Air Quality and Comfort Constrained Energy Efficient Operation of Multi-Unit Buildings

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Overview

Maintaining optimum indoor air quality (IAQ) through effective ventilation is critical for the well-being and productivity of building occupants. Control strategies aimed at improving the efficiency of heating, ventilation and air conditioning (HVAC) systems must jointly operate ventilation as well as heating and cooling processes. To this end, we propose a framework for minimizing energy consumption of the HVAC system in a multi-unit building, while meeting thermal comfort and IAQ requirements.

Introduction

- Air quality impacts wellness and occupants' productivity.
- Research in the area of building HVAC control has mostly focused on ensuring the occupants' thermal comfort .

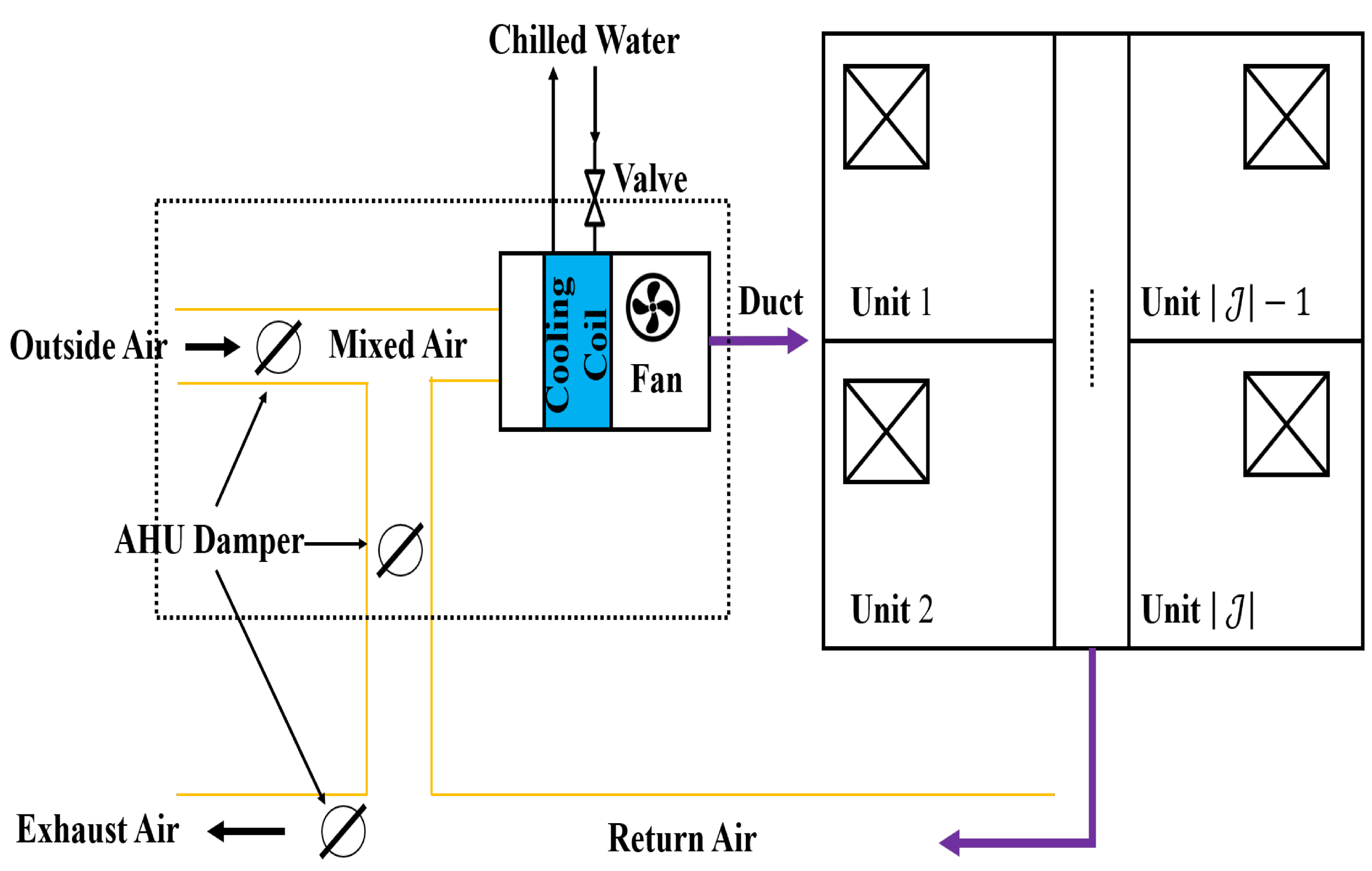

Fig 1: Overall HVAC system (Air handling unit, Cooling/heating coil, VAV boxes, Fan) in our multi-unit building model

- A need to develop a holistic approach for concurrently managing IAQ and indoor temperatures optimally.

Optimization Framework/Method

- Objective function

$$\min \int P(t)\,dt = \frac{C_p}{\eta COP} \sum_{j} \int \dot{m}_j(t)[U]\,dt$$

$$U = \beta(t)T_j(t) + \big(1-\beta(t)\big)T_\infty(t) - T_S$$

- Constraints

$$0 \le \dot{m}_j(t) \le \bar{m} \;\; \forall j, \qquad 0 \le \beta(t) \le 1,$$

$$O_j(t) \le O_j^{max} \;\; \forall j, \qquad \left|T_j(t) - \Delta_j\right| \le \delta_j \;\forall j$$

- Evolution of CO_2 concentration

$$V_j \frac{dO_j(t)}{dt} = \frac{\dot{m}_j(t)}{\rho}\big(O_{mix}(t) - O_j(t)\big) + Z_j(t)\,\sigma$$

$$O_{mix}(t) = [1-\beta(t)]O_{out}(t) + N(t)$$

$$N(t) = \beta(t)\frac{\sum_{j\in J} O_j(t)\dot{m}_j(t)}{\sum_{j\in J}\dot{m}_j(t)}]$$

- Zonal temperature dynamics

$$C_j \frac{dT_j(t)}{dt} = \frac{T_\infty - T_j(t)}{R_j^{\circ}} + c_p \dot{m}_j(t)(T_S - T_j(t))$$

C_j : thermal capacitance of zone j,
V_j : volume of zone j,
ρ is the density of air
R_j^o: thermal resistance of zone j with ambient
$O_j(t)$: zonal CO_2 concentration
T_S : supply air temperature (constant)
$T_j(t)$: temperature of zone j at time t
$O_{mix}(t)$: CO_2 concentration in the mixed air
σ : per-person CO_2 contribution
$Z_j(t)$: occupancy in zone j at time t
$T_\infty(t)$: ambient temperature,
$\dot{m}_j(t)$: mass flow rate of air to zone j at time
$P(t)$: energy consumed by the cooling coil
η : efficiency of the cooling coil
C_p: specific heat capacity of air
COP : coefficient of performance of the chiller
$\beta(t) = 1$: the AHU damper is OFF
$\beta(t) = 0$: the AHU damper is ON

Simulation Setup

occupancy patterns:
with DR-amenability
without DR-amenability

Outdoor temperature, T_∞= 30°c
Outdoor air CO_2 Concentration, O_∞= 150 ppm

Zonal temperature setpoint = 20°c
Target indoor CO_2 concentration, O_∞= 300 ppm

Summary of Results

Case Study: Simulation Results with DR Amenability

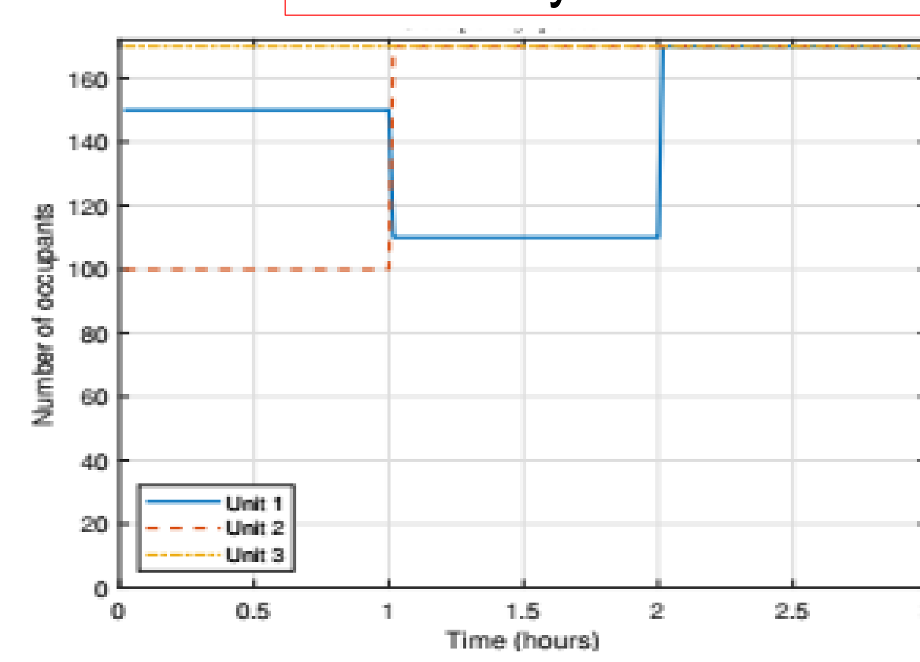

Fig 2 : Occupancy Pattern

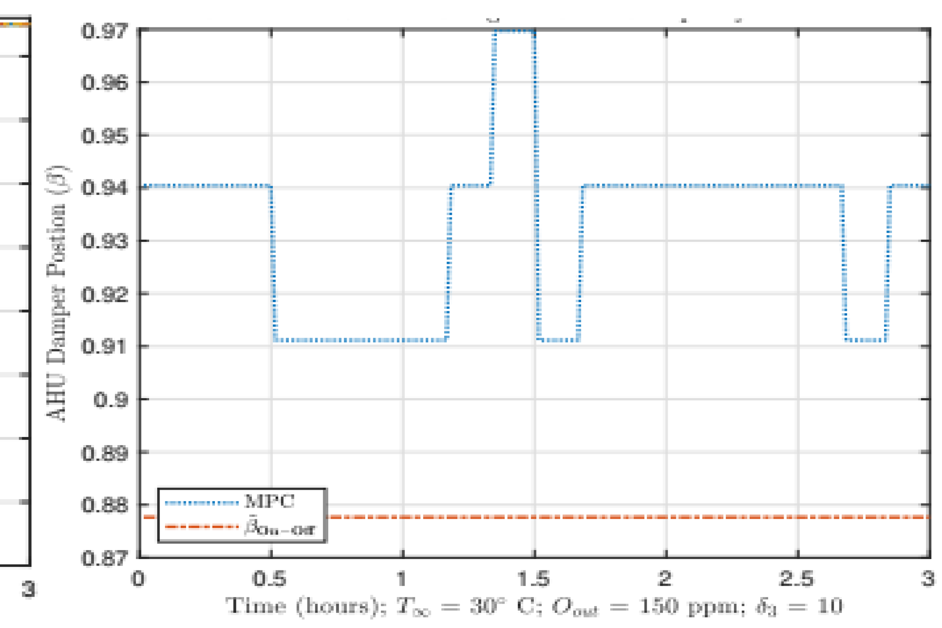

Fig 3 : Damper position

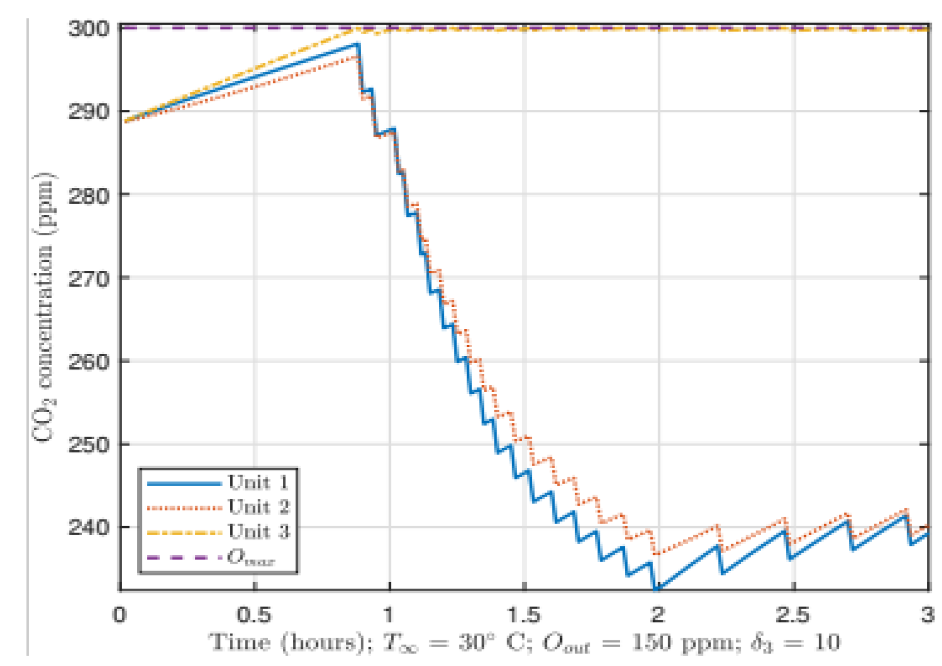

Fig 4 : CO_2 dynamics (JOTAC)

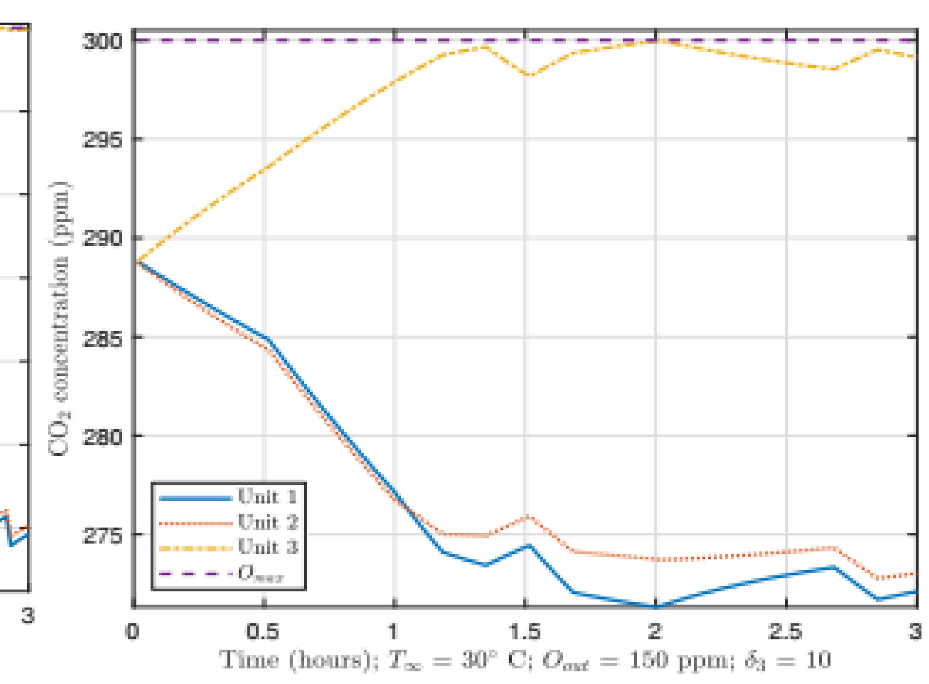

Fig 5 : CO_2 dynamics (MPC)

Table 1 : Energy savings difference between JOTAC and MPC

Scenerio	Energy (MJ)		% Energy Savings
	JOTAC	MPC	
A	9.091	9.322	2.48
A'	6.646	7.094	6.32
B	9.267	9.506	2.51
B'	7.156	7.837	8.69
C	9.091	9.265	1.88
C'	6.530	6.876	5.03

- Our proposed control strategy (JOTAC) could potentially result in energy savings of nearly 8.69% when compared to the MPC-based approach.

Future Work

- Formal Proof of near-optimality of the dynamic versions
- Validation using real building data sets
- ML/RL driven approach-based on the bilinear structure to develop PIML models

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Benefits

- **Provides optimum indoor air quality for occupants' wellness and productivity**
- **Maintains thermal comfort conditions within acceptable limits**
- **Reduces power consumption of variable air volume HVAC systems which can subsequently lead to a reduction in energy prices**

Support

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