Experimental performance investigation of cooling or heating coil valves and their impact on temperature controls

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Motivations

- HVAC valves often suffer from hysteresis effects and nonlinearities
- Valve characteristics determine control performance
- Control performance -> comfort delivery, system reliability and energy efficiency

Objective

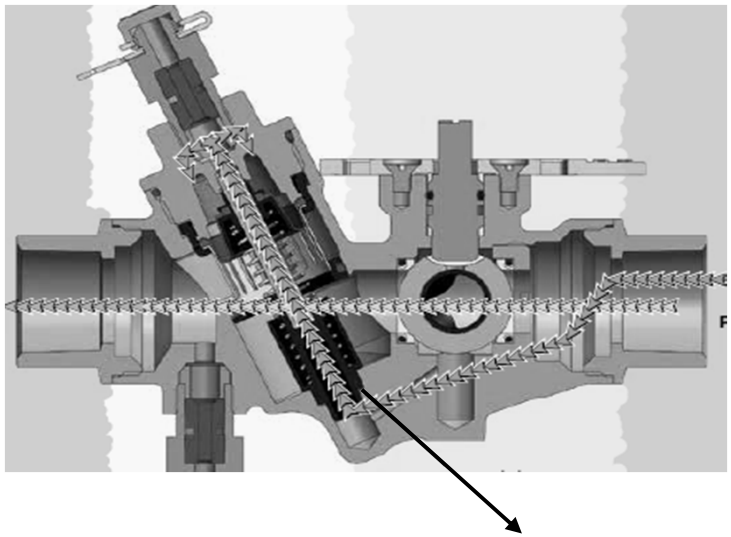
- Investigate the effects of valve types and characteristics on control performance through field experiments

Impacts

- Improved valve control algorithms
- Guide for valve selection

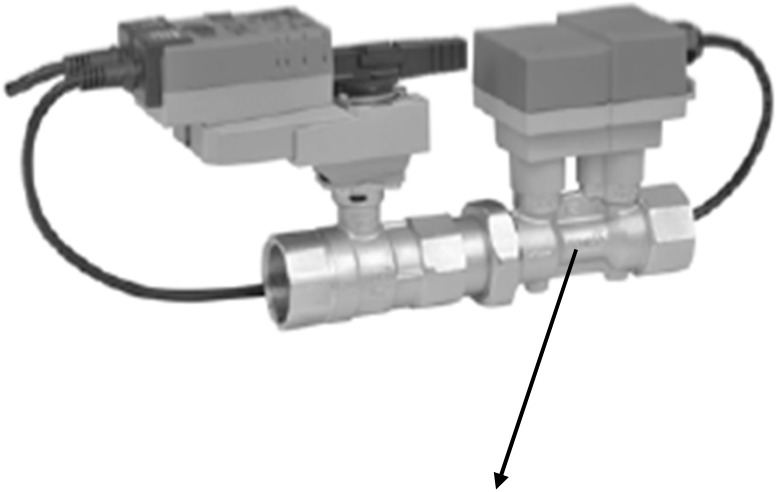
MPIC & EPIC Valves

MPIC valve (mechanical pressure independent control)



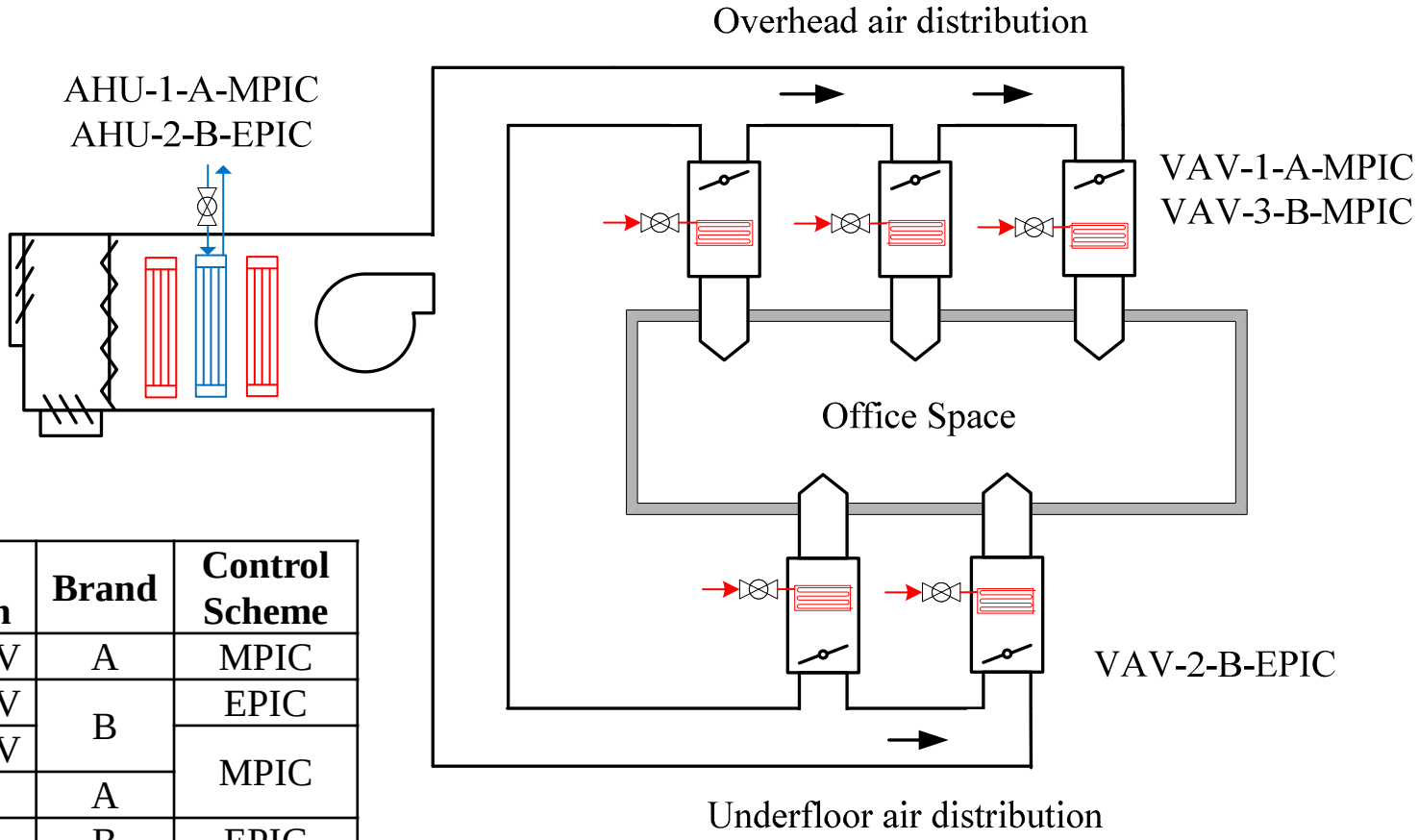
Pressure compensating cartridge

EPIC valve (electronic pressure independent control)



Internal flow meter

Field Site Test Plan



Valve ID	Coil Location	Brand	Control Scheme
VAV-1	OAD VAV	A	MPIC
VAV-2	UAD VAV	B	EPIC
VAV-3	OAD VAV		MPIC
AHU-1	AHU cl.	A	
AHU-2	AHU cl.	B	EPIC

Fig. Experiment setup: Living Lab 3 of Center for High Performance Buildings at Purdue

Valve Info and Test Plan

Common features of all testing valves

- Pressure independent valves
- Equal percentage flow control
- Ball valves

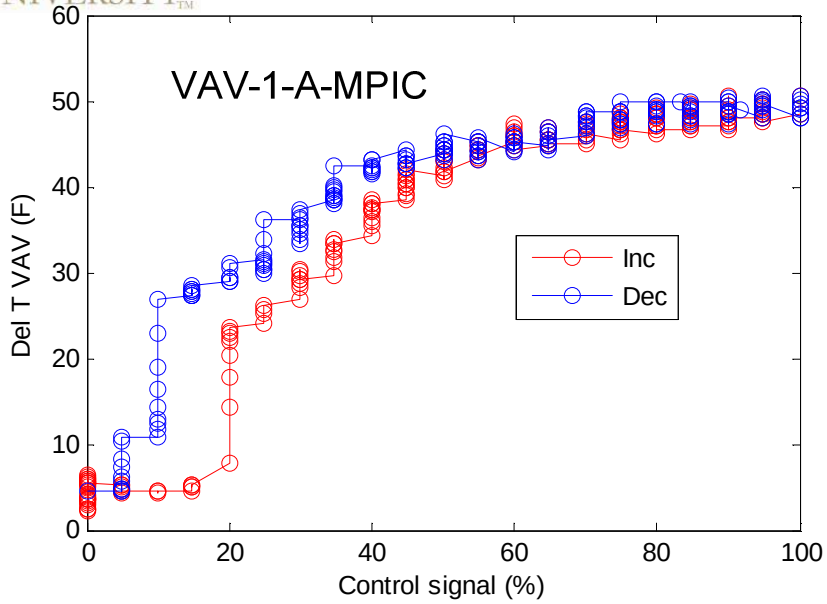
Open loop tests (for both VAV and AHU valves)

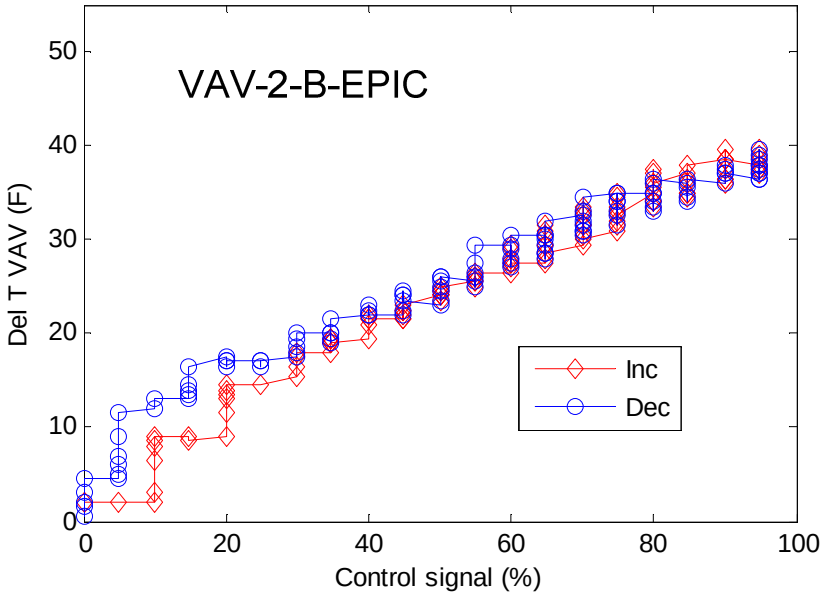
- Step valve control command from 0% to 100% and then back to 0%
- 5% step change and 8-min hold time
- Maintain a fixed upstream air temperature and flow for each valve category

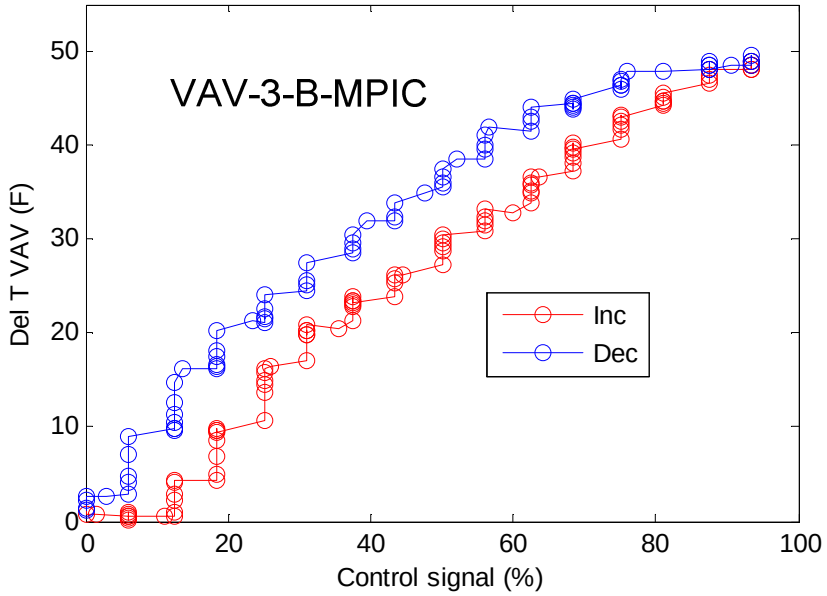
Closed loop (feedback control) tests

- VAV valves: to maintain a constant zone air temperature
- AHU valves: to track the supply air temperature setpoint

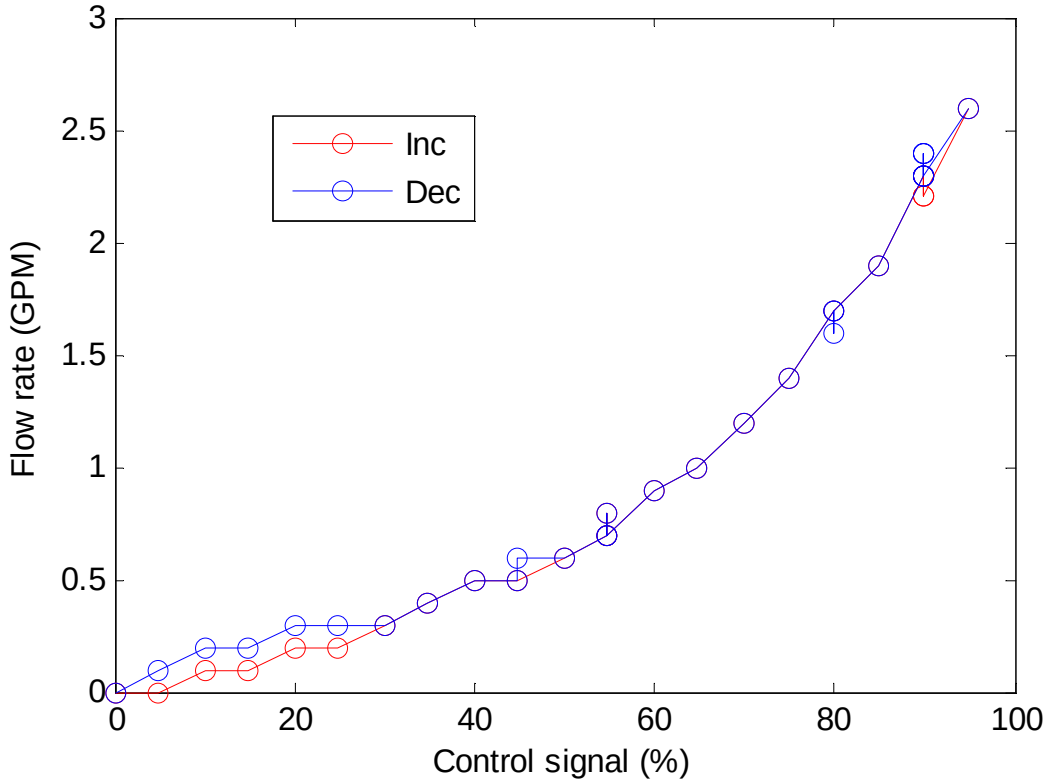
VAV Open-Loop Test Results





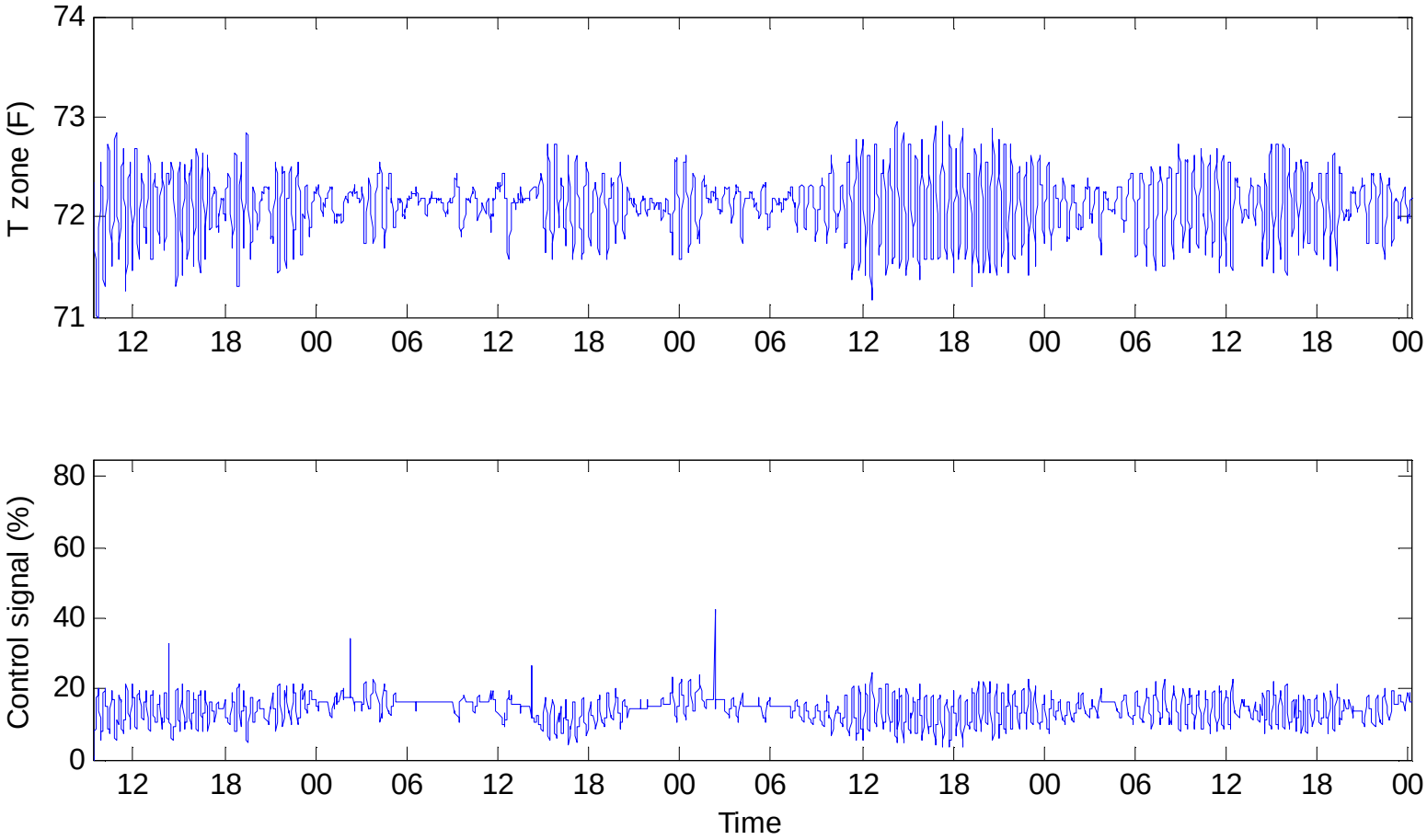


VAV-2 Open-Loop Test Results



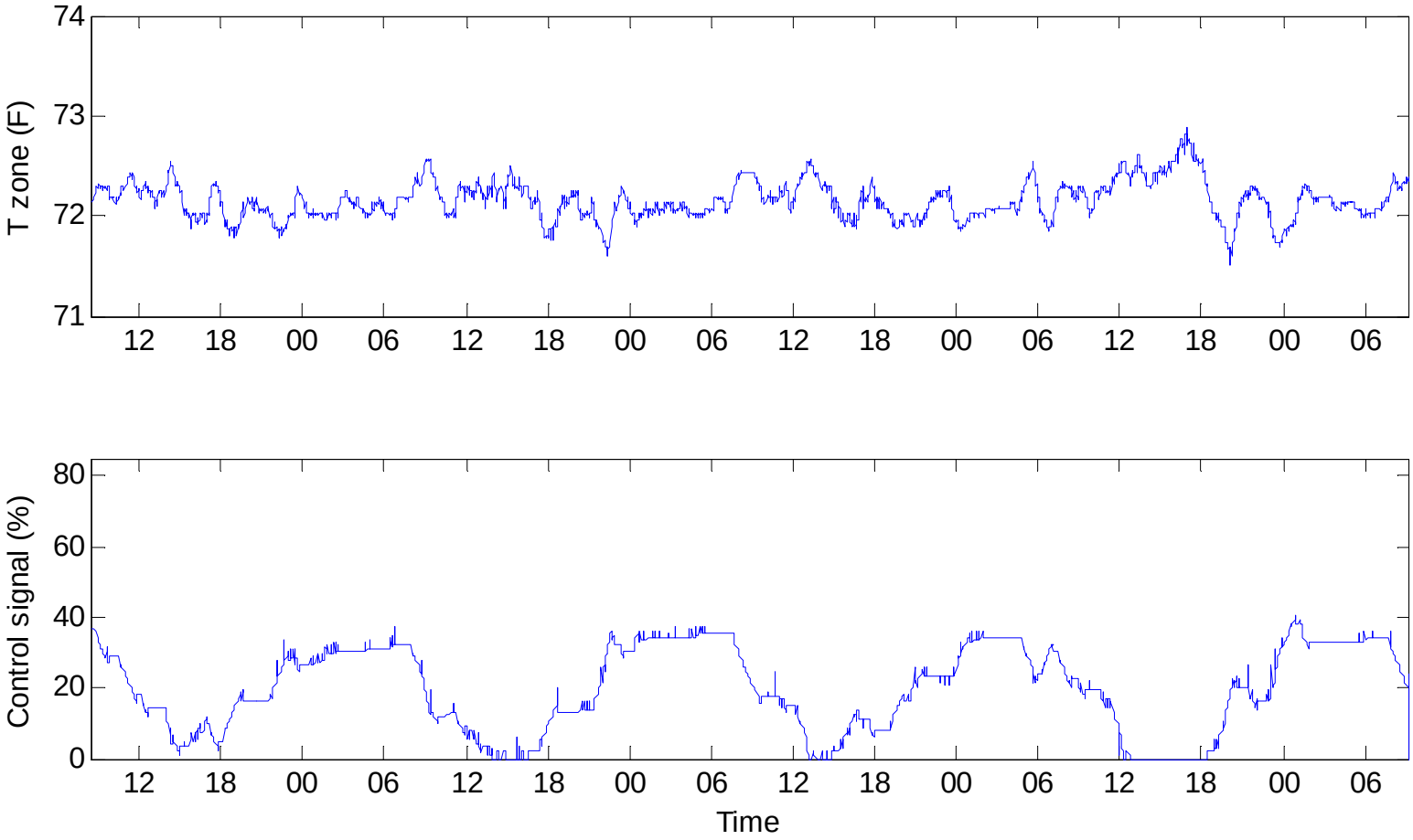
- Hysteresis in the low end is caused by 5% tolerance of the valve internal controller

VAV-1-A-MPIC Closed-Loop Test Results



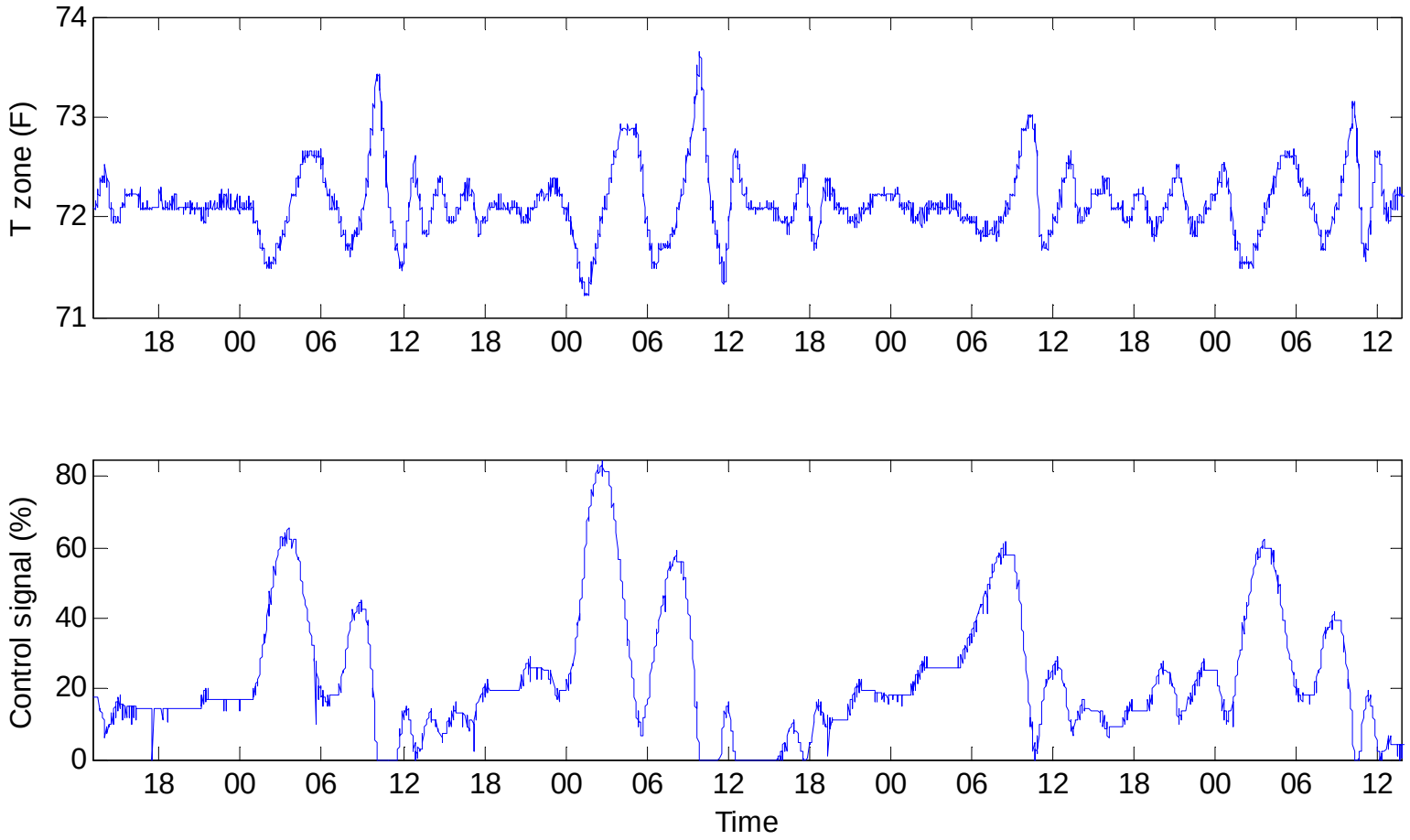
- Hystereis + nonlinearity in VAV-1 -> control chattering and temperatsure fluctuation
- Cannot detect load pattern due to control chattering

VAV-2-B-EPIC Closed-Loop Test Results



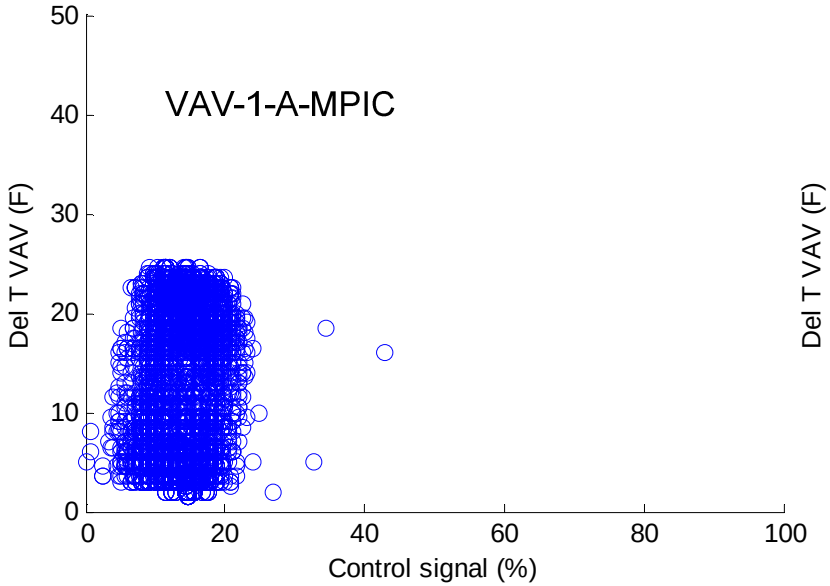
- Negligible hysteresis + good linearity in VAV-2 -> tight temperature control
- Clear load pattern

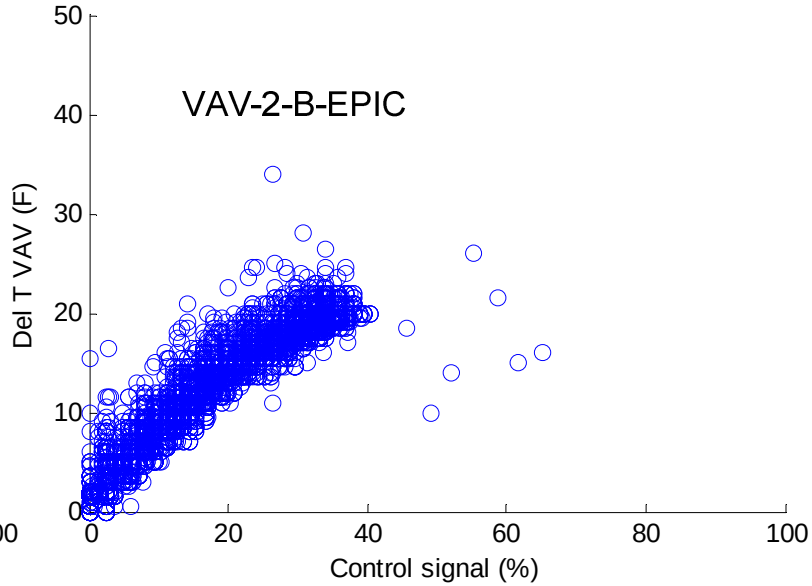
VAV-3-B-MPIC Closed-Loop Test Results

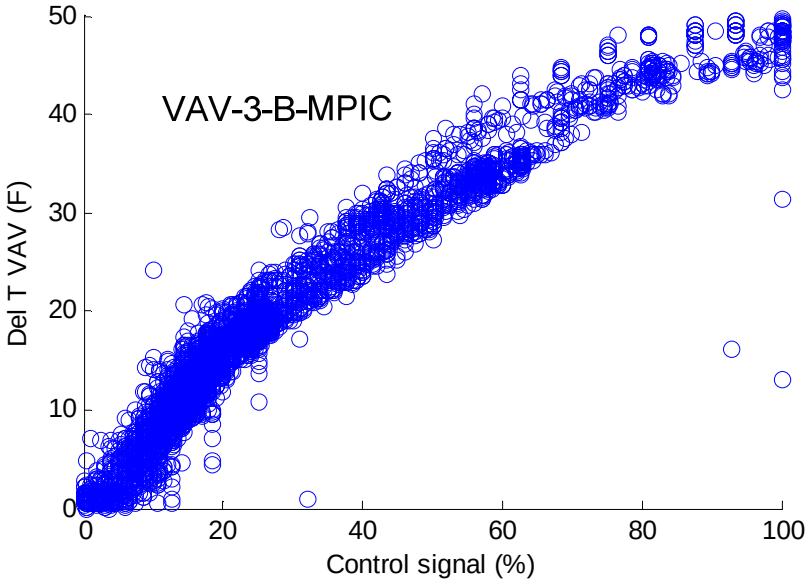


- Hysteresis + good linearity in VAV-3 -> low frequency oscillation in control action and temperature
- Control fluctuation leads to unnecessarily high peaks

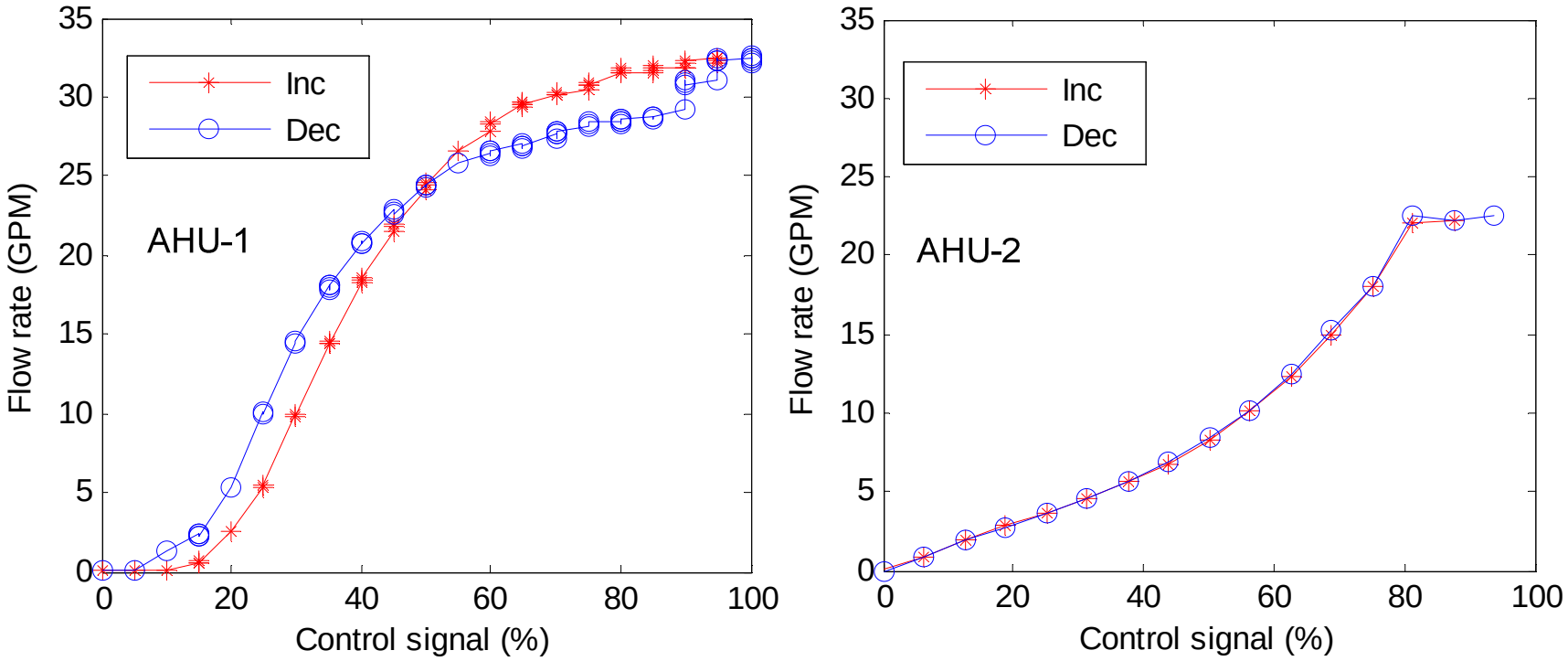
VAV Closed-Loop Test - Scatter Plots





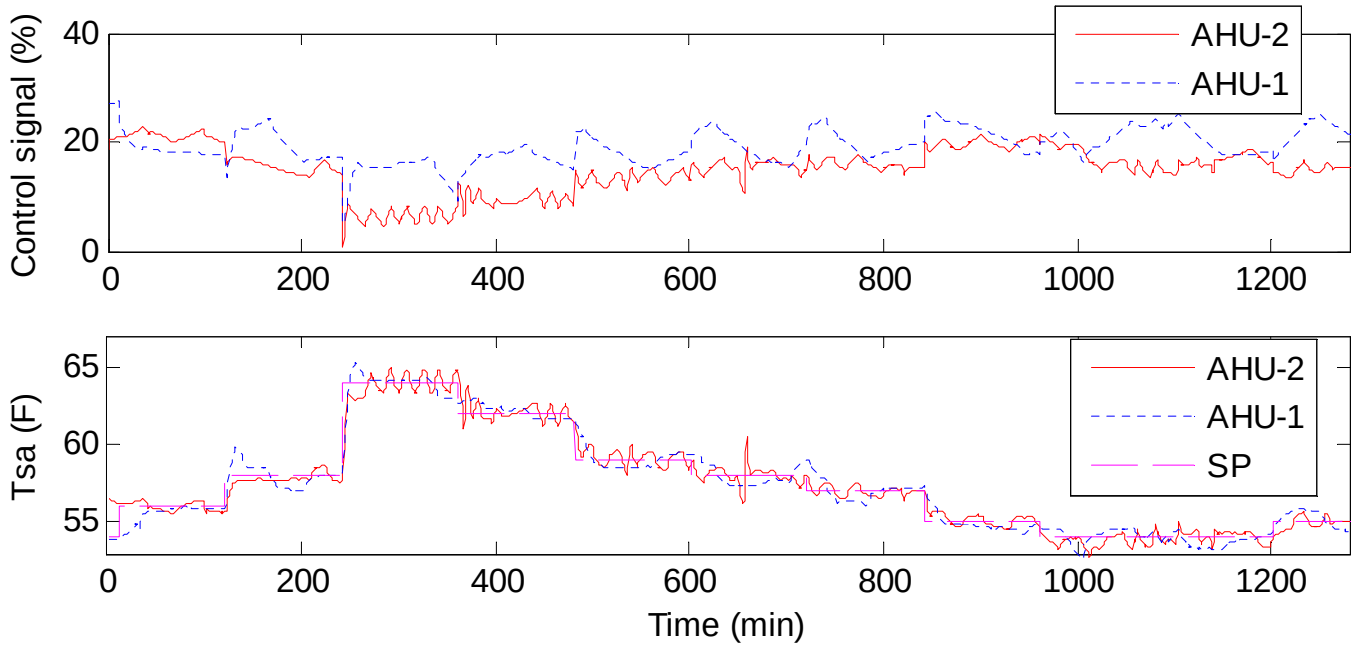


AHU Open-Loop Test Results



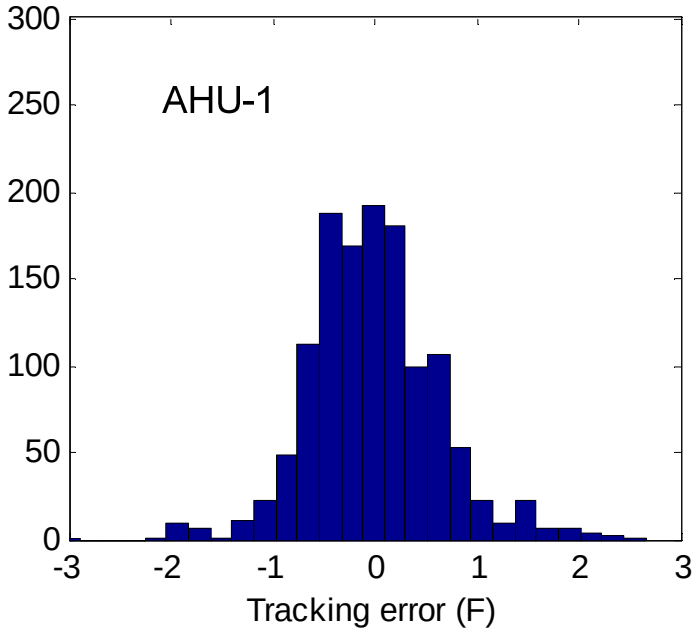
- AHU-1 (MPIC): significant hysteresis and obvious nonlinearity; authority loss at control signal > 60%
- AHU-2 (EPIC): no hysteresis; smooth control until control command reaches 80%

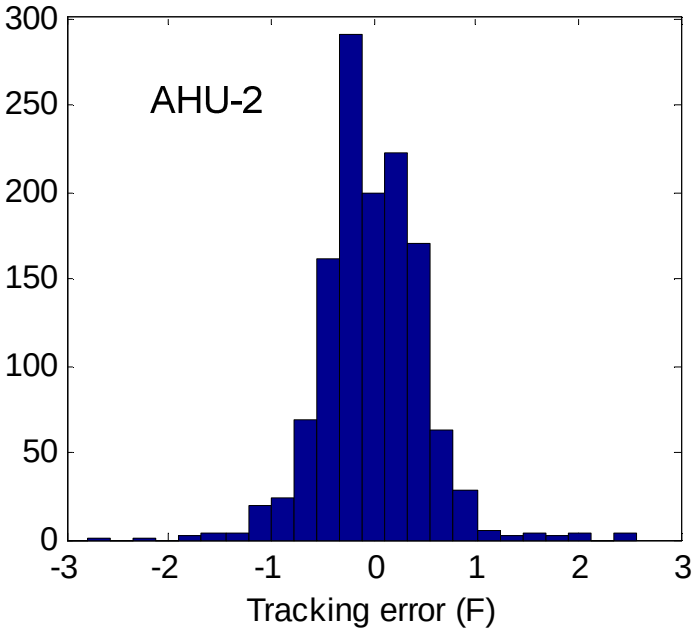
AHU Closed-Loop Test Results



- Resetting SAT setpoint to reduce VAV reheat
- AHU-1: low frequency oscillation due to hysteresis
- AHU-2: high frequency oscillation due to 5% internal control tolerance

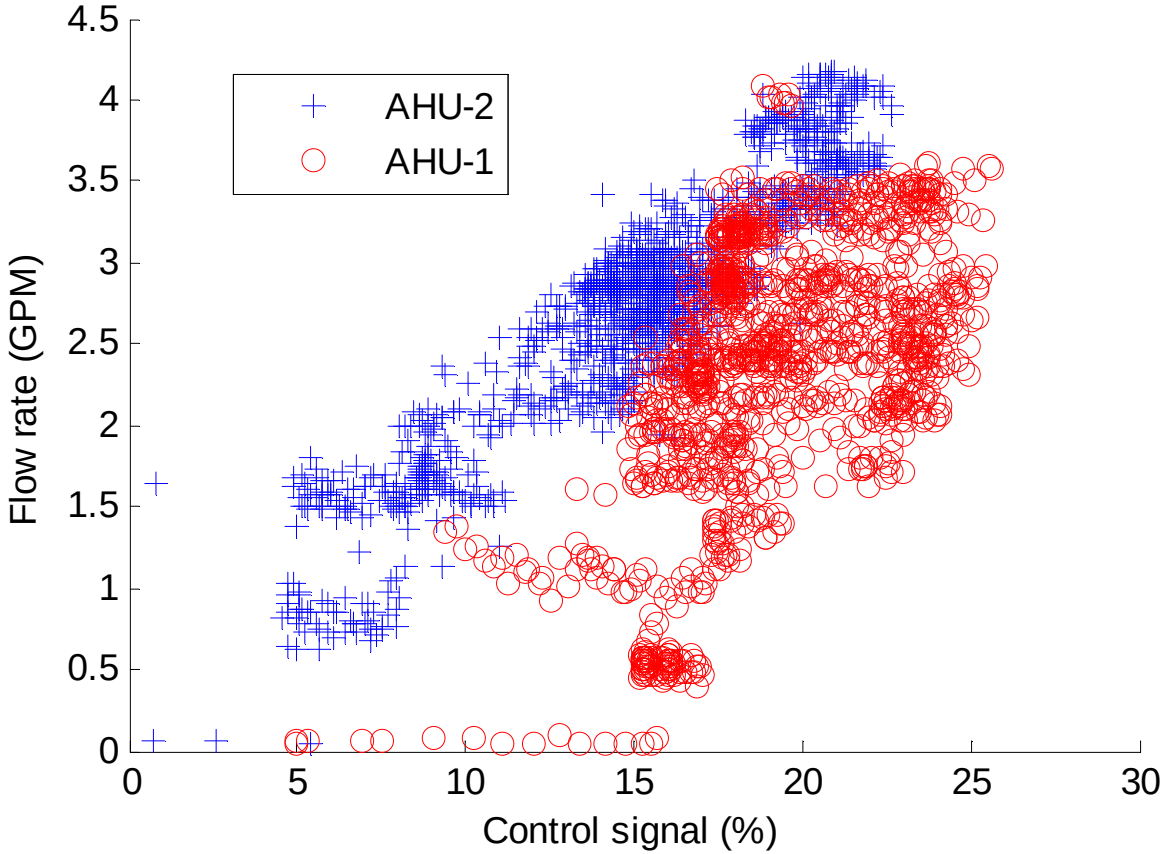
AHU Closed-Loop Error Histogram Plots





- AHU-2 outperforms AHU-1 in the setpoint tracking performance

AHU Closed-Loop Test - Scatter Plot



- AHU-2 plot shows clear and close-to-linear relationship
- AHU-1 plot exhibits random relationship caused by hysteresis
- An improved control algorithm in a companion paper applied to AHU-1

Conclusions & Discussions

- Valve performance varies significantly among different manufacturers and control schemes
  - EPIC valves have negligible hysteresis while all tested MPIC valves show significant hysteresis
  - Control linearity differs for valves of different brands
- Valve hysteresis and linearity characteristics have a significant impact on control performance
  - Hysteresis + nonlinearity -> control chattering + temperature fluctuation
  - Hysteresis + good linearity -> low freq. control oscillation
  - Zero-hysteresis + good linearity -> stable control
- Internal control tolerance in EPIC can lead to high freq. oscillation
- Control oscillation leads to unnecessarily high power peaks
- Motivation for an improved valve control approach:
  - (R12) Cai, J. and Braun, J.E., “Self-Learning Backlash Inverse Control of Cooling or Heating Coil Valves Having Backlash Hysteresis”, *International Ref. and A. C. Conference at Purdue*, 2016

Thank you!
Q&A

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