

Dynamic Modeling and PID Control of an HVAC Room System in MATLAB Simulink

1. Introduction

This project demonstrates the modelling and closed-loop control of a room's thermal dynamics using MATLAB Simulink and Simscape. The objective is to maintain the room temperature at a desired set point (298.15 K, equivalent to 25°C) despite thermal disturbances arising from conductive heat flow through the wall due to outside temperature.

The system implements:

- A Thermal Mass to represent the room's heat capacity.
- Conductive wall model for heat transfer between outdoor air and room.
- A Controlled Heat Flow Rate Source that injects or removes heat (HVAC).
- A PID controller that computes required HVAC power to regulate temperature.

2. Mathematical Model

[Refer Figure 1] The thermal behavior of the room can be approximated using the energy balance equation:

$$C * (dT/dt) = Q_{HVAC} + Q_{wall}$$

Where:

- C — thermal mass (J/K)
- T — room temperature (K)
- Q_{HVAC} — controllable heating/cooling from HVAC (W)
- $Q_{wall} = (T_{out} - T_{room}) / R_{th}$ — conductive heat transfer through wall

A positive Q_{HVAC} raises temperature (heating), while negative Q_{HVAC} removes heat (cooling).

Conductive heat transfer uses Fourier's law:

$$Q_{wall} = U * A * (T_{out} - T_{room})$$

where U is the overall heat transfer coefficient and A is wall area.

3. Simscape Implementation

Simscape thermal components used:

- Thermal Mass — holds temperature dynamically.
- Conductive Heat Transfer — wall between outside and room.
- Temperature Source — assigns outdoor temperature.
- Controlled Heat Flow Rate Source — HVAC power actuator.

Ports are connected with correct thermal reference and Simulink–PS/PS–Simulink converters to allow signal exchange with Simulink control logic.

HVAC port mapping (correct configuration):

- Port A → Room node
- Port B → Thermal reference (0 K reference)

Negative heat flow through HVAC reduces the room temperature, enabling active cooling.

4. PID Control Design

The PID controller regulates room temperature to the setpoint:

$$e(t) = T_{\text{ref}} - T_{\text{room}}$$

Controller output:

$$P_{\text{HVAC}} = K_p * e + K_i * \int e \cdot dt + K_d * de/dt$$

Chosen gains after iterative testing:

$$K_p = 500 \quad K_i = 0.05 \quad K_d = 0$$

Saturation limits:

$$\text{HVAC power} \in [-3000 \text{ W}, +3000 \text{ W}]$$

Large thermal inertia and slow wall conduction make D unnecessary. Integral action removes long-term steady-state offset.

5. Simulation Results

Simulation was run for 15 000 seconds to observe long-term dynamics.

Initial temperature: ~ 293 K (20°C)

Observed behavior:

- Temperature rises to $\sim 301\text{--}302$ K due to heat entering from the wall.
- HVAC cooling engages (negative power).
- Temperature slowly decreases toward the 298 K setpoint.
- No oscillations; system is stable and well-damped.
- Small steady-state error reduces gradually thanks to integral action.

This response is characteristic of 1st-order thermal system with slow dynamics and continuous disturbance.

6. Inference

The HVAC controller successfully offsets thermal disturbances and regulates room temperature.

Key insights:

- Thermal systems have inherently slow dynamics.
- Integral action is essential for eliminating steady-state heat-gain errors.
- Negative HVAC power confirms correct cooling implementation.
- PID gains must balance responsiveness and stability; excessive integral gain causes slow oscillations.

The final configuration provides:

- Smooth rise from initial condition.
- Minor overshoot (< 2 K).
- Gradual convergence toward setpoint.
- Robust rejection of external heat load.

This validates the correctness of physical modeling and PID design.

7. Conclusion

The project successfully models and controls a room's thermal environment using Simscape and PID control.

The HVAC actuator, wall conduction, and thermal mass interact realistically, offering a strong demonstration of mechatronic and system modeling principles.

This model can be extended with:

- Time-varying outdoor temperature.
- Multi-zone models.
- Energy optimization strategies.

The completed project is suitable for academic reports, resumes, and engineering portfolios.

APPENDIX

1. MATLAB HVAC Model

