Scheduling of Non-Pre-emptive Pre-Cooling Processes for an In-building Air Distribution System

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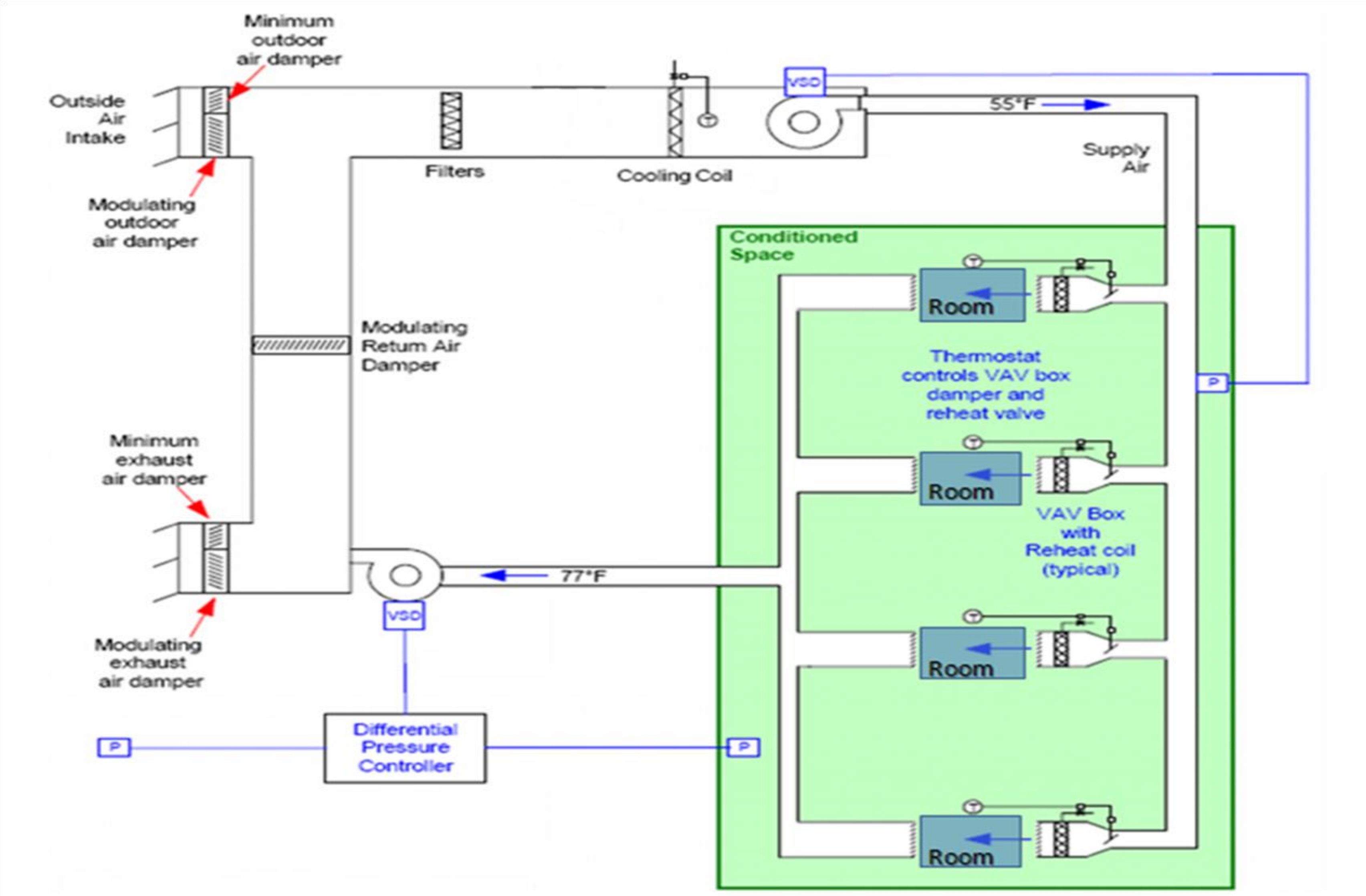
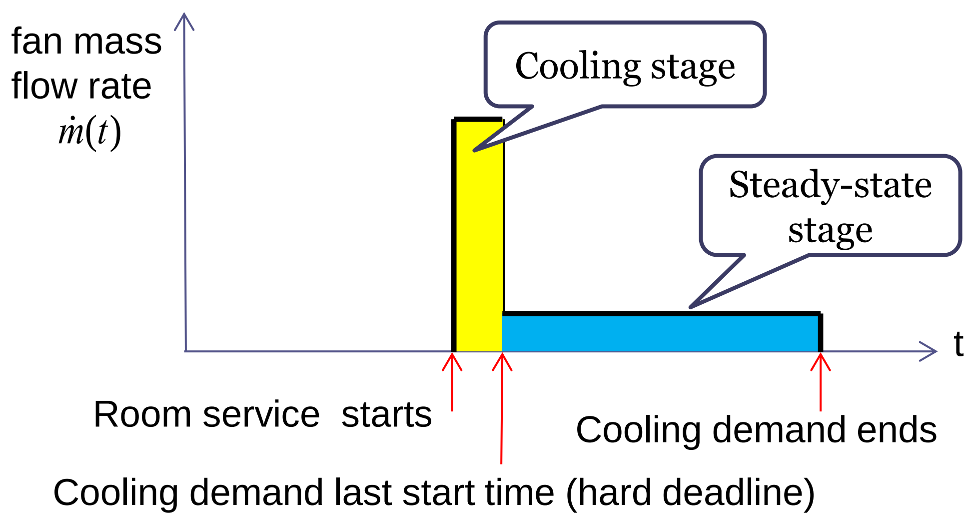
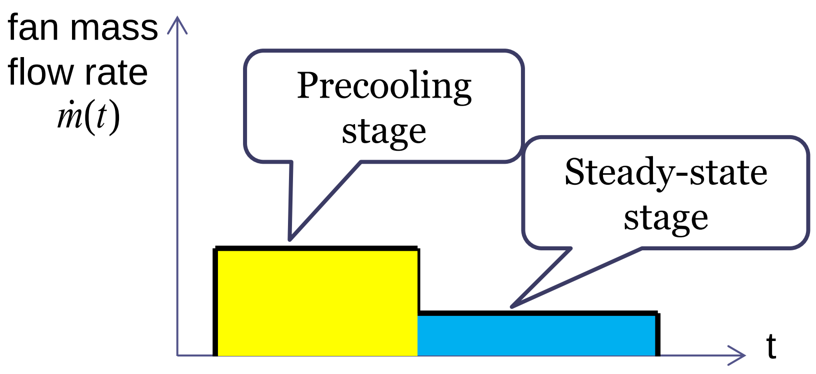
THE IN-BUILDING PART OF HVAC



MOTIVATION

- Air distribution fans = 30% of overall HVAC power consumption.
- Power consumption of each fan $\propto$ cube of the generated mass flow rate.
- Elongated cooling processes saves energy
- Exploit nonlinearity of fan power function.





ASSUMPTIONS

- The following parameters are known in advance from the Building Operating Systems using occupancy sensing and forecasting and fixed during HVAC operation period:
  - the initial room temperature T_r
  - desirable room temperature T_s
  - cooling service hours (t_b to t_e)
- Other known parameters:
  - Maximum flow rate of each room
  - Fan flow capacity
  - Cooling load (radiation, air circulation, solar heating) – assumed invariant.
- Air mixing in each room is assumed to be instantaneous

FORMULATION OF A PLANNING PROBLEM

Optimal Planning Problem:

Minimize $J = \int_0^T \left(\sum_{i=1}^n I_i^b(t, t_i^b, t_i^e)\dot{m}_{i,1} + I_i^e(t, t_i^e, t_i^{de})\dot{m}_{i,2} \right)^3 dt$

(A. Kelman and F. Borrelli. Bilinear model predictive control of a HVAC system using sequential quadratic programming. In IFAC World Congress, 2011.)

Define $I_i^b(t, t_i^b, t_i^e) = \begin{cases} 1, if\ t_i^b \le t < t_i^e \\ 0, otherwise \end{cases}$

$I_i^e(t, t_i^e, t_i^{de}) = \begin{cases} 1, if\ t_i^e \le t \le t_i^{de} \\ 0, otherwise \end{cases}$

Subject to the following constraints:

(1) $0 \le t_i^b < t_i^e \le t_i^d < t_i^{de}$ — $t_i^d, t_i^{de} -$ *Service starting and ending moment*

(2) $\dot{Q}_i \le \dot{m}_{i,1}, \dot{m}_{i,2} \le C_i$ — $C_i -$ *Maximum flow rate in room i*

(3) $\left\{ \sum_{i=1}^n I_i^b(t, t_i^b, t_i^e)\dot{m}_{i,1} + I_i^e(t, t_i^e, t_i^{de})\dot{m}_{i,2} \right\} \le C_{fan}$ — $C_{fan} -$ *Maximum fan flow rate*

(4) $\dot{m}_{i,2} = \dot{Q}_i \frac{(T_e - T_{s,i})}{(T_{s,i} - T_c)}$ — *Steady state thermal balance*

(5) $T_{s,i} = \left[T_{r,i} - \frac{\dot{m}_{i,1}T_c + \dot{Q}_i T_e}{\dot{m}_{i,1} + \dot{Q}_i} \right] e^{-\frac{\dot{m}_{i,1} + \dot{Q}_i}{M_i}(t_i^e - t_i^b)} + \frac{\dot{m}_{i,1}T_c + \dot{Q}_i T_e}{\dot{m}_{i,1} + \dot{Q}_i}$

M_i: Air mass in room i, T_c: Cool air temperature, $\dot{m}_{i,1}$:Mass flow rate of cool, $\dot{m}_{i,2}$: Air Mass flow rate after cooling, $\dot{Q}_i$: Equivalent environmental mass flow, t_i^d, t_i^b, t_i^e :Demand, beginning and ending time for cooling, $T_{r,i}$, $T_{s,i}$, T_e: Current, desired and external temperatures.

SIMULATION RESULTS

The values used in the experiment are:

M_i – 10kg T_c– 4°C $T_{r,i}$ – 27°C T_e–30°C Q_i - 40kg/hour

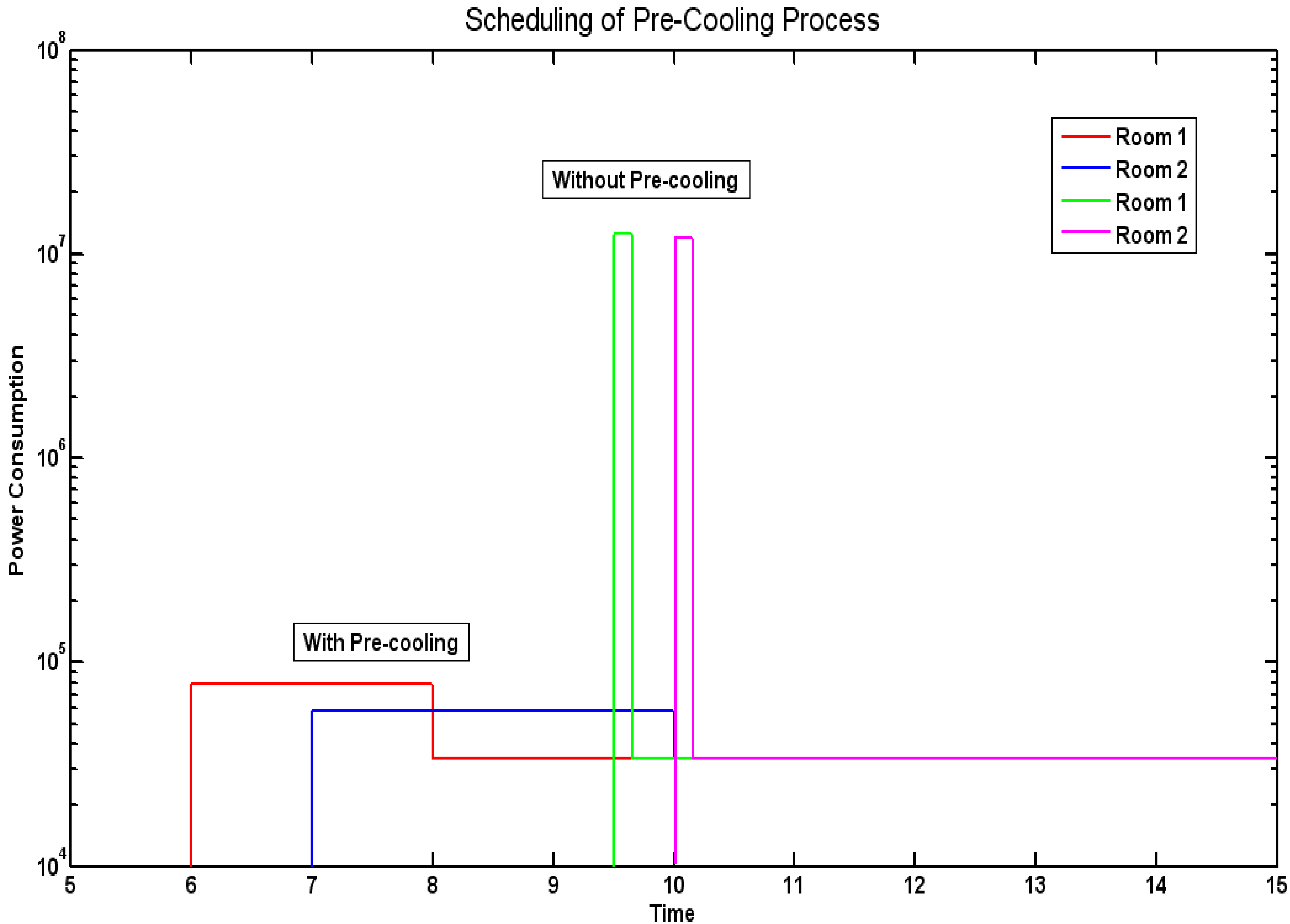
Variables	Room 1	Room 2
$T_{s,i}$	22°C	23°C
t^d (hours)	09:40	10:10

Energy consumed

Without Pre-cooling : 3432140 J

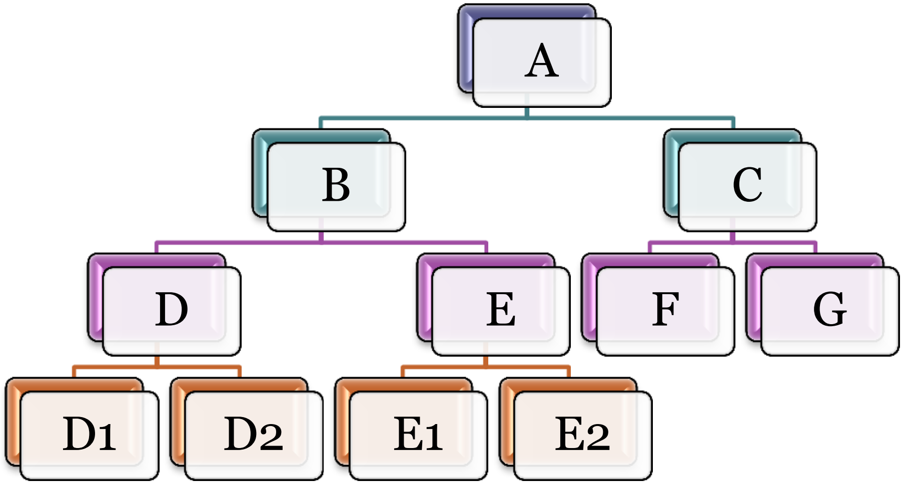
With Pre-cooling : 734000 J

Using scheduled non-preemptive pre-cooling processes, results in around 80% total energy saving.


Scheduling of Pre-Cooling Process
Power Consumption
Time
Without Pre-cooling
With Pre-cooling
Room 1
Room 2
Room 1
Room 2
10^8
10^7
10^6
10^5
10^4
5
6
7
8
9
10
11
12
13
14
15

NESTED PARTITION OPTIMIZATION

- Partition feasible region into sub regions.
- For each sub region, randomly generate feasible solutions.
- Compare the average of the solutions for each region to obtain which region is most promising.
- Further partition the most promising region into further sub region and aggregate the complimentary region into one region.
- If one of the sub regions is found to be promising this region now becomes most promising. But, if the complimentary region is found to be best, the algorithm has to backtrack to a previous solution.
- End algorithm when consequent solutions are almost the same.



ACHIEVEMENTS and FUTURE GOALS

- Achievements
  - Conceptual optimal planning problem formulation
  - First simulation showing promise of planning idea
  - Preliminary investigations on computational aspects of problem

- Plan for 2013
  - Develop efficient methods to solve planning problem
  - Incorporate air-mixing dynamics
  - Introduce preemptive precooling processes with piecewise constant mass flow rates
  - Investigate precooling process with arbitrary mass flow rate functions to unifies preemptive and non-preemptive cases in a general planning problem
  - Explore impact of uncertainty from cooling demand forecasts