACR/DesiccantWheel

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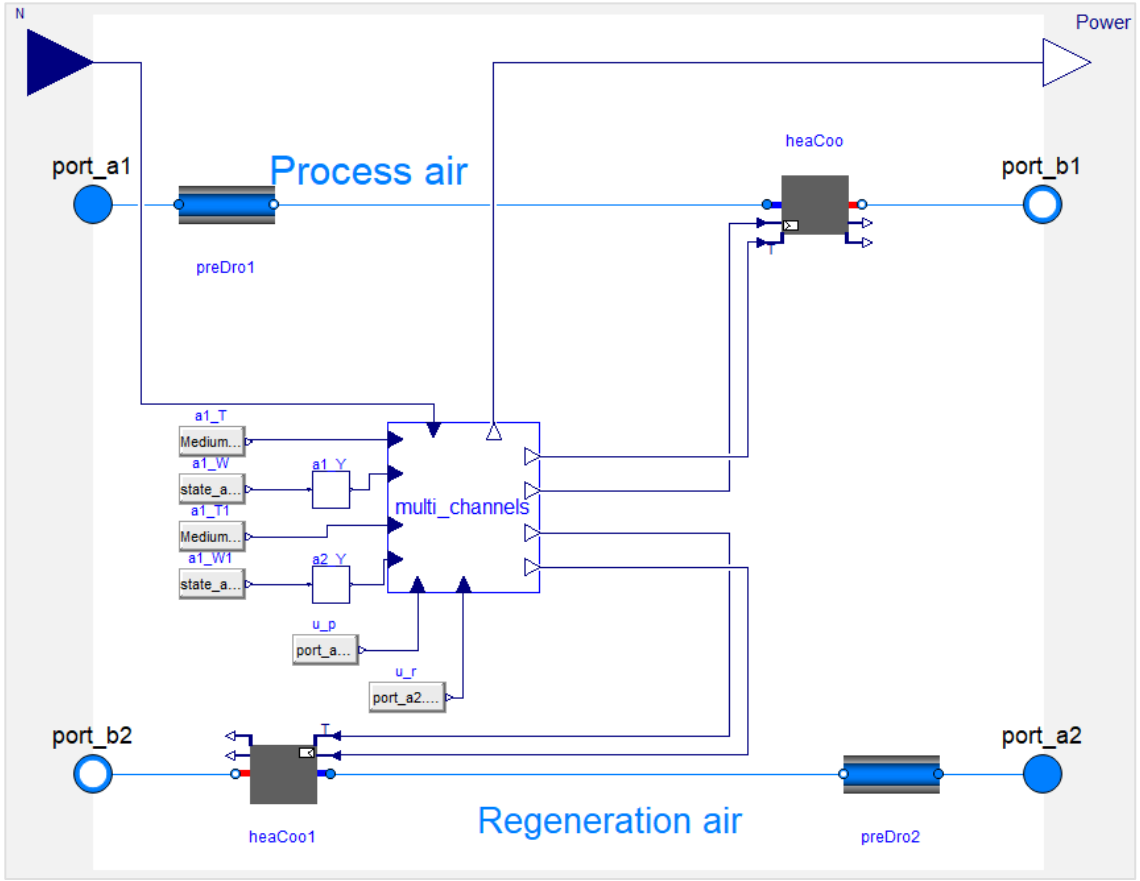
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Thank you

Questions and discussion

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Backup: Physics Model in Dymola



- **Base class** `FourPortHeatMassExchanger` (Buildings library) supplies the four fluid ports.
- `multi_channels`: the MultiElements model computes outlet *T* and *Y* for both streams.
- heaCoo, heaCoo1: PrescribedOutlet blocks impose these states at the outlet ports, with no extra balance equations.
- preDro1, preDro2: pressure drop on each stream.
- N in, Power out: wheel speed and motor power.