ENERGY IN TIME WORKSHOP

European Research Conference: Buildings
Europäische Forschungskonferenz: Gebäude

Fault Diagnosis and Adaptive Control of VAV Dampers in a Multizone Building

Tejaswinee Darure

University of Lorraine

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World Sustainable Energy Days
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Energy in TIME

- Energy IN TIME is a Large-scale integrating project within the 7th Framework Programme FP7-NMP, Subprogramme EeB.NMP.2013-4
- The main objective is to reduce the energy consumption and cost in the operational stage of buildings
- Development of an innovative simulation-based control technique with the overarching objective of automating the generation of optimal operational plans tailored to the actual building and users requirements

UL contribution

- Design of fault detection and diagnosis techniques (WP4)
- Design of adaptive control modules for fault at component and system level (WP3)

Issues and Objectives

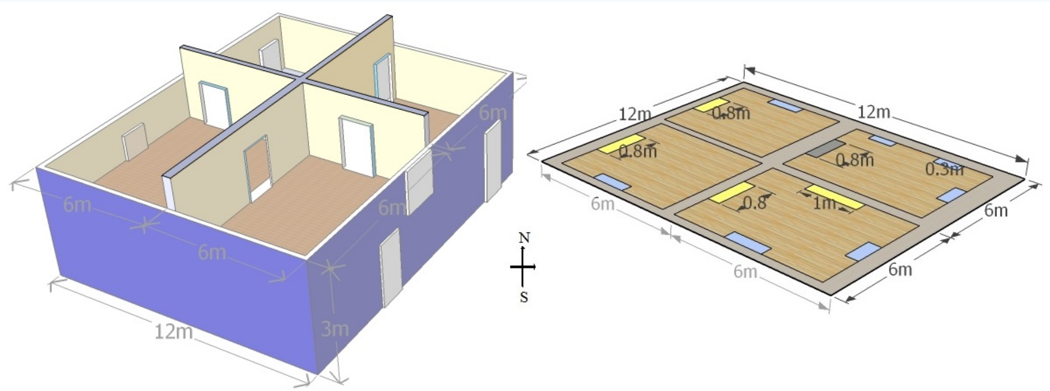
❑ Objectives

- ❖ Developments in fault detection and diagnosis algorithms for system and equipment level faults
- ❖ Reconfiguration of control strategies to adapt fault recovering the functionality of HVAC system and its demonstration on building simulator

❑ Issues

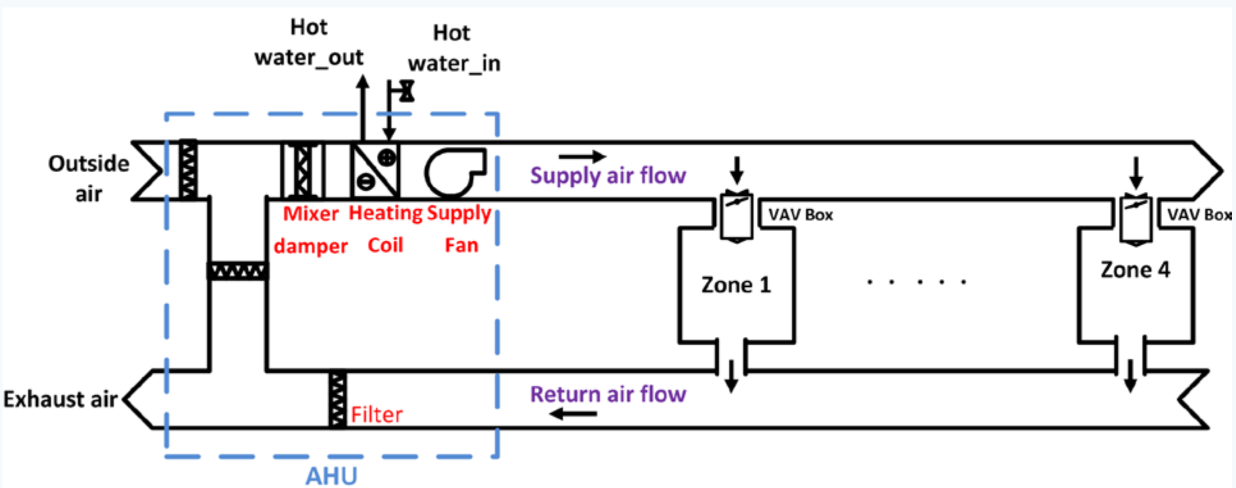
- ❖ The mathematical modeling of overall building system
- ❖ The economic model predictive control optimization problem for large scale building
- ❖ Fault adaptive control through integration of fault detection and diagnosis algorithms with predictive control

Benchmark Building description



Building Model Development in SIMBAD

- ❖ SIMBAD →HVAC toolbox for the MATLAB/SIMULINK
- ❖ Flexibility in simulation with available weather data (for Nancy)
- ❖ Platform for application of different control strategies

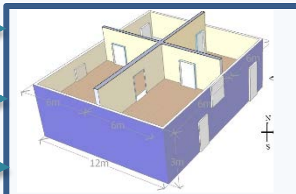


- Every zone contains:
  - i) Temperature sensor
  - ii) VAV box
- Air Handling Unit consists:
  - i) Mixer
  - ii) Heating Coil
  - iii) Supply fan

Mathematical Model structure

Inputs
- Supply air temperature
- Supply air flow

Disturbances
- weather
- Occupancy schedule



Building System

→ Zone Temperature } **Output**

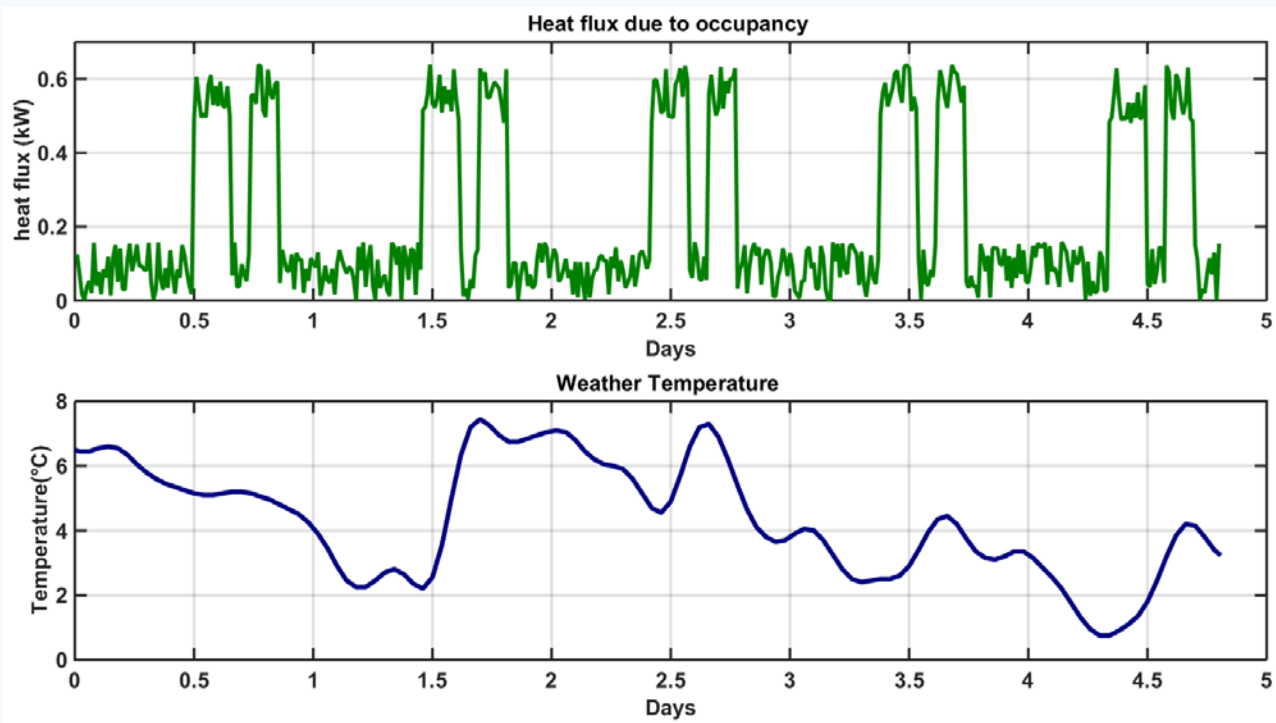


Figure: Disturbance

→ **Type of building:**

***office* type**

→ **Weather: Nancy**

France

Fault Detection and Diagnosis

- Dedicated bank of unknown input residual generators is designed based on the linearized thermal model of the building
- Disturbances are considered to be known
- Residuals are generated (residual : the difference between actual and computed signal)

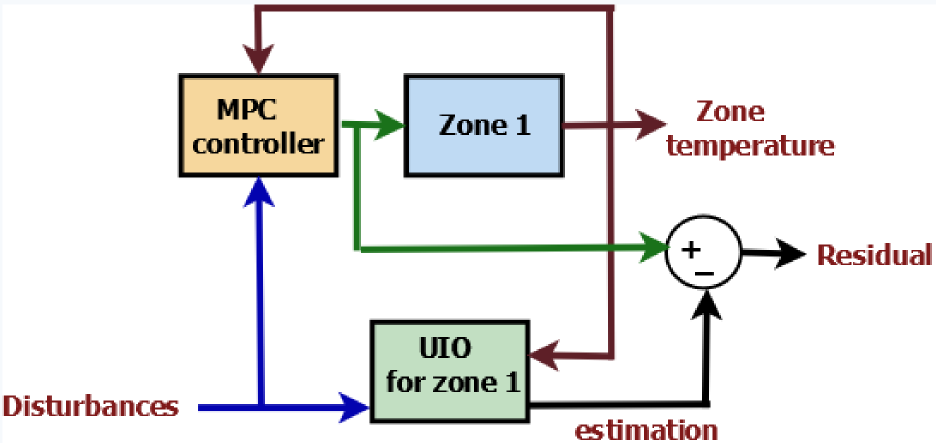


Figure: FDD structure

- Each residual generator is driven by all outputs and all inputs except one input.
- When all sensors are fault-free and fault occurs in i^{th} zone-actuator, residual follows isolation logic as

$$|r_i(k)| \geq Threshold_i$$

$r_i(k)$ represents the residual for i^{th} zone actuator

Simulation example

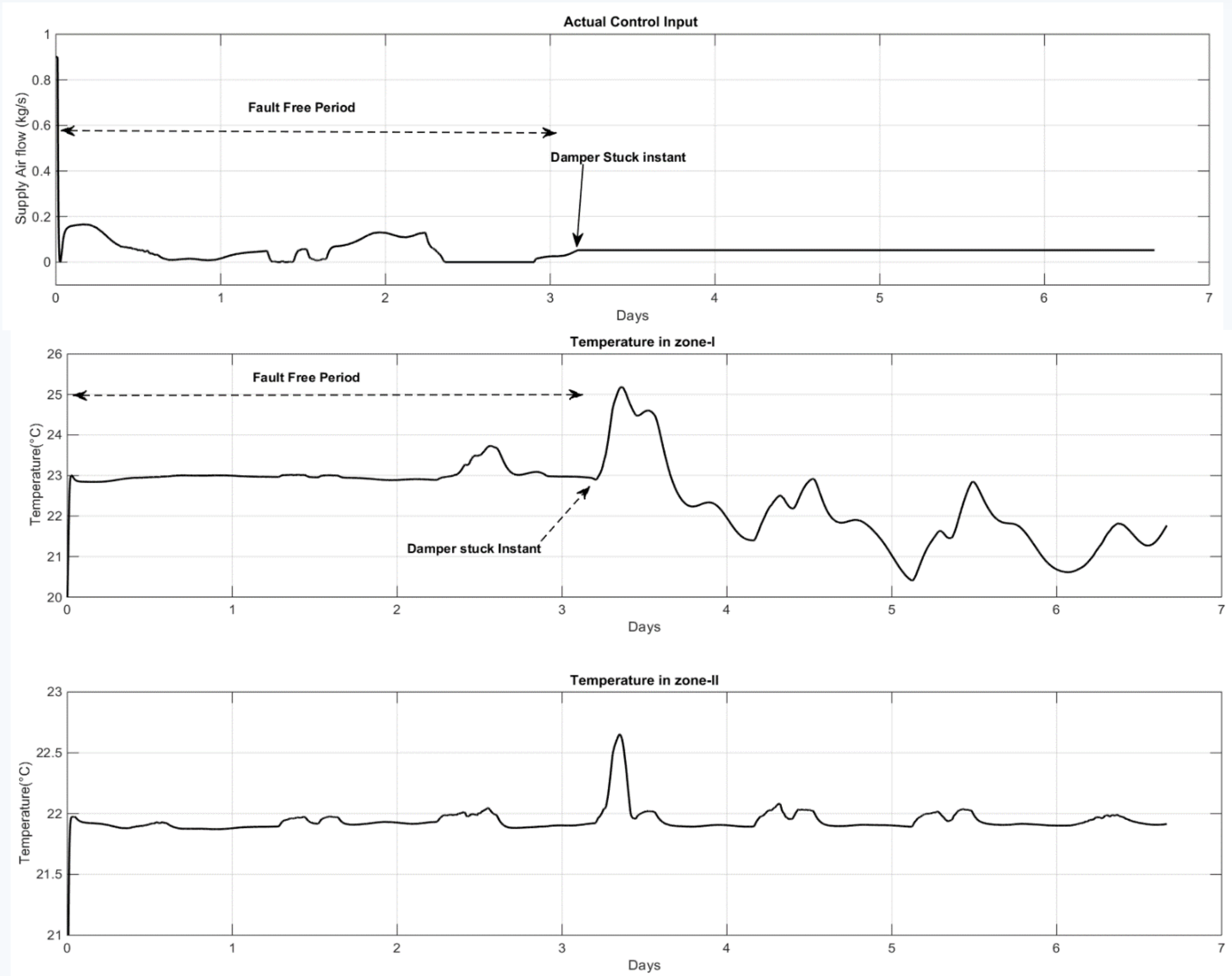


Figure: Effect of damper stuck on zone temperatures

Damper in zone 1 stucks at the start of a 3rd day

Zone-1 temperature

Zone-2 temperature

When absolute value of residual is greater than threshold, the fault is detected and from the value of residual, diagnosis is followed.

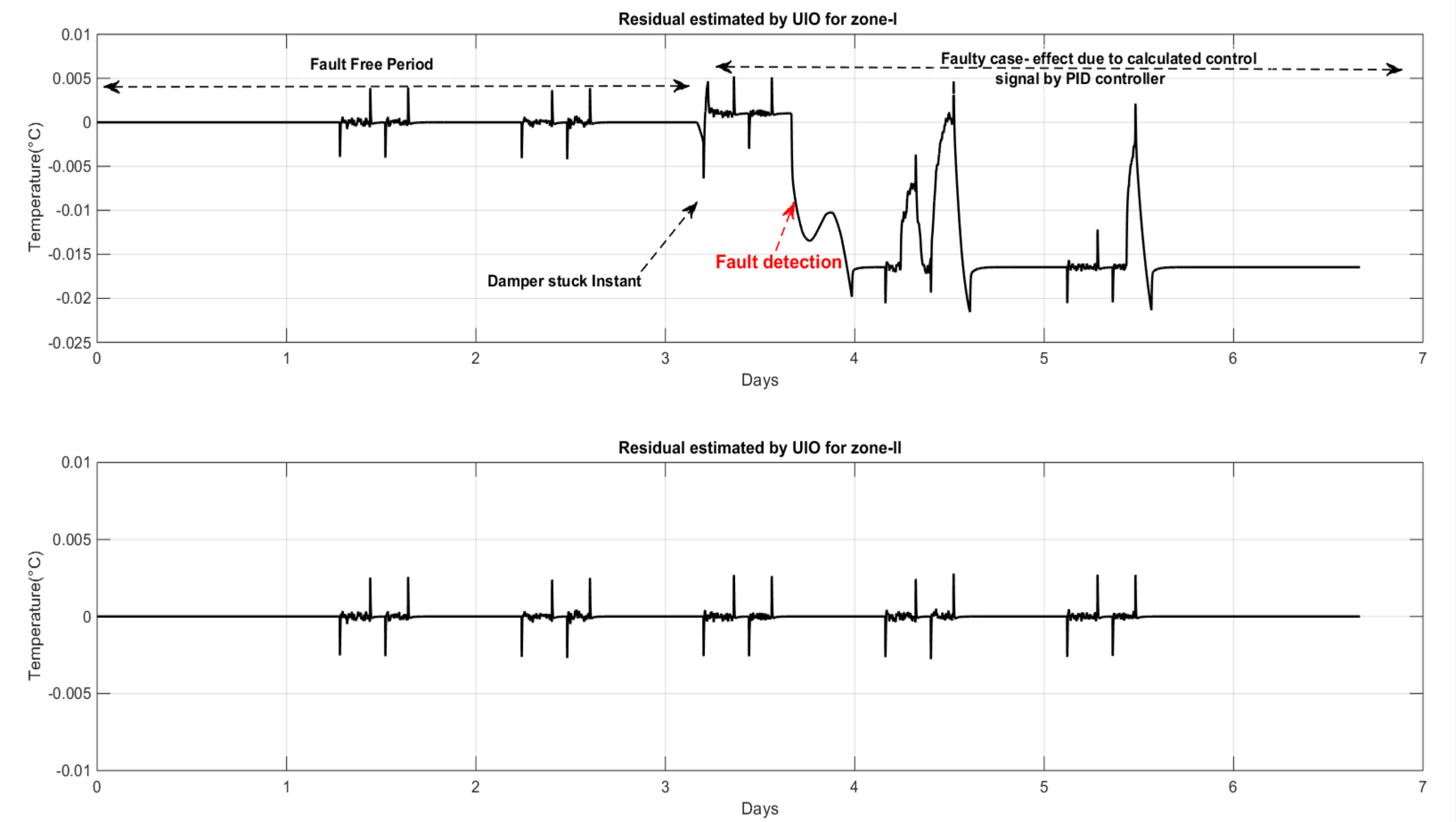
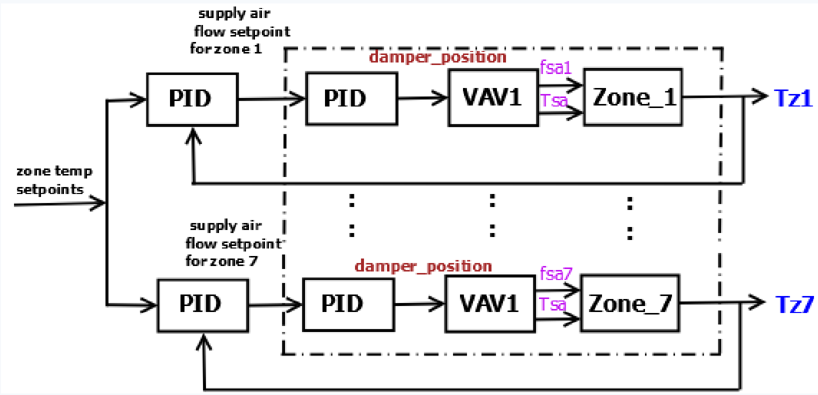
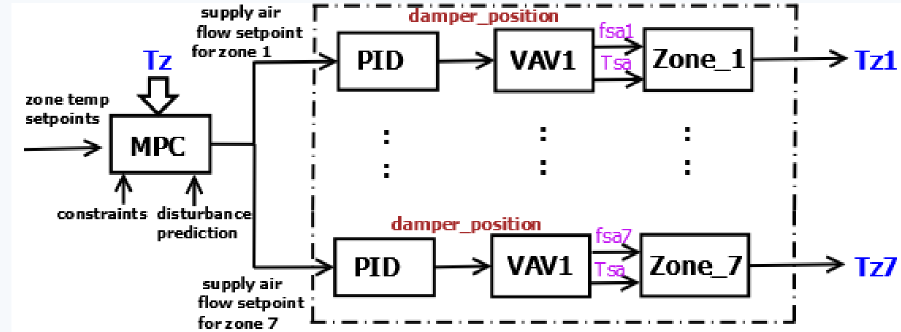


Figure: Detection of damper stuck

Fault Tolerant Control





Cost function

$$J_{total} = \underbrace{(\hat{y} - \mathbf{ref})\mathbf{Q}(\hat{y} - \boldsymbol{ref})^T}_{\text{setpoint Tracking}} + \underbrace{\boldsymbol{uRu}^T}_{\text{control effort}}$$

Constraints

f_{min}	0 kg/s	T_{samin}	20°C	y_{min}	19°C
f_{max}	0.4 kg/s	T_{samax}	40°C	y_{max}	25°C

Q and ***R*** are weights*
Horizon is of one Day.

- $\boldsymbol{ref}$ is desired temperature setpoints
- $\boldsymbol{u}$ is control input vector as $[f_{sai} \quad T_{sa}(k)]^T$
- $\boldsymbol{y}$ is output vector as $[\ T_{zi}(k)]^T$
- f_{min} is minimum flow from VAV box
- f_{max} is maximum flow from VAV box
- T_{samin} is minimum supply air temperature AHU can provide.
- T_{samax} is maximum supply air temperature AHU can provide.
- y_{min} is lower temperature limit for comfort zone
- y_{max} is upper temperature limit for comfort zone

FTC Contd.

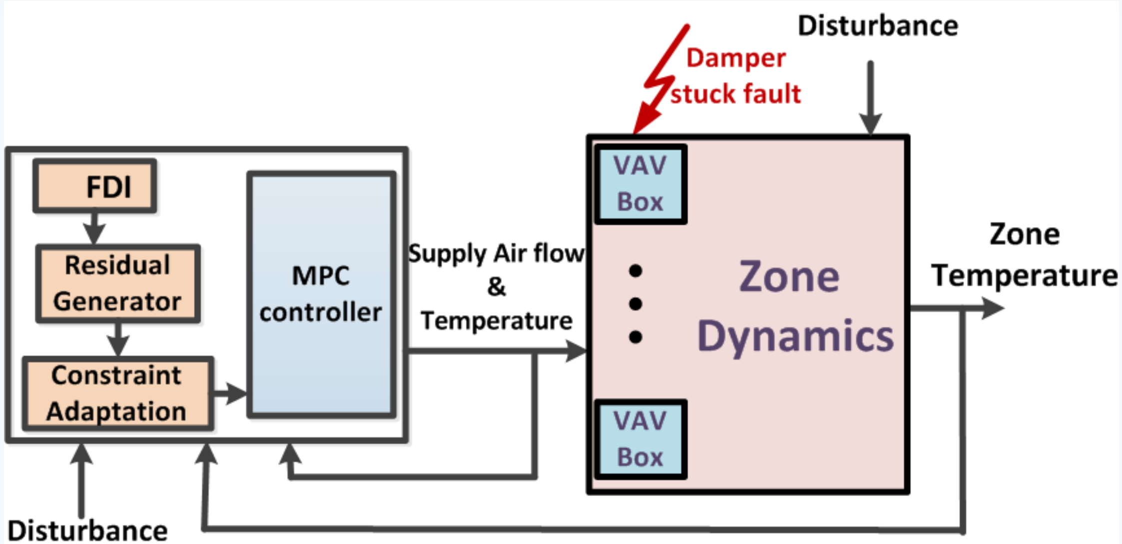
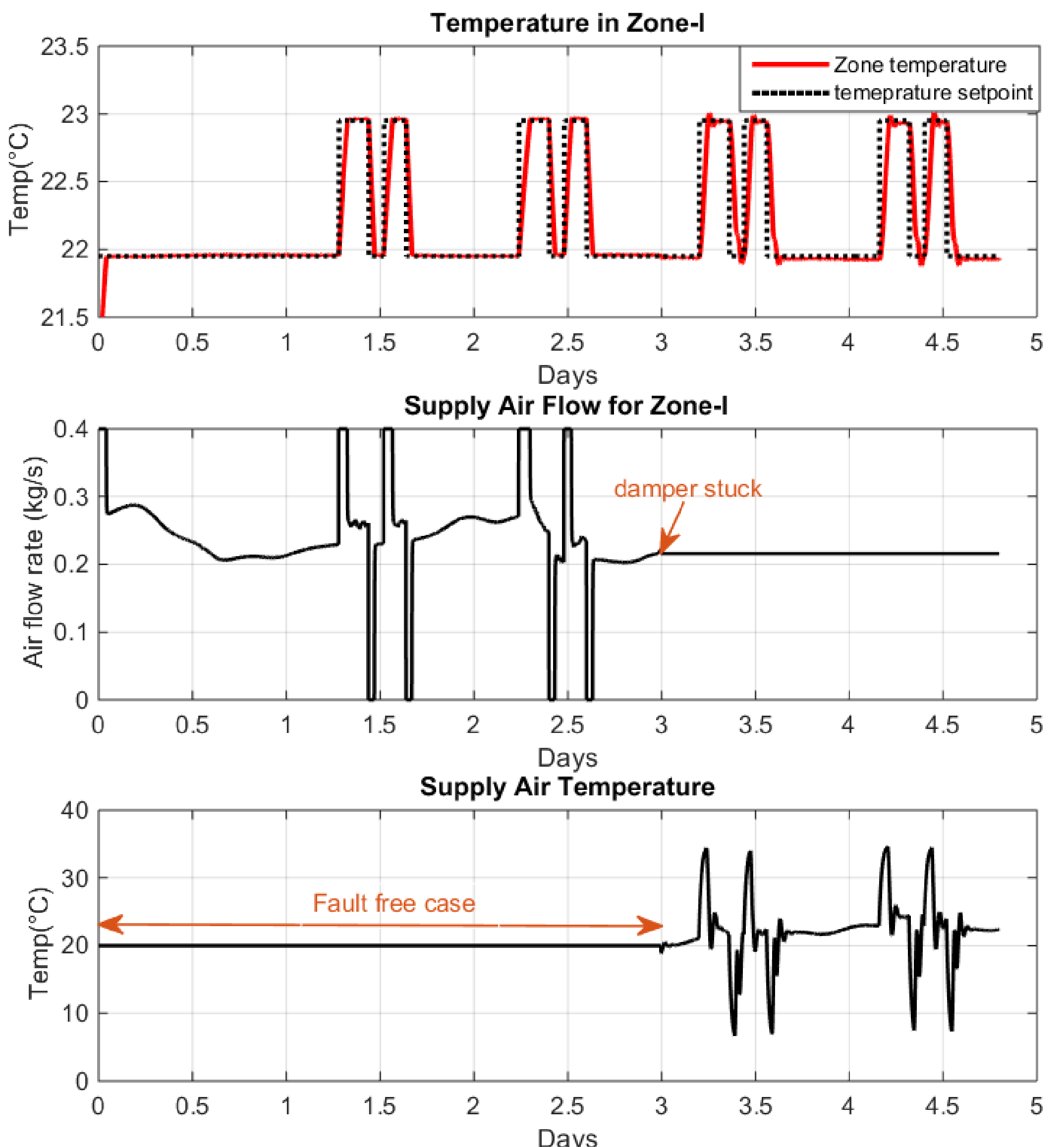


Figure: FDD and FTC structure

- FDD module detects and diagnose fault has occurred at zone-I where the stuck is at 52% allowing 0.21 kg/s fixed supply air flow.
- Online modification is done of the constraints on the decision variables under damper stuck failures occurrence.
- This information is updated in the MPC of the zone level temperature controller.
- Constraints are switched, which allows calculation of supply air temperature at fixed stuck supply air flow to maintain zone -1 temperature at 22°C

Simulation example- damper stuck case



References

- Lennart Ljung, *System Identification :Theory for users* Prentice Hall,2003.
- J. B. Rawlings and D. Q. Mayne, *Model Predictive Control : Theory and Design* Nob Hill Pub., Jan 1, 2009
- J.M. Maciejowski, *Predictive Control with Constraints*, Prentice Hall,2002.
- Petru-Daniel Morosan,Romain Bourdais *Building temperature regulation using a distributed model predictive control* Energy and Buildings 42,(1445-1452),2010
- Matt Wallace and Ryan McBride, *Energy efficient model predictive building temperature control* Chemical Engineering Science 69,(45-58),2012
- Wei Liang, Rebecca Quinte, *MPC control for improving energy efficiency of a building air handler for multi-zone VAVs*, Building and Environment 92,(256-268),2015
- Yudong MA, Anthony Kelman, *Predictive Control for Energy Efficient Buildings with Thermal Storage*, IEEE Control Systems Magazine, February 2012

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Thank you

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