Optimization Control Strategies for HVAC Terminal Boxes

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ABSTRACT

The HVAC terminal boxes are one of the major building HVAC components. They directly impact the building room comfort conditions and the energy costs. How to operate the box in a highly energy efficient way and maintain the room comfort level is an important topic in today's building energy management and HVAC control field. The authors developed novel optimized control strategies and operation schedules for the terminal boxes for both occupied and non-occupied hours. The optimized control schedules were implemented in a medical complex during the commissioning. This not only improved the building comfort conditions but also reduced the energy costs.

Key words: terminal box, AHU, optimized control, VAV box, CV box, setback, operation schedule, energy consumption, energy savings, EMCS, occupancy schedule.

INTRODUCTION

The HVAC systems consume more than 30% of commercial building energy consumption. The ways to save building HVAC energy include HVAC system capital improvements such as VFD conversions, replacement of the motors or chillers, control system upgrades such as new modern EMCS upgrade, lighting improvements, and commissioning. Among those energy saving measures, commissioning is the most cost-effective measure to reduce energy bills and improve building comfort conditions. On average, the payback for commissioning is less than 1.5 years. The terminal boxes in the building provide the conditioned air to the room and are important components of the HVAC system. There are four main types of terminal boxes, including double duct constant volume (DDCV), double duct variable volume (DDVAV), single duct constant volume (SDCV) and single duct variable volume (SDVAV). How to run the boxes effectively directly impacts the commissioning results. For the building with a modern EMCS control system, optimizing box operation can be achieved through the EMCS system plus a detailed site survey and troubleshooting [Zhu, et al., 2000; Liu, et al., 1996; Zhu, et al., 2000; Claridge, et al., 1996; Liu, et al., 1995; Warn and Norford, 1993; Liu, et al., 1998]. Through a commissioning process for a large medical complex, the authors developed new control strategies for the DDVAV box. Also, setback strategies for the VAV and CV boxes were developed. All the new operation schedules were implemented in this complex. As a result, the room comfort level was improved, the box heating capacity was increased, and the energy consumption was reduced. This paper presents these activities and the results.

BUILDING AND TERMINAL BOX INFORMATION

The commissioning target is a large medical complex with multi-functional medical facilities. The complex gross area is 1,470,000 ft^2. The complex primarily consists of outpatient clinic rooms, nuclear medicine, pharmacy areas, ICUs, CCUs, surgical areas, inpatient beds, emergency rooms, diagnostic areas, research labs, offices, animal holding areas, cafeteria, computer rooms, and training class rooms. The terminal boxes are used to provide the conditioned air to those rooms.

There are 90 major AHUs serving the whole complex in which VFDs are installed in 65 AHUs. In the complex, there are 2,700 terminal boxes in which 27% are DDVAV boxes, 71%

are DDCV boxes, and 2% are SDVAV boxes. The terminal boxes are controlled by a York control system. The programs can be modified through the EMCS system. The operation of the boxes can be monitored in the central computer. Every box has the air flow rate setting of total min CFM (CFM_{min}), total max CFM (CFM_{max}), cooling min CFM ($CFM_{c,min}$), cooling max CFM ($CFM_{c,max}$), heating min CFM ($CFM_{h,min}$), heating max CFM ($CFM_{h,max}$).

DEVELOPMENT OF OPTIMIZATION CONTROL STRATEGY FOR TERMINAL BOX

Control Logic Problems Observed for VAV Box

Through the commissioning, it was discovered that the control logic of the DDVAV boxes was not like the normal DDVAV box. It was the same as the constant volume boxes but with different airflow settings. The minimum air flow CFM_{min} settings for VAV boxes were the same for both day and night, and ranged from 30% to 90% with an average of 60% of maximum air flow CFM_{max} for the box. Therefore, the supply airflow to the building was only slightly changed at occupied and unoccupied periods. The VAV boxes mixed more hot and cold air during normal load conditions when compared to normal VAV box operation. It consumes more heating and cooling air under normal room load conditions. Also, the heating capacity was limited for some boxes due to the existing box design setting. In some cases, the boxes can only supply a certain amount of hot air even in the full heating mode even though the hot duct of the boxes can allow more air flow through. Instead, the boxes use more cold air $CFM_{c,min}$ to compensate the minimum air flow CFM_{min} requirement. Figure 1 and Figure 2 present the original control logic and operation schedules for the VAV box and CV box, respectively.

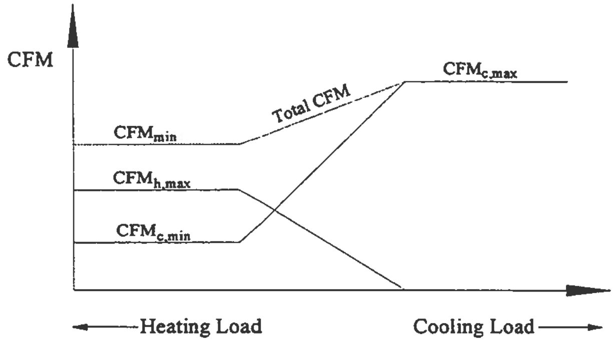


Figure 1. Original control logic and operation schedule for VAV box

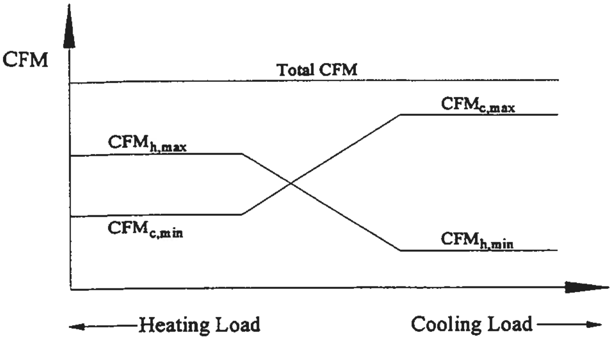


Figure 2. Original control logic and operation schedules for CV box

Improved Control Logic and Operation Schedules for VAV Box

The authors developed a new control schedule for the VAV box operation and implemented it in the VAV boxes. The new control sequences for VAV boxes have the following features:

(1) $CFM_{h,max}$ = min{Total min CFM, 95% of box hot duct design capacity}

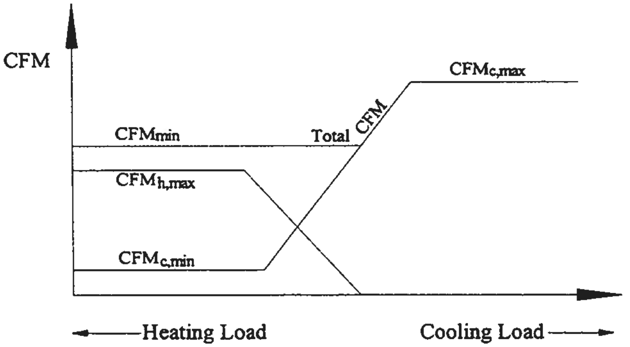
(2) The hot air flow design capacity is based on the inlet hot duct size of the box.

(3) Using a suitable amount of cold air to compensate total min CFM if necessary.

$CFM_{c,min}$=max{0, Total min CFM-$CFM_{h,max}$}

In this way, the hot air capacity is increased for the full heating mode, the mixing of cold and hot air is reduced and also the design total minimum airflow is satisfied.

Figure 3 is the new control schedule for VAV boxes.



If CFM_{min} > $CFM_{h,max}$ (due to hot duct inlet size limit)

Figure 3-1. The new VAV box operation control schedule when minimum CFM requirements exceed hot duct capacity

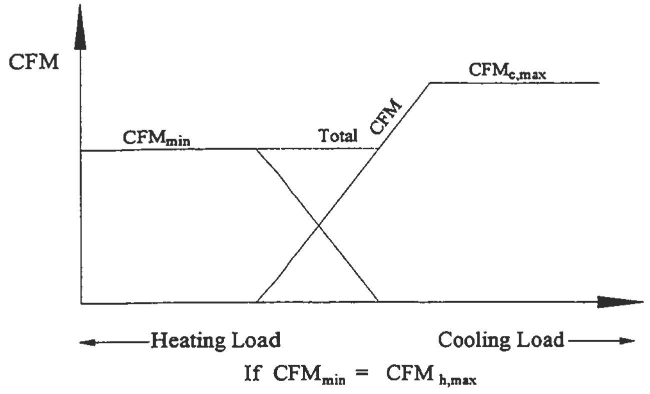


Figure 3-2 The new VAV box operation control schedule when minimum CFM requirements equal or less than the hot duct capacity

The new control logic and operation schedules have been implemented in all the VAV boxes. As a result, the simultaneous cooling and heating during normal load conditions were reduced; the heating capacity was increased by 30% on average and without capitol costs for the improvements.

New Setback Operation for Terminal Box

It was discovered that the DDVAV boxes had the same amount of minimum airflow during occupied periods as unoccupied periods. The minimum airflow ranged from 30% to 90% of the relevant maximum airflow for the box with an average of 60%. This value is higher than necessary during unoccupied periods because of lower loads. These settings consumed more electric and thermal energy. Most VAV boxes are installed in non-critical areas; the space are not occupied 24 hours. This was a big potential to reduce energy costs. For the CV box, the boxes supply the same amount of air to the rooms no matter if the room is occupied or not. For a big percentage of the rooms equipped with CV box, the occupancy schedules are not 24 hours. If those boxes can be implemented with a setback schedule, the fan power and thermal consumption will be reduced significantly.

The authors developed a whole set of procedures to perform the setbacks for these boxes.

1. Occupancy Time Schedule Survey

The commissioning team performed a very detailed survey for the occupancy time schedules room by room for the entire 1,470,000 square feet complex. The time schedule forms include the AHU number, box number, CV or VAV box, room or rooms served, min CFM, max CFM, room usage, occupancy time schedule, comments, etc.

2. Proposed Setback Time Schedules

The authors developed the proposed setback time schedule based on the survey results. A total of 1700 terminal boxes have setback schedules for the entire complex.

3. Verification of the Setback Time Schedules

The commissioning team met with the occupancy representatives, facility management and operations personnel and let them evaluate the time schedules. The setback time schedules had to be approved before implementation.

4. Control Logic for VAV Box at Setback Period

Keep room temperature same as occupied period (existing setpoints).

Reduce the total flow minimum to 0 at unoccupied periods for the box. (Note: the box can provide enough air when the loads increases).

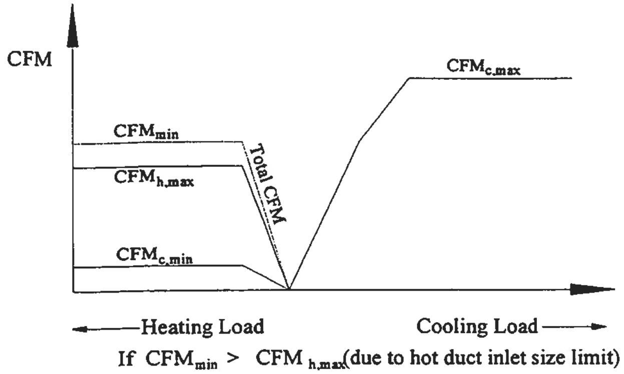


Figure 4-1 The new control logic for VAV boxes at setback period if minimum CFM requirement exceed hot duct capacity

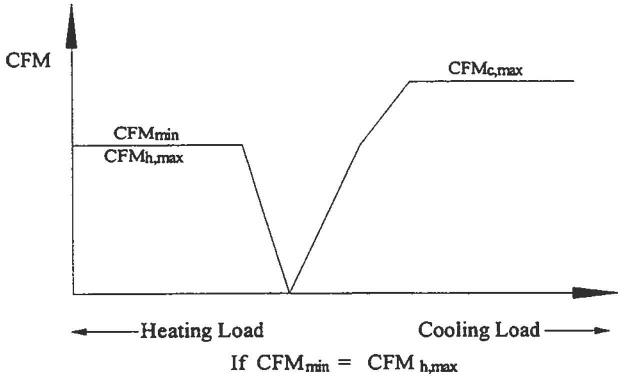


Figure 4-2. The new control logic for VAV boxes at setback period if minimum CFM requirement equal or less than the hot duct capacity

5. Control Logic for CV Box at Unoccupied Period:

Keep room temperature same as occupied period (existing setpoints).

Reduce the total flow to a certain amount (percentage of total flow) at unoccupied periods for the box. The percentage is obtained based on the building pressure level.

Unoccupied Override Button Ability

The box has an override button on the thermostat. However, the original control program is only useful when the AHU is shutdown. When someone pushes the button, the fan will be back online. The button is not functioning if the fan is running 24 hours a day. Our goal is that when the boxes go to setback mode, if any individual box needs normal air conditioning, that individual box can get normal air conditioning, but other boxes can still remain in the setback mode.

The authors modified the control program for every box, which has setback operation. Now, every setback box has the override function.

Implementation of New Control Schedules for Terminal Boxes

The new control schedules for VAV boxes operation and different setback schedules have been implemented in all the VAV boxes and setback CV & VAV boxes during the commissioning period. The procedure is as follows:

1. Develop an input database of the VAV and CV boxes, which include box number, net number, node number, and setback time during weekday & weekend, box maximum and minimum CFM, etc.
2. Generate the new program using script file. The new programs include VAV modification, setback and override ability.
3. Implement the modification area by area, starting from building C, then building M, building A, building B & building R.

Troubleshooting and Fine-tuning for the Boxes

During the commissioning period, it was found that there were different kinds of the problems for the terminal boxes before and after the program modifications. The goal of troubleshooting is to help the HVAC operators solve the existing operations and maintenance problems and ensure the commissioning is successfully accomplished. The commissioning team checked the box operation first by the central computer and printed the list of the trouble boxes. We performed an analysis, then conducted field measurements for the trouble boxes. The major measurements include static pressure, air flow and temperature, if needed and inspection of the box conditions such as flexible duct, kinked duct, bad actuator, incorrect size of the inlet duct for the box, mixing vane resistance, etc. After the troubleshooting, problems were identified in over 200 boxes for the complex. The maintenance personnel fixed the problems based on our recommendations.

After the implementation, we checked the VAV box operation and the setback results for every boxes during the day and night using check files developed by our team. We also fine-tuned the setback time schedules according to the requirements from the occupancy and building proctors.

RESULTS

The new VAV control logic and operation schedules have been implemented in a total of 719 VAV boxes. The heating capacity for the VAV boxes have been increased by 30% on average and the simultaneous cooling and heating were reduced under normal load condition. No capitol improvements were needed.

The setback operation schedules were implemented in over 1700 boxes for the entire complex. There is no impact on the room conditions if someone wants normal air conditioning during a normally unoccupied period.

Those commissioning measures play a very important role for the energy savings for the project. The indoor condition was maintained in a reasonable status, ranging from 70°F to 76°F during the setback period.

CONCLUSIONS

The authors developed a whole set of optimization control strategies for the HVAC terminal box operation, which included the new VAV box control logic and the box setback during unoccupied periods. We also developed the detail procedures to perform the terminal box commissioning. The actual energy cost savings based on the utility bills, for seven months during the commissioning period and four months following the major commissioning measures implementation are over $ 255,000. The terminal box operation improvements play a very important role in obtaining the savings. The optimization control strategies can be a very good reference for other building commissioning projects and the HVAC terminal box control.

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