RESEARCH ON VAV-BOX CONTROL PERFORMANCE EVALUATION BASED ON HARDWARE AND SOFTWARE SIMULAION

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ABSTRACT

Variable Air Volume (VAV) box is a key unit to save energy and satisfy indoor thermal comfort in the VAV air-conditioning system. Dynamic control performance of VAV box is critical in designing and commissioning the VAV systems. This paper focuses on the development of simulation platform that facilitates the evaluation of control characteristic of VAV box. Co-simulation platform of indoor thermal environment is built by using software and hardware. The software sector of the simulation platform is composed of MATLAB® and FORCECONTROL® industrial Distributed Control Software (DCS). MATLAB can be used as strategy level algorithm execution and FORCECONTROL can be used as supervisory control and management. Programmable Logic Controller (PLC) is used as hardware sector to control the humidifier and heater to simulate indoor thermal load environment and test VAV box response performance. The evaluation outcomes help the engineers accelerate the process of regulating the VAV box and commissioning VAV system in the field.

KEYWORDS

VAV box, control performance, co-simulation, HVAC component, dynamic characteristic

INTRODUCTION

The increasing of building energy consumption is drastic during these years in China. At the same time, the energy consumption from heating, ventilation, air-conditioning (HVAC) systems in commercial and residential buildings generally takes up 40% to 54% total building energy consumption in China. Therefore, more and more attention needs to be put on the HVAC energy saving technologies in

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buildings. Generally, energy saving equipment used in HVAC systems and optimal system design can help reduce energy consumption in buildings. Another effective method is to use optimal control strategies and methods to not only enhance the operating efficiency of HVAC&R equipment, but also improve indoor thermal comfort.

HVAC systems can be generally divided into Constant Air Volume (CAV) system and Variable Air Volume (VAV) system. In CAV system, zone load thermal variation is responded by adjusting air-supply temperature, while the air-flow rate is maintained to be constant. In VAV system, the set-point of air-supply temperature is relatively fixed. Air-flow rate is regulated and controlled to satisfy zone thermal loads.

Compared with the CAV system, the energy saving and operation cost of VAV systems are lower because the significant reduction in fan energy consumption can be achieved when air-conditioning system is operated at low load periods (McQuiston et al., 1988). The air handling unit (AHU), air-loop equipment and VAV terminal equipment are three main sub-systems in the VAV-air conditioning systems. Among those sub-systems, the terminal equipment such as VAV-box is a key module which will pose critical effects on the whole system, because air-supply rate is partly adjusted by terminal equipment to meet the zone thermal load (Yeqiao Zhu et al., 2000). Therefore, considerable researches have been placed on the optimal control of VAV-boxes and performance evaluation.

The control structure of HVAC system is divided into local control level and supervisory control level based on their control scopes. The basic control function is achieved by equipment or sub-system to operate properly in the local control level. Optimal control strategies are implemented to search global optimization in HVAC&R system to save energy consumption, lower the operation cost and maintain the demands of thermal comfort indices (S. Wang & Z. Ma). The optimal control of VAV-boxes belongs to the local control level.

LITERATURE REVIEW

The HVAC system energy and control simulation have draw considerable attention during these years. And the advantages of simulation have long been acknowledged by the HVAC community. HVAC control simulation not only helps the control designers find operation procedures, but also helps engineers to commission the HVAC systems.

M Trcka and J L.M. Hensen (2010) gave a review of the HVAC simulation methods. In their research work, they analyzed the methods of modeling HVAC system control. Five modeling approaches were defined as pure conceptual system modeling, system-based modeling approach, component-based system modeling approach, component-based multi-domain system modeling approach and equation-based system modeling approach (M. Trcka et al., 2010). Meanwhile, numerous software and platform were developed to simulate HVAC systems. In another article, they categorize the simulation tools into three types according to their specialized functions: HVAC components, HVAC control and HVAC systems (M. Trcka et al., 2011).

Mingjie Zheng evaluated the application of various HVAC simulation programs including MicroHASP, Micro/ACSS, FACES, LCEM, TRNSYS, DOE-2, EnergyPlus and DeST. These software tools help to increase the speed of HVAC system commissioning process (M. Zheng et al.,). Stephen Treado (2011) analyzed simulation-based approaches for the purpose of building control system design and integration. They used HVACSIM+ to simulate building control systems for designing, refining and verifying the performance of the systems (Stephen Treado, 2011).

The development of co-simulation platform for the purpose of Control-oriented HVAC performance simulation is drawn more attention because of its advantage to combine different features from various programs and software. Among the co-simulation platforms, MATLAB software is widely used to aid the design of HVAC control system.

MATLAB has been considered to be a powerful tool not only to perform numerical analysis, but also to provide a platform to design and validate control algorithm. Several toolboxes in MATLAB aid system control designers to design proper controller. At the same time, SIMULINK tool provides a graphical environment to simulation dynamic systems.

P. Riederer (2005) introduced the MATLAB/SIMULINK software to simulate HVAC system. MATLAB/SIMULINK can be used not only as a modeling and simulation tool for specific physical components and systems, but also as a design tool for control system in commissioning and fault detection.

Basically, there are two methods to incorporate MATLAB into HVAC control system simulation. The first method is to develop MATLAB/SIMULINK toolbox or models which can be used to simulate component or system dynamic control features.

Yan Chen et al., (2014) developed a HVAC simulation platform based on dynamic models by using MATLAB SIMULINK tools. Two steps are proposed in order to simulate the dynamic performance of HVAC system. They proposed two steps when simulating the dynamic performance of HVAC system. The first step is to develop dynamic models. And the second step is to integrate dynamic models into simulation model. University of Illinois at Urbana-Champaign developed the THERMOSYS toolbox for MATLAB/SIMULINK which provided modeling and simulation tools for vapor compression systems (B. P. Rasmussen, 2006).

Another method is to couple MATLAB with other simulation tools. By this way, the designers can take advantage of plentiful HVAC environment provided by other HVAC programs, and hence, the process of development and system control validate of HVAC system can be accelerated.

The method of HVAC dynamic control simulation based on TRNSYS models and SIMULINK was proposed by using Dynamic Link Library (DLL-based) components in both simulation environments (P.Riederer, et al., 2009). Ehsan Asadi et al., (2012) proposed a multi-objective optimization model by using TRNSYS, GenOpt and MATLAB. Yudai Liu et al., (2013) introduced a receding-horizon supervisory control of HVAC system by Wrapping TRNSYS into MATLAB function.

The method of co-simulation which couple software and hardware must be paid more attention because this method can provide even more flexibility to simulate

actual environment and the controller control characteristics.

Building Controls Virtual Test Bed (BCVTB) is one of such co-simulation platform. BCVTB was developed by Lawrence Berkeley National Laboratory. It couples various simulation programs and software (Michael Wetter, 2013). Another important feature is this simulation platform integrated BACnet which makes it possible to exchange data with BACnet equipment. Also, it provides analog and digital interface to connect external monitoring and control devices.

DESCRIPTION OF THE PLATFORM

The simulation platform consists four parts—VAVBOX hardware, simulative indoor thermal load with PLC controller, DCS software and MATLAB® software. Figure 1 shows the structure of co-simulation platform.

FORCECONTROL® is a general Distributed Control Software (DCS) used in process control, intelligent building control and other control fields (Yang Hong-xiang et al., 2009). The advantages of DCS software are its abundant graphic widgets and hardware interfaces. Furthermore, the function of distributed network control provided by FORCECONTROL® make it easier to be used for building a distributed control platform.

Simulative indoor thermal load includes thermal resistance heaters and electrode humidifiers which can be adjusted by automatic method or manual method to simulate the equipment or occupant's thermal load. The heaters and humidifiers is controlled by the Programmable Logic Controller.

Here, indoor temperature, relative humidity and CO_2 concentration are chosen to evaluate the indoor environment conditions. Therefore, indoor thermal and environment monitor subsystem includes indoor temperature sensors, indoor relative humidity sensors, wind speed sensors and CO_2 sensor.
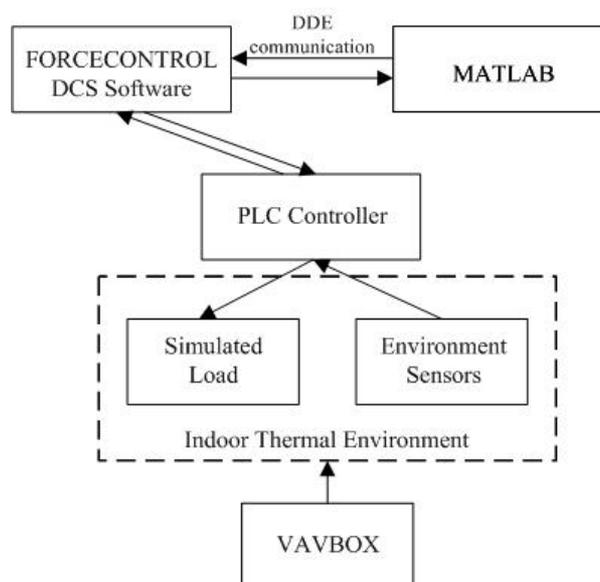

Figure 1. Structure of co-simulation platform

The co-simulation platform uses Dynamic Data Exchange (DDE) method to

finish the data communication between the FORCECONTROL software and because these two kinds of software support DDE communication mechanism. Therefore, DDE method can be used conveniently to achieve the function of data exchange between the DCS software and MATLAB.

DDE is a process communication protocol technique based on information service provided by Windows® environment. A client/server method is adopted in the DDE technique. A data provider is worked as a server and a data receiver is worked as a client. Three-level communication including application level, topic level and item level is used in DDE to define specific name of application program and communication content.

The FORCECONTROL software provides the DDE control box to achieve the function of DDE communication. In MATLAB, S function is used as DDE customer. Init.s, FromServer.s and ToServer.s functions are used to initialize the program, obtain and send data from or to the FORCECONTROL software.

SIMULATION RESULT

A type of non-pressure controlled VAV air-conditioning terminal is used in a single room through co-simulation platform. A cascade control is usually adopted in controlling the indoor temperature of non-pressure controlled VAV air-conditioning system. Air volume setpoint is given to the by the differences of measured value and setpoint value of indoor temperature. Air volume control loop send control signal to the damper based on the difference of setpoint value and measured value of air volume. And air volume is regulated to control indoor temperature. Figure 2 shows the cascade control of VAVBOX in the experiment.

An office room with width 2m, length 3.5m, and high 3.5m was used in the test. A VAVBOX was controlled by the Direct Digital Controller (DDC). The indoor temperature setpoint is 25°C. Figure 3 shows the indoor temperature and relative humidity responses when the VAVBOX started to actuate. From the testing, VAVVBOX could meet the thermal demand of simulated indoor thermal load when a 200W heater and a humidifier with 10g/m water were actuated. Temperature could be regulated to setpoint by the VAVBOX with 180 seconds. And indoor relative humidity decreased from 55% to 43% with 180 seconds due to fresh air supply by VAVBOX. Hence the dynamic response characteristic of VAVBOX can be obtained.
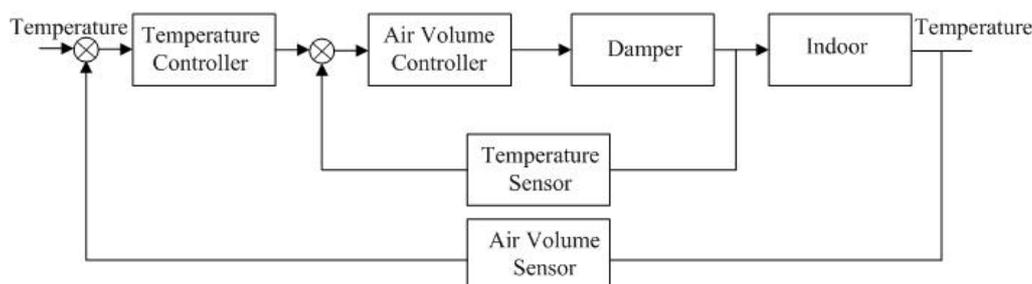

Figure 2. Cascade of VAVBOX in non-pressure controlling type of VAV air-conditioning system
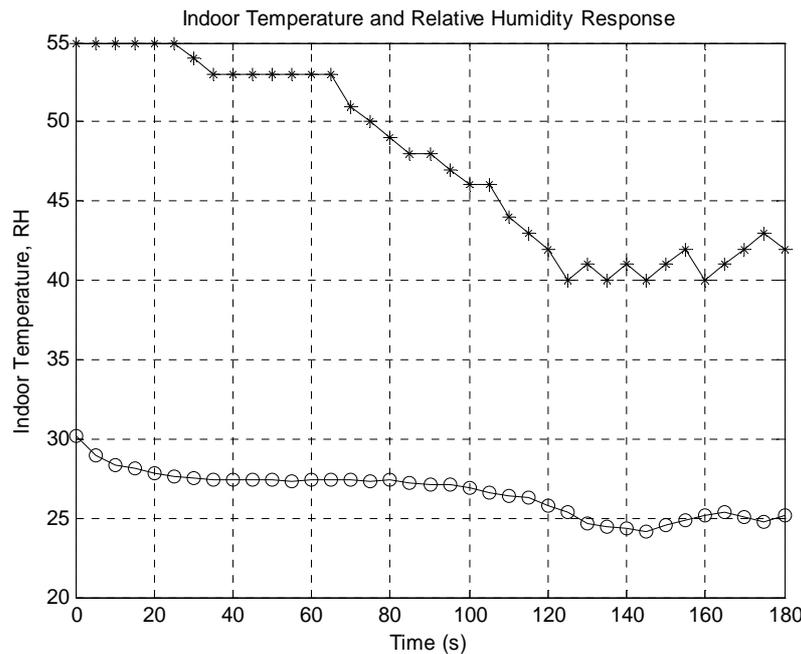
Figure 3. Indoor temperature and humidity response

FUTURE WORK

The pre-commission regulation of VAVBOX before actual operation plays a significant role in VAV air-conditioning system operation and management. Most pre-commission regulation works of VAVBOX are limit to the regulation of maximum and minimum wind capacity. However, in most cases, this kind of regulation does not include the consideration of indoor thermal load which is critical to the actual operation. Hence, lots of working status may be neglected due to the simplicity of pre-commission. This may cause various problems in the automatic operation including system. Therefore, co-simulation combining the hardware and software may play the same important role in testing actual operation.

The co-simulation platform developed in this research combines DCS software and MATLAB simulation software and provides a convenient method to evaluate VAVBOX dynamic response feature.

Here we selected indoor temperature, humidity, wind speed and CO_2 density as four indices instead of PMV-PPD index to evaluate the indoor thermal condition. In the future work, PMV-PPD index is planed to be used to evaluate the effects of VAVBOX dynamic response on the indoor thermal load. Furthermore, characteristics of one VAVBOX in single room and single indoor thermal load are selected in this research. But more research works are still needed in the future for the multi-room VAVNBOX dynamic response characteristics which are difficult and time-consuming in the practical regulation and commission of VAV air-conditioning systems. We expect this co-simulation platform provide a more convenient environment to test multi-VAVBOX with coupled characteristics before commissioning.

CONCLUSION

HVAC simulation can not only help HVAC system designers optimally design but also help engineers analyze the key factors related to the system control, and hence accelerate execution and save debug cost in the field. The co-simulation method can not only help researcher validate control algorithm, but also facilitate the pre-commission made by the practical engineers. The simulation platform developed here integrates the hardware and software to initially evaluate indoor thermal response and VAVBOX control characteristics. More research and development works should still be executed to evaluate the multi-VAVBOX controlling characteristics.

REFERENCES

B. P. Rasmussen, A. G. Alleyne, Dynamic Modeling and Advanced Control of Air Conditioning and Refrigeration Systems, 2006.

Ehsan Asadi, Manuel Ganmeiro da Silva, Carlos Henggeler Antunes, Luis Dias, "A multi-objective optimization model for building retrofit strategies using TRNSYS simulations, GenOpt and MATLAB", Building and Environment, 56(2012), pp.370-378.

F.C. McQuiston, J.D. Parker. "Heating, ventilating and air-conditioning, 3rd edition" John Wiley & Sons, Inc.

M Trcka, J.L.M. Hensen, HVAC system simulation: overview, issues and some solutions, Proceeedings of the 23rd IIR International Congress of Refrigeration. 2011.

Michael Wetter, Co-simulation of building energy and control systems with the Building Controls Virtual Test Bed, Journal of Building Performance Simulation, 9(2013), pp.185-203

P. Riederer, W. Keilholz, V. Ducreux, Coupling of TRNSYS with simulink-a method to automatically export and use TRNSYS models within simulink and vice versa, 11th International IBPSA Conference Glasgow, Scotland, July 27-30, 2009.

P. Riederer, MATLAB/SIMULINK for building and HVAC simulation state of the art, Ninth International IBPSA Conference Montreal, Canada, August 15-18, 2005.

S.Wang, Z.Ma, "Supervsory and Optimal Control of Building HVAC Systems: A Review", HVAC&R Research, 14:1, 3-32, Jan 2008.

Stephen Treado,   Payam Delgoshaei, Andrew Windham, Simulation-based approaches for building control system design and integration, 12th International IBPSA Conference Sydney, Australia, November 14-16, 2011.

Yang Hong-xiang, Wang Rui-hua, Zhu Shi-ning, Wang Pu. Design of Real-time Simulation Platform for Control System Based on Configuration Software and Matlab. Journal of System Simulation. V21.N23.2009. pp. 7448-7451. [In Chinese]

Yeqiao Zhu, Mingsheng Liu et al., "Optimization Control Strategies for HVAC Terminal Boxes", Proceedings of the Twelfth Symposium on Improving Building Systems in Hot and Humid Climates, San Antonio, TX

Yudai Liu, Yiqun Pan, Zhizhong Huang, Simulation-based receding-horizon supervisory control of HVAC system, 13th International IBPSA Conference Chambery, France, August 26-28, 2013.

Mingjie Zheng, Song Pan. Application of various HVAC simulation and visual tools to commissioning. www.repository.tamu.edu.