INTRODUCTION

Buildings are a large consumer in smart grids and Heating, Ventilation, and Air Conditioning (HVAC) systems account for a significant portion of electrical usage. While reducing the power input of HVAC systems would reduce the energy cost, for the occupants’ comfort it is important to keep the temperature and CO2 concentration level for each zone at a preferred set level. Hence, to control an HVAC system the problem formulation should minimize both energy cost and discomfort cost. In this paper, we try to minimize the long-term energy cost as well as user’s thermal discomfort and user’s air quality discomfort for a multif-zone building. Considering uncertainties in electricity price, outdoor temperature, the preferred temperature level, the preferred air quality (CO2 concentration level), and external thermal disturbance, we formulate a stochastic problem to minimize the time average expected total cost. To this end, Lyapunov optimization technique is used to satisfy the physical and time constraints of the problem at each time interval and minimize the cost without the need to predict any system parameters. Simulations show that the proposed algorithm reduces energy cost effectively with minor expense to thermal and air quality comfort.

MODEL AND FORMULATION

A commercial HVAC system for a building with N-zones (e.g. rooms) is shown below. The HVAC system consists of an Air Handling Unit (AHU) for the whole building and a set of Variable Air Volume (VAV) boxes for each zone. The AHU is composed of dampers, a cooling coil, and a Variable Frequency Drive (VFD) fan. The dampers in the VAV boxes mix the outside fresh air with the air returned from each zone to satisfy the air conditioning and ventilation requirement of each zone. The cooling coil cools down the mixed air and the VFD fan delivers the mixed air to the VAV box in each zone. In each VAV box, there are a damper and a reheating coil, where the damper is used to adjust the rate of supply air into the room and the reheating coil reheats the supply air when needed. By controlling an air supply rate for each zone, we can keep the temperature in each zone (Ti) and CO2 concentration level (Ci) in the occupants comfortable range. The dynamic models for Ti [1] and CO2 [2] are:

\[ T_{i,t+1} = d_i T_i + \mu_i (T_{supply} - T_i) + \frac{\theta_i}{m_i} Q_i \]  
\[ C_{i,t+1} = C_i + \phi_i (C_{supply} - C_i) + \frac{\theta_i}{m_i} P_{i,CO2} \]

Where \( d_i \), \( b_i \), \( a_i \) and \( q_i \) are constants related to physical properties of the building. Therefore, our objective is to find the optimal \( m_i \) that satisfies the occupants’ comfort while minimizing the energy cost of the cooling coil and VFD fan.

OBJECTIVE FUNCTION

The objective function for the problem consists of two parts for each zone:

- The energy cost which is a function of random electricity price \( S_t \) and other stochastic functions \( f_s \) and \( g_b \).
  
  Energy cost = \( m_i f_s + S_i g_b \)

- The discomfort cost which is the difference between next state of the system and the most comfortable state defined by occupant.

\[ \text{Discomfort cost} = \Phi_i (T_{i,t+1} - T_{ref}) + \Phi_i (C_{i,t+1} - C_{i,ref})^2 \]

We want to minimize the long term expected value of these two cost functions for all zones, where the expectation is taken over all the uncertainties in the problem:

\[ P1 \min_{m_i} \lim_{T \to \infty} \frac{1}{\tau} \sum_{t=1}^{T} \{ \text{Energy cost} + \text{Discomfort cost} \} \]

subject to

\[ \left(1 - 2\right) \]

\[ \tau_{min} < T_i < \tau_{max} \]  
\[ C_i < C_{i,ref} \]  
\[ m_{min} < m_i < m_{max} \]

METHODOLOGY

To solve P1, in addition to the constraints (1 – 5), we should note that the future system parameters are unknown. As mentioned before, HVAC system has unknown power demand that is related to many factors, namely the most comfortable temperature level and CO2 concentration level decided by occupants, the lower and upper bounds of indoor temperature, outdoor temperature, external thermal disturbance and number of people in each room.

To deal with these challenges, we proposed an algorithm based on the Lyapunov Optimization Technique (LOT). We incorporate the constraints (1 – 4) into the construction of virtual queues and try to opportunistically minimize the expectation in P1.

The concept of the proposed algorithm is summarized as follows:

- Constructing virtual queues associated with indoor temperatures and CO2 concentration level of all zones.
- Obtaining the drift-plus-penalty term according to the LOT framework [3].
- Minimizing the upper bound given in the right-hand-side of the drift-plus-penalty term.

Based on the above concept, we can propose an online energy management algorithm without knowing HVAC system power demand and predicting any system parameters in each time slot.

For each time slot \( t \), we first observe \( T_{i,t}, T_{i,t+1}, T_{i,t+2}, T_{i,t+3}, T_{i,t+4}, C_{i,t}, C_{i,t+1}, \ldots, P_{i,t}, P_{i,t+1}, \ldots \) then we solve P1 for \( m_{i,t} \) – note that using LOT framework, the objective function is a quadratic function of \( m_{i,t} \) at each timestep and therefore the optimum/(minimum) point of the parabola is analytically available.

So far, we took care of constraints (1 – 4) using virtual queues in our LOT framework. To ensure that (5) is satisfied, we use

\[ m_i = \max(\min(\sigma_i, m_{i,t}), m_{i,t}) \]

After finding \( m_i \), we update \( T_{i,t+1} \) and \( C_{i,t+1} \) using (1 – 2).

CONCLUSION

Results on the right show \( m_{i,t}, T_i \) and \( C_i \) respectively for a timespan of a month. Real data is used for electricity price [4] and outdoor temperature [5], these results show that satisfying the system constraints, we were able to minimize the consumed energy cost for an HVAC system in a multif-zone smart building satisfying the occupants ventilation needs both for temperature and air quality. The algorithm acts on real time and does not need to predict any parameters or know their probability distribution function.

REFERENCES