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# Distributed Air Flow Control

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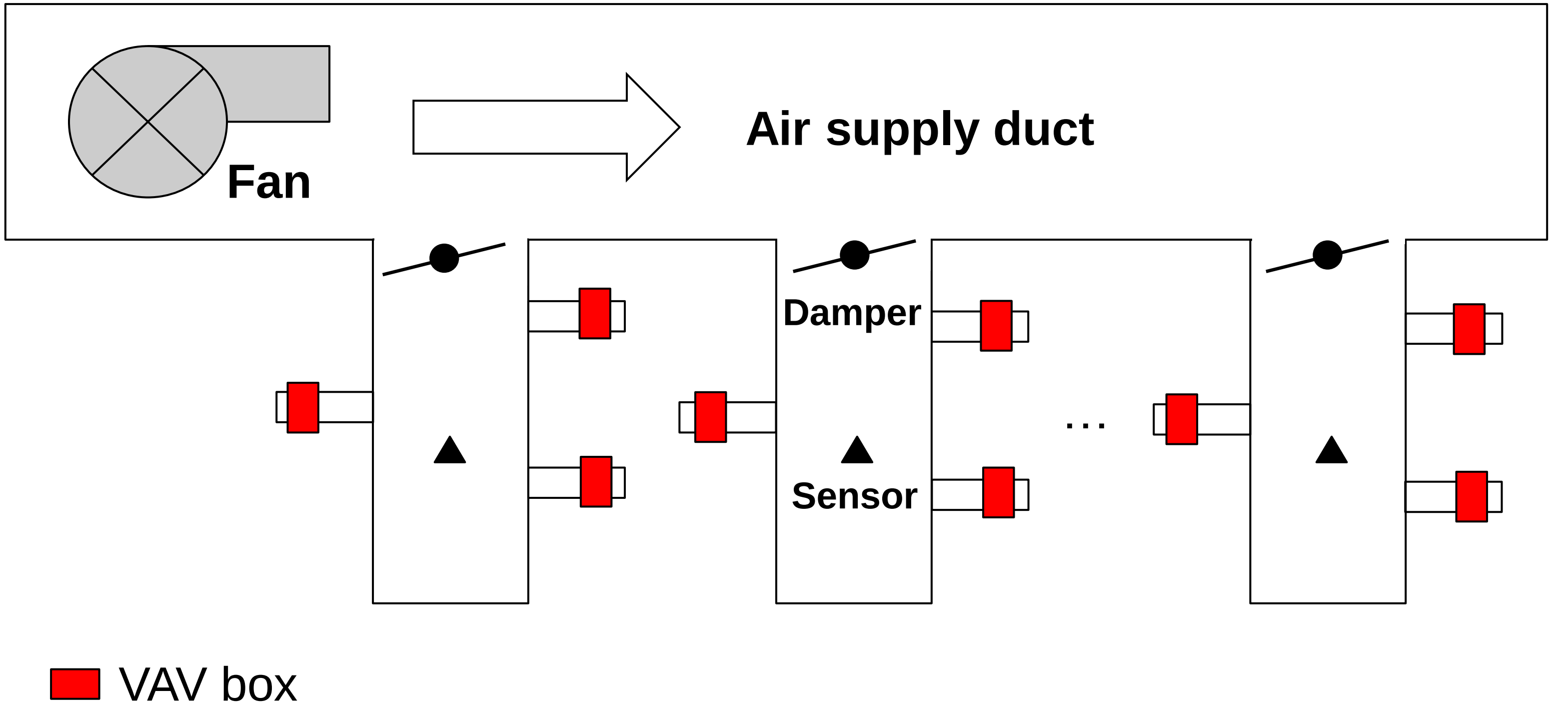
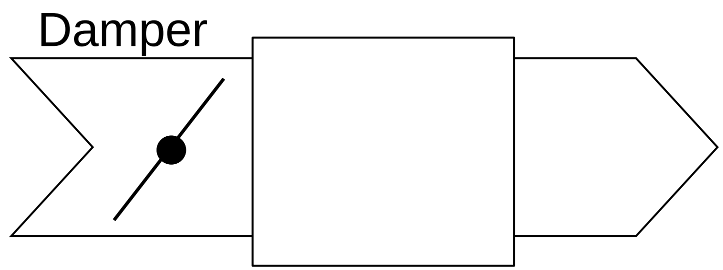
# Air Supply System

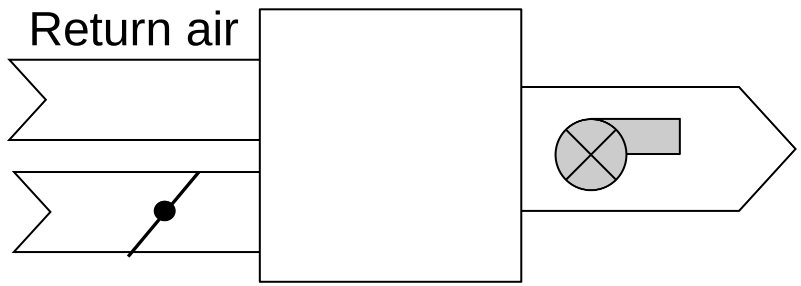


# VAV Box

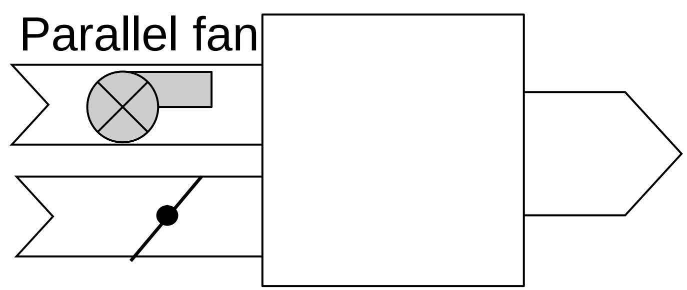
1. Single duct




2. Series fan




3. Parallel fan



# Motivation

- When one pressure damper opens more, the air pressure of all the other branches drops which causes all the other pressure dampers open and therefore fluctuation in air flow.
- The power consumption of fan is proportional to the cube of air flow rate. A fluctuating air flow rate causes more energy consumption.
- A distributed cooperative control strategy can be introduced to reduce this air flow fluctuation.

# Motivation

- Distributed cooperative controller can also lead to more reliability and less computational burden. The pressure control dampers are based on local pressure information and they are connected as a network. It is more robust to packet dropout. Decentralized controllers also share the computational burden of centralized controller.

# Temperature Model

- Temperature model of zone

$$\dot{T}_i(t) = \dot{m}_i(t)K_{1,i}(l - T_i(t)) + K_{2,i}(s_i - T_i(t))$$

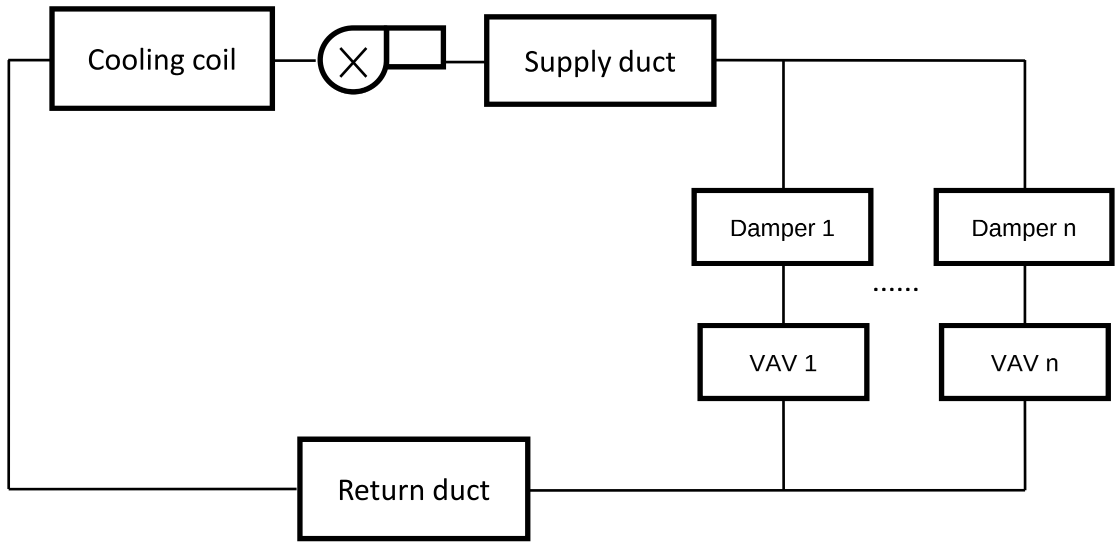
- $T_i$, $l$ and $s_i$ are temperatures of zone $i$, supply air and heat sources;

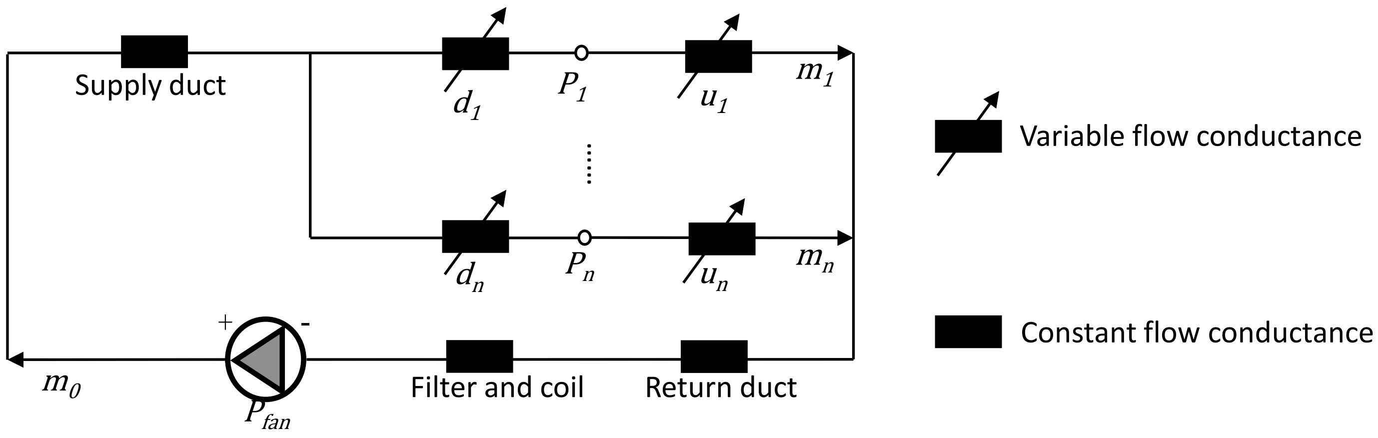
$$\dot{m}_i(t) = u_i(t)\sqrt{\frac{2p_i(t)}{\rho}}$$

  is the mass flow rate, $u_i$ is the VAV damper open area, $p_i$ is the air pressure of branch $i$, $\rho$ is the air density;

- $K_{1,i}$ and $K_{2,i}$ are constants.

# Pressure Model



# Pressure Model

- Pressure model of branch $i$

$$\sqrt{p_i(t)} = f_i(d_1(t), \cdots, d_n(t), u_i(t), t)$$

$d_j$ is the pressure damper open area, $u_i$ is the VAV box damper open area, $f_i$ is a nonlinear function satisfying

$$\frac{\partial f_i}{\partial d_i} > 0, \quad \frac{\partial f_i}{\partial d_j} < 0, \quad -F < \frac{\partial f_i}{\partial u_i} < 0, \quad \sum_{k=1}^{n} \frac{\partial f_i}{\partial d_k} > 0$$

# Challenges

- No universal air pressure model exists.
- The air pressure and air flow rate are coupled. When adjusting VAV box to control the air flow rate, the air pressure is affected which conversely affects the air flow rate.
- The damper of pressure control are coupled.

# Objective

- Adjust the pressure control dampers in a cooperative manner such that the air flow rate is smooth when the environment is changing.
- The pressure at each branch is equal to a desired value.
- Adjust the VAV box so that the temperature at each zone converges to a comfort level.

# Control Strategy

- Two level control

- Temperature control (low level)

  Based on temperature measured by the sensors in the zone to control VAV box and supply cool air flow

- Pressure Control (high level)

  To adjust the damper such that the air pressure at each branches are around a desired value

# Cooperative Controller

- The control input of $u_i$ and $d_i$ are

$$\dot{d}_i(t) = \alpha\left[\sum_{k\in N_i}\left(\sqrt{P_k(t)} - \sqrt{P_i(t)}\right) + \beta\left(\sqrt{P_0} - \sqrt{P_i(t)}\right)\right]$$

$$\dot{u}_i(t) = \gamma(T_i(t) - T_0)$$

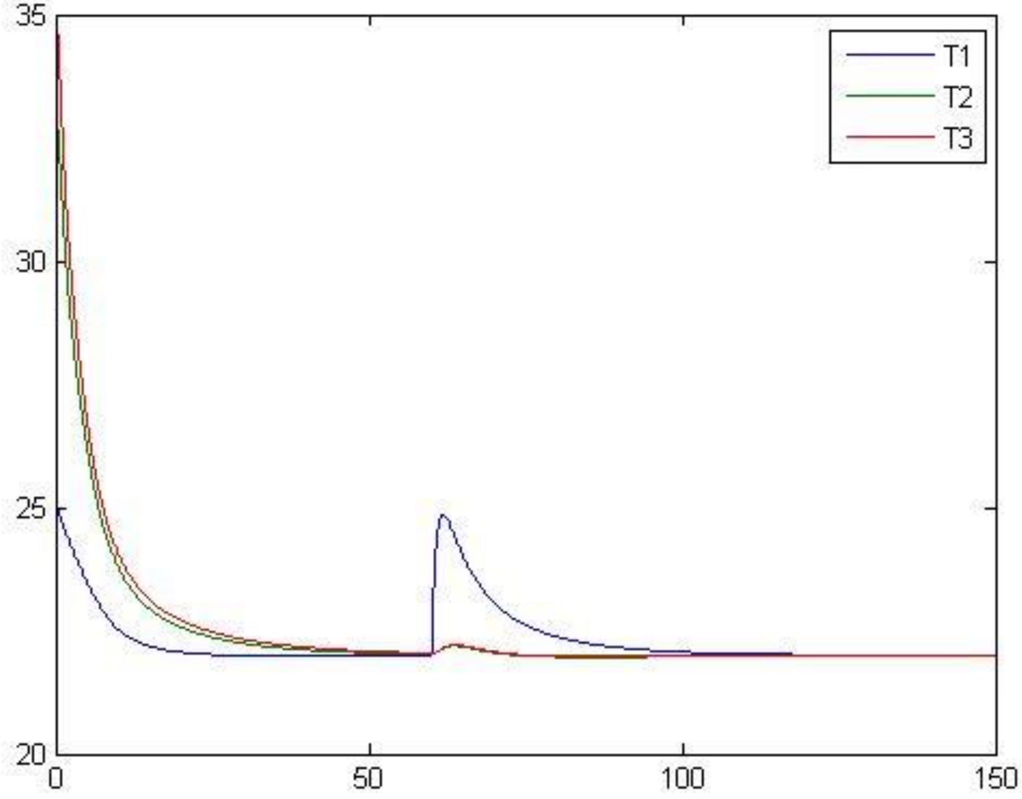
- α, $\beta$ and $\gamma$ are positive constants.
- There exists a closed set $B$ such that when $p_i(0) - p_0$, $T_i(0) - T_0$ and $u_i(0) - \bar{u}$ are in $B$,

$$\lim_{t\to\infty}(p_i(t) - p_0) = 0, \quad \lim_{t\to\infty}(T_i(t) - T_0) = 0$$

where $\bar{u}$ is the steady control input.

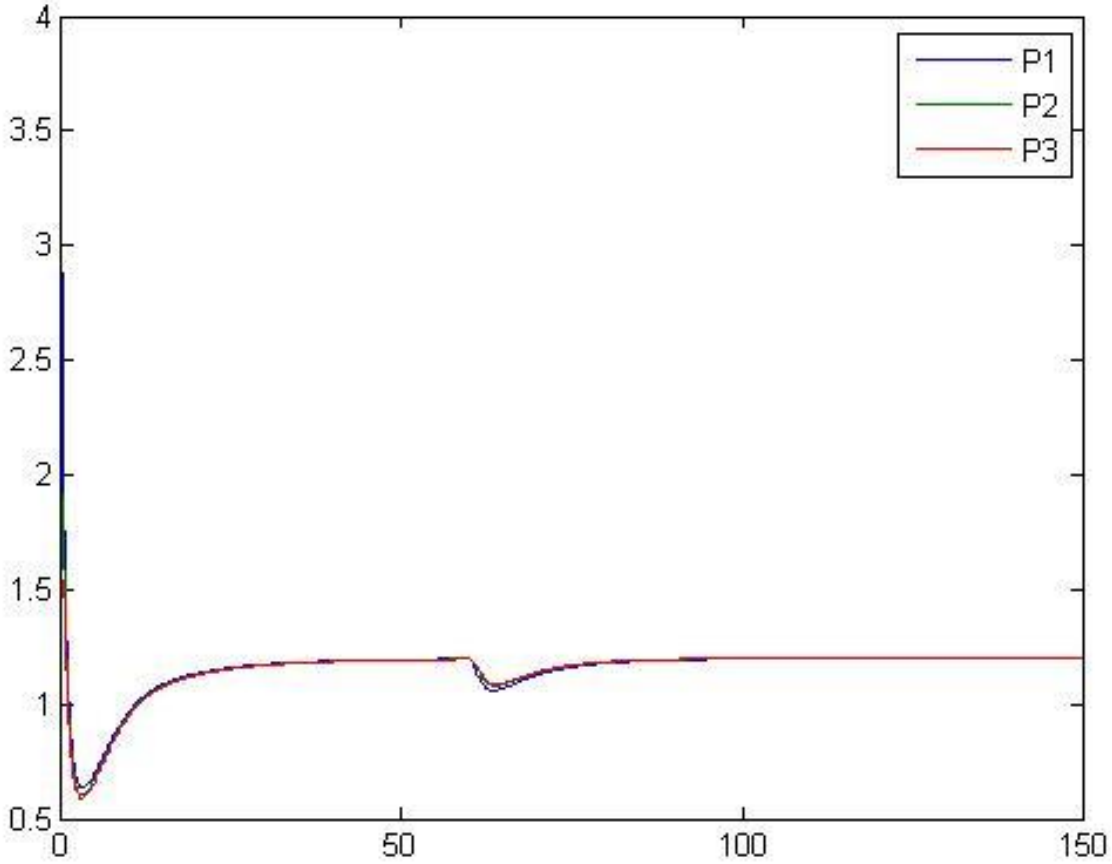
# Simulation

- Three zones are considered. The cooling load is suddenly added at 60.



# Simulation

- The pressure changes correspondingly at 60.



# Thank you!