Evaluation of Fault Detection and Diagnostics Tools by Simulation Results of Multiple Vapor Compression Systems

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Paper 2605
R-16: Automated Fault Detection and Diagnostics
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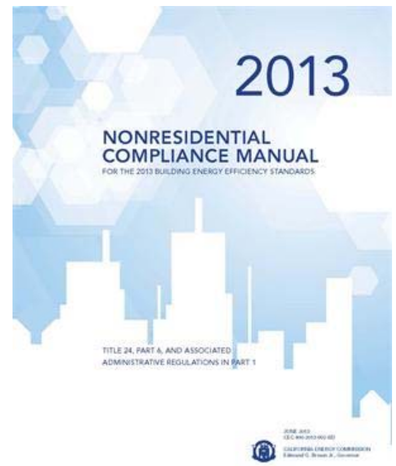
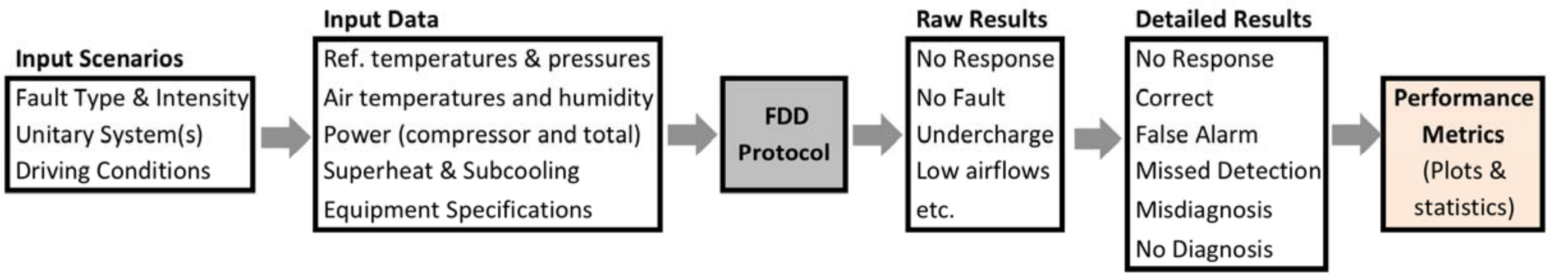
Background

- Fault detection and diagnosis (FDD)
  - Detect abnormal operation (fault)
  - Diagnose cause or location of fault
  - Avoid equipment wear, energy waste, loss of capacity
- FDD use is increasing
  - California's Title 24 building code
  - Commercial vendors
- **How well does it work?**
  - Yuill & Braun (2013) gave FDD evaluation methodology and taxonomy
  - Focuses on unitary vapor compression air-conditioning equipment



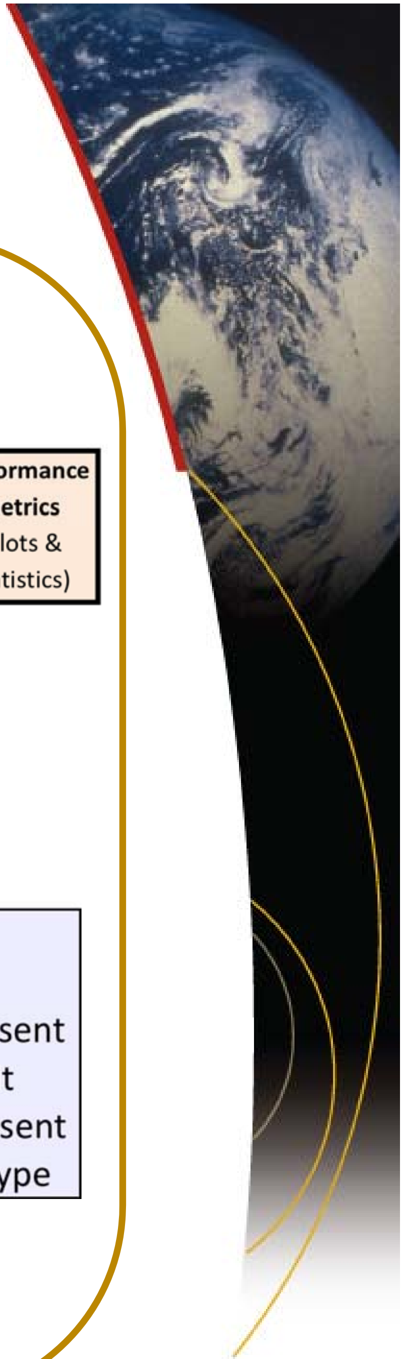
Evaluation Methodology Summary



- Seven fault types; six possible test outcomes

Fault	
Undercharge	UC
Overcharge	OC
Evaporator Airflow	EA
Condenser Airflow	CA
Liquid Line Restriction	LL
Non-condensable Gas	NC
Valve Leakage	VL

Outcome	Description
No Response	Uncertain or unable to give response
Correct	Correctly identifies state of system
False Alarm	Detects a fault; no signficant fault is present
Misdiagnosis	Correct detection, diagnoses wrong fault
Missed Detection	Fault is present; FDD says no fault is present
No Diagnosis	FDD detects fault; can't diagnose fault type



Evaluation Methodology Summary

- Raw results organized by Fault Impact Ratio (FIR):

$$FIR_{COP} = \frac{COP_{faulted}}{COP_{unfaulted}} \qquad FIR_{capacity} = \frac{capacity_{faulted}}{capacity_{unfaulted}}$$

- End results use rates (multiple scenarios)
  - E.g. % Misdiagnosis for 85% < FIR_{COP} < 95%

- For details, see Yuill & Braun (2013)

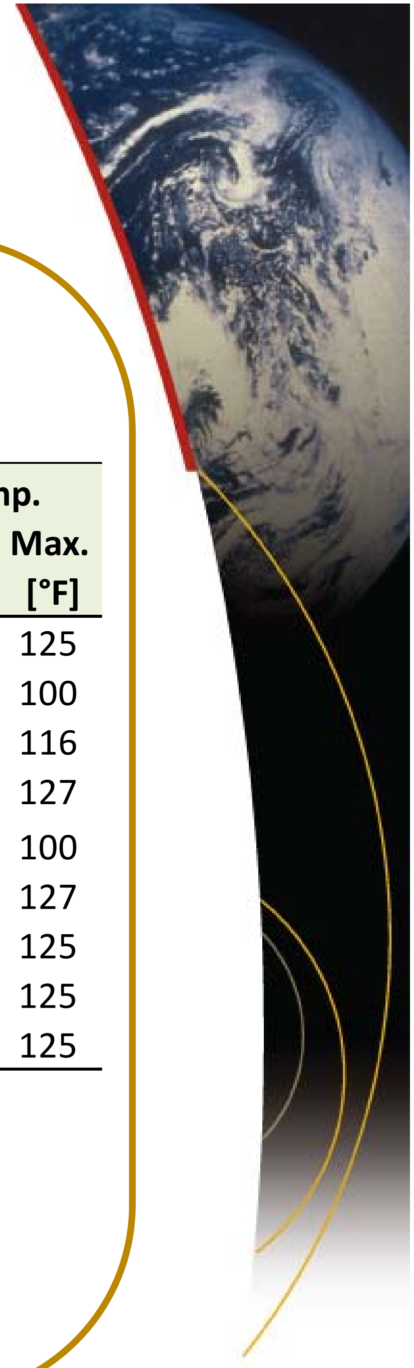
- Measurement data were used, but we propose using simulation data

Evaluation Methodology Summary

- Measurement data

						Number of tests								Temp.	
ID	Type	Capacity [tons]	Refrig.	Exp. Device	Comp. Type	No Fault	UC	OC	EA	CA	LL	NC	VL	Min. [°F]	Max. [°F]
RTU 3	RTU	3	R410A	FXO	Scroll	24	25	12	21	6	0	0	0	67	125
RTU 7	RTU	3	R22	FXO	Recip.	39	34	0	26	36	34	0	33	60	100
RTU 4	RTU	5	R407C	FXO	Scroll	17	15	12	19	8	0	0	0	67	116
Split 1	Split	3	R410A	FXO	Recip.	1	29	1	0	0	0	0	0	82	127
RTU 2[1]	Split	2.5	R410A	TXV	Scroll	16	12	12	21	15	16	15	16	70	100
Split 2	Split	3	R410A	TXV	Recip.	2	30	7	0	0	0	0	0	83	127
Split 3	Split	3	R410A	TXV	Scroll	4	4	7	0	0	0	0	0	82	125
Split 4	Split	3	R22	TXV	Scroll	4	8	0	8	0	0	0	0	82	125
Split 5	Split	3	R22	TXV	Scroll	4	4	4	6	0	0	0	0	82	125
					Total:	111	161	55	101	65	50	15	49		

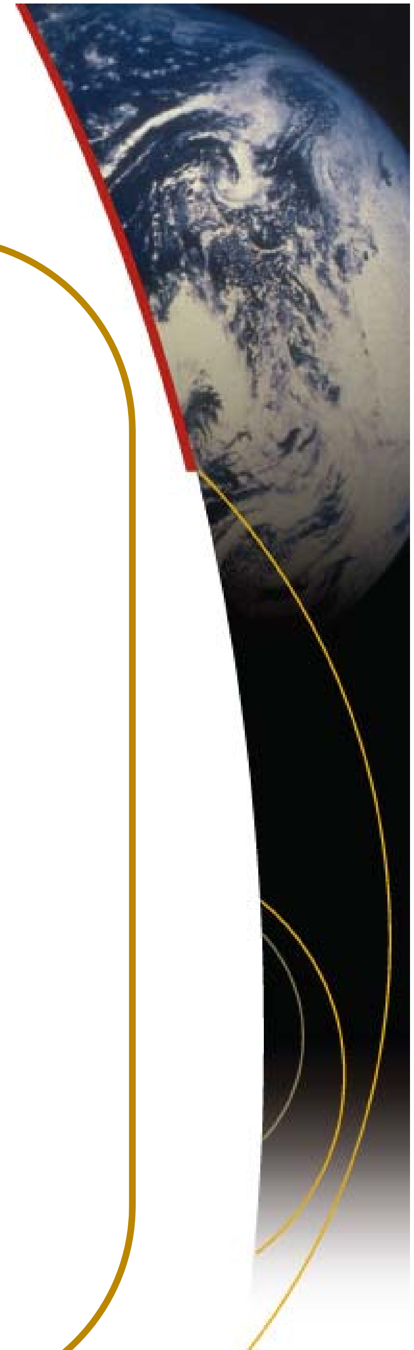
1. RTU 2 is a split system, but was named using an earlier naming convention.



Gray Box Model

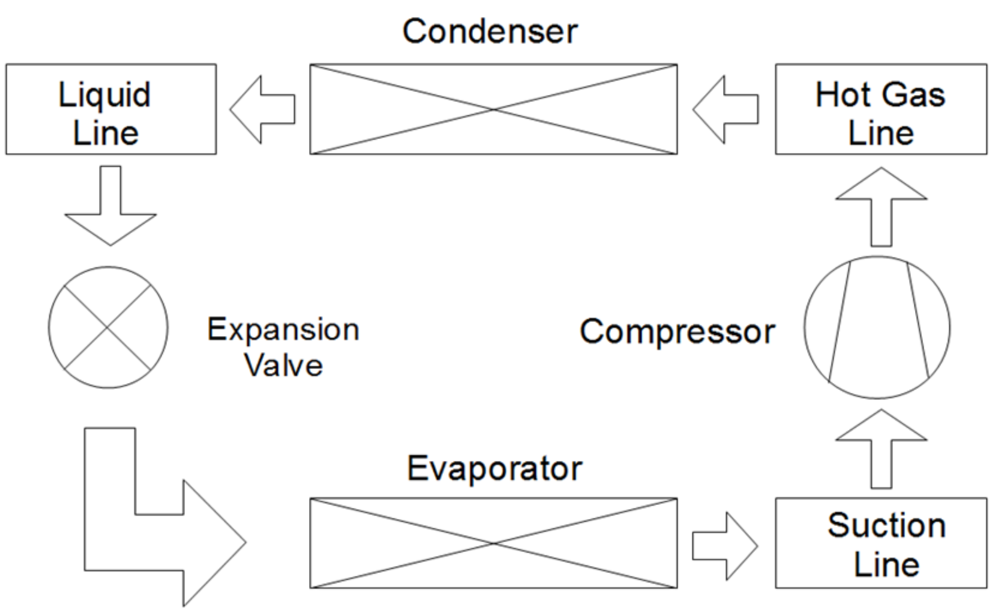
- Simulation data generated with *gray-box* model
- Black box model
  - Data driven
  - Not directly connected to physics
  - Fairly easy, but needs lots of data
- Forward model (aka white box)
  - Physics based (geometry, physical properties & laws)
  - Quite difficult, but needs no measurement data

Black Box + White Box = Gray Box



Gray Box Model

- Cheung & Braun (2013a, 2013b)
- Components
  - Some black box; some forward
  - Connected with physical laws (e.g. conservation of mass)

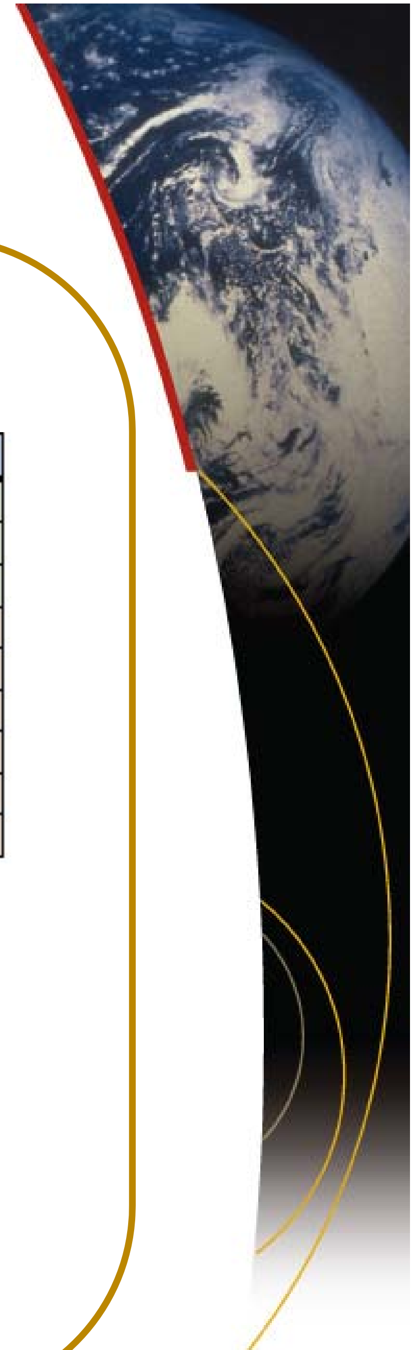


Simulation Data

- Conditions

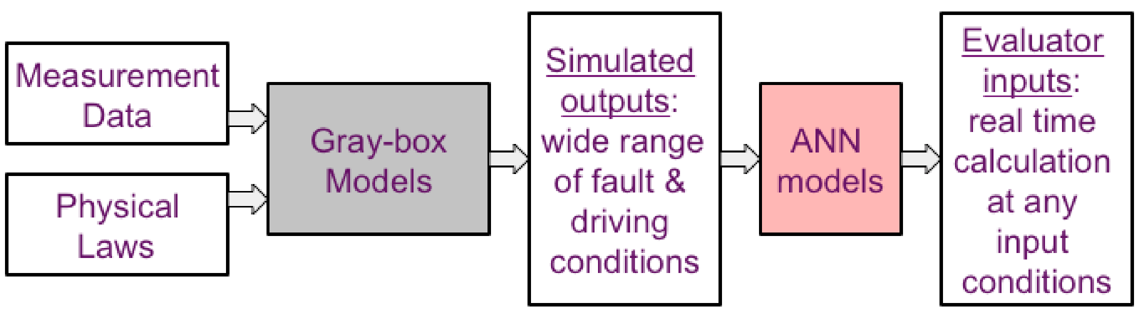
Variable	Values
Condenser air inlet temperature (T_{amb}) [°F]	65, 75, 85, 95, 105, 115
Evaporator air inlet temperature (T_{ra}) [°F]	70, 77, 84
Evaporator air inlet wet-bulb temperature (WB_{ra}) [°F]	55, 65, 75
Charge level [%]	70, 80, 90, 100, 110, 120, 130
Reduction of evaporator airflow [%]	0, 10, 25, 40, 55
Reduction of condenser airflow [%]	0, 10, 23, 37, 50, 60
Liquid line restriction level [%]	0, 50, 100, 300, 600, 1200, 2000, 3500
Non-condensable level [%]	0, 10, 30, 45, 80, 100
Compressor valve leakage level [%]	0, 10, 20, 35, 50

- Combines to give 1536 conditions per unit
  - Single fault only
- Even distribution of faults and conditions



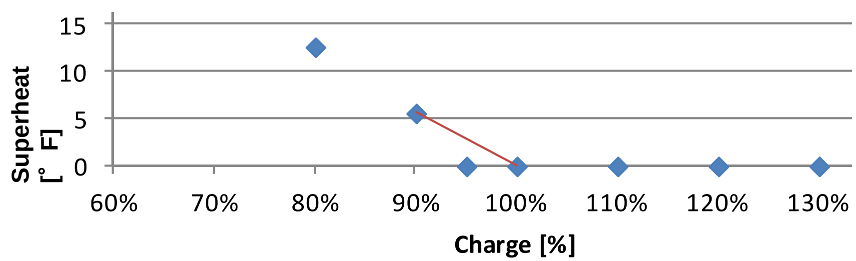
Simulation Data

- Model takes average 29 seconds per scenario
  - ~15,000 scenarios takes too long
- Train automated neural network (ANN) models
  - Much faster than gray-box
  - Need lots of data and some special data
  - About 120 models needed
  - In progress, but very good performance so far



Simulation Data

- Special cases needed: cusps
  - Singular points
  - E.g. Superheat
  - Also near-cusps



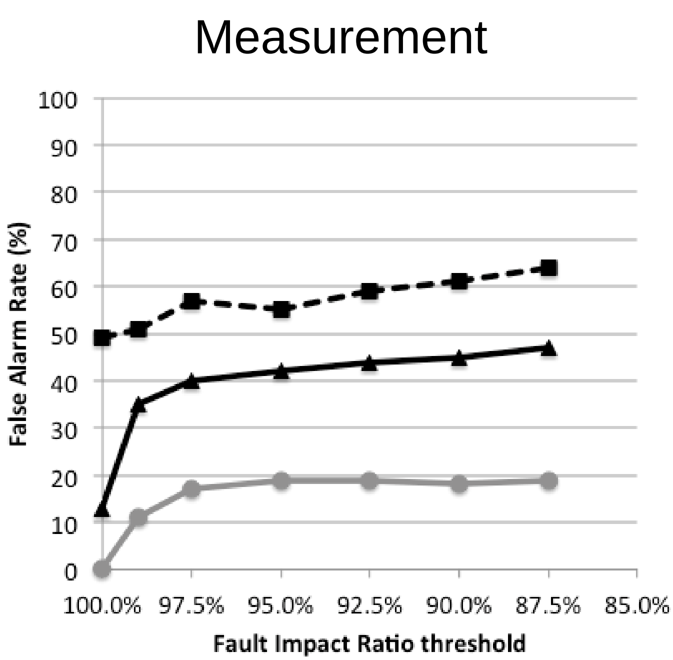
- 14,074 points in final data set

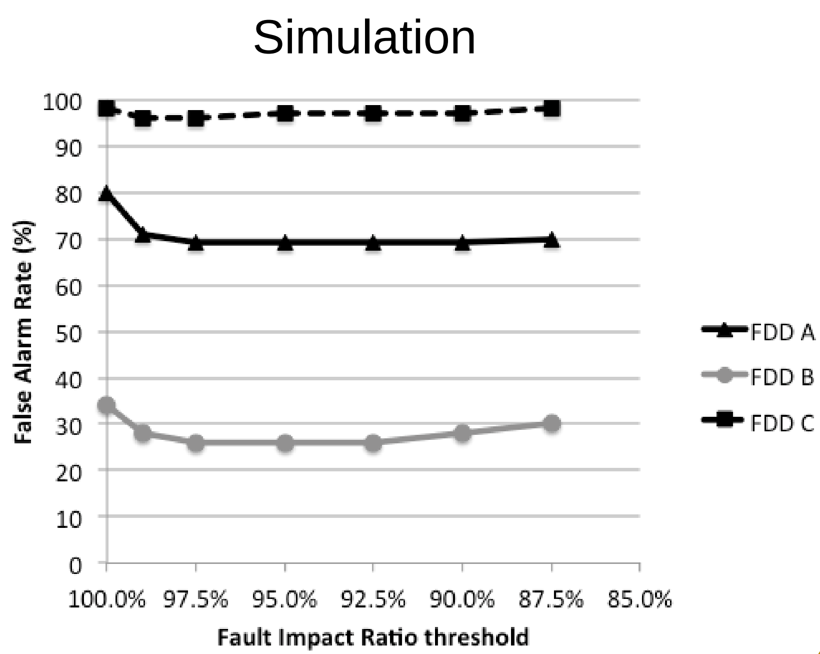
Example Results

- 3 FDD protocols' evaluation results with measurement & simulation data
  - From California's building energy code
  - Commercial
  - Utility
- First result: False Alarms
  - Protocol detects fault
  - No *significant* fault present (results for varying FIR values)
  - 1° F < Superheat < 36° F
  - Charge < 105% of nominal

Example Results

- False Alarms
  - Rank order preserved
  - Magnitudes quite different

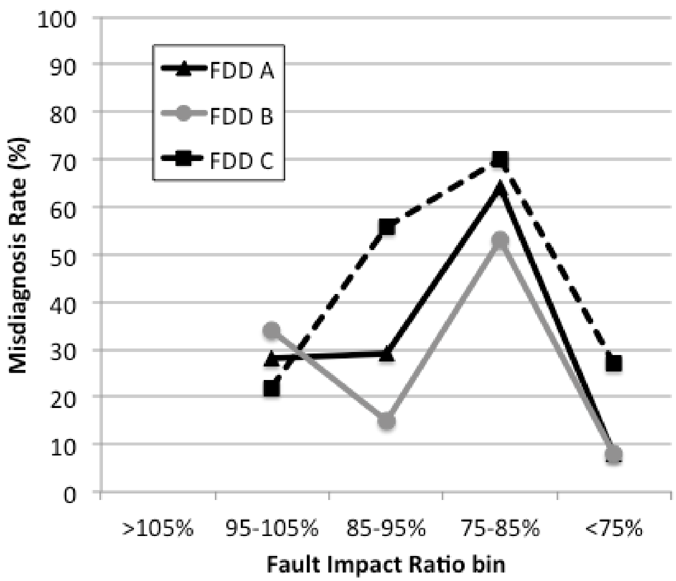




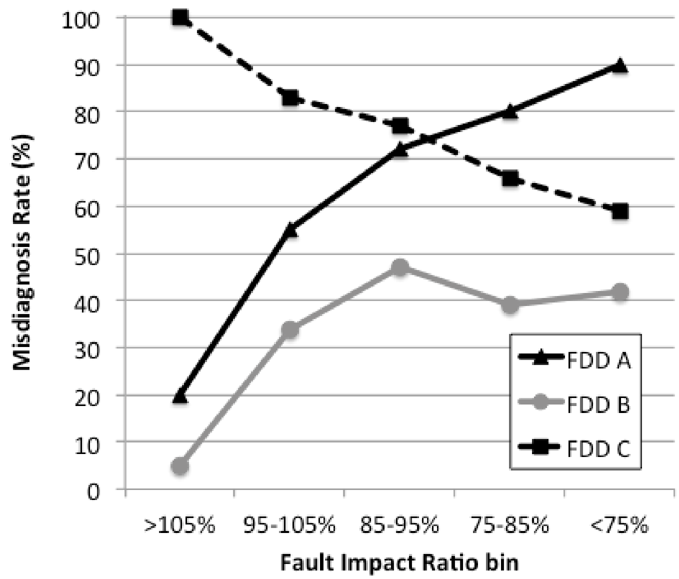
Example Results

- Misdiagnosis (shown for FIR_{COP} bins)
  - Rank order mainly preserved
  - No clear relationship with FIR

Measurement



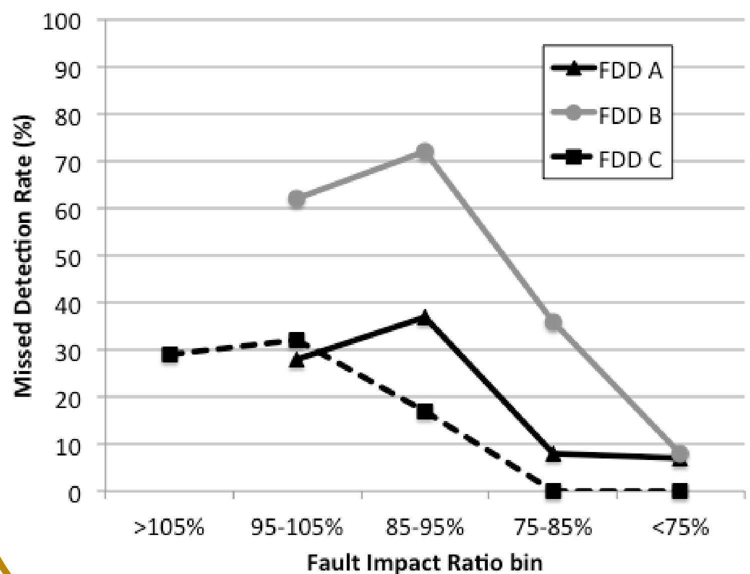
Simulation



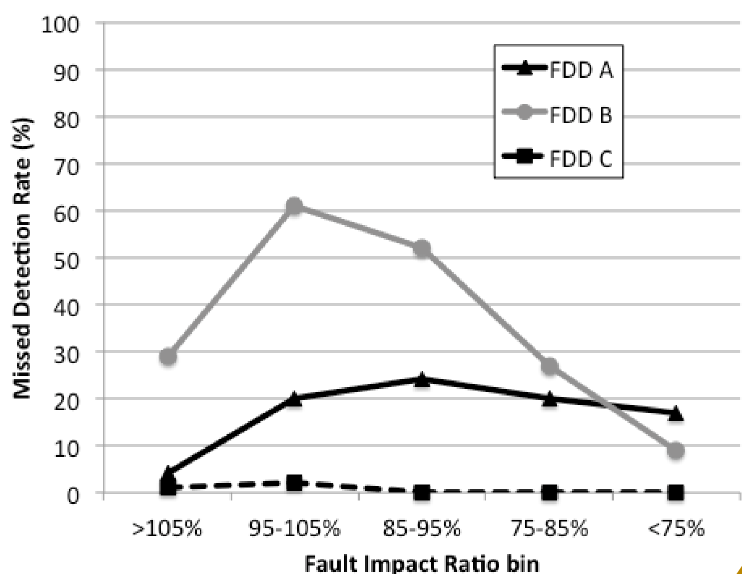
Example Results

- Missed Detection (shown for FIR_{COP} bins)
  - Rank order mainly preserved
  - Results are difficult to interpret

Measurement



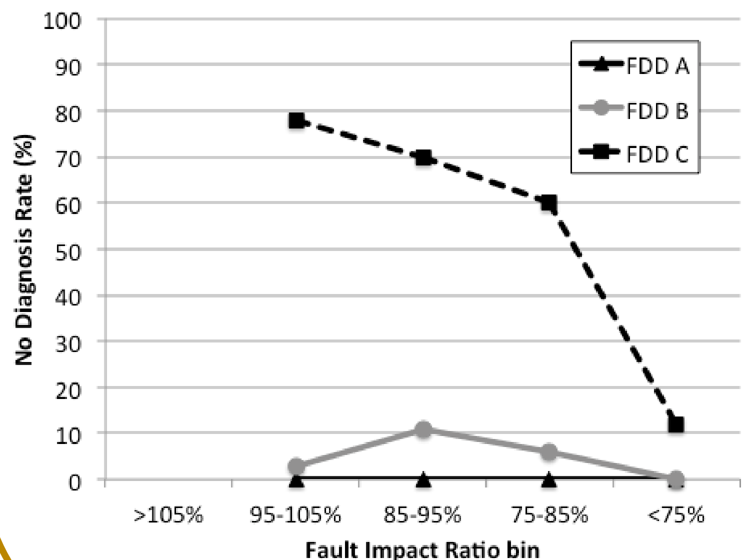
Simulation



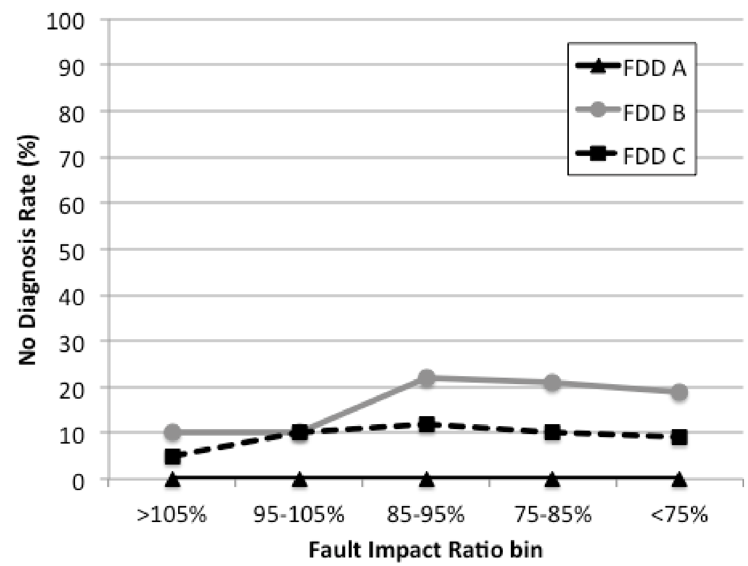
Example Results

- No Diagnosis (shown for FIR_{COP} bins)
  - Rank order mainly preserved
  - Strange result for FDD C; possible error in measurements

Measurement



Simulation



Conclusions

- FDD tools should be evaluated
- Model data are necessary for good FDD evaluation
  - Large number of data needed to characterize performance
  - Allow control of input space
  - Input space has large effect on FDD performance
  - Rank order generally preserved compared with measurement data results

Thank you

Questions

References

Cheung, H. and Braun, J.E., 2013a, Simulation of Fault Impacts for Vapor Compression Systems by Inverse Modeling Part I: Component Modeling and Validation, *HVAC&R Research*, vol. 19, no. 7: p. 892-906.

Cheung, H. and Braun, J.E., 2013b, Simulation of Fault Impacts for Vapor Compression Systems by Inverse Modeling Part I: System Modeling and Validation, *HVAC&R Research*, vol. 19, no. 7: p. 907-921.

Yuill, D.P. and Braun, J.E., 2013, Evaluating the performance of FDD protocols applied to air-cooled unitary air-conditioning equipment. *HVAC&R Research*, vol. 19, no. 7: p. 882-891.