IECON 2020 Tutorial Proposal

Title of the Proposal:
Air balancing technologies for the super low energy buildings

- Presenter(s):
Professor Cai Wenjian, Associate Professor, School of Electrical and Electronic Engineering, Nanyang Technological University
Professor Zhang Xin, Assistant Professor, School of Electrical and Electronic Engineering, Nanyang Technological University
Dr. Cui Can, Research Fellow, SJ-NTU Corporate Lab, Nanyang Technological University

- Brief description:
Mechanical ventilation systems are designed to maintain a comfortable indoor environment by supplying a precise amount of processed air to the air-conditioned space. It is one of the major energy consumers in the building sector, especially for tropical countries like Singapore where air-conditioning operates on a 12-months basis. A well-balanced ventilation system improves the thermal comfort and indoor air quality, as well as can reduce the energy consumption of the building. It is estimated that air balancing technologies can bring up to 40% energy saving compared with an imbalanced ventilation system. As a result, the air balancing technologies are very important to realize energy saving for green buildings. However, the existing air balancing method lacks systematic theory, which are based on a ‘trial and error’ way. Unfortunately, the human experiences cannot guarantee satisfied air balancing requirement, resulting in more labour cost, lead to worse indoor air quality and more energy waste.

In this tutorial, targeting to overcome the above problems of the existing air balancing methods, a family of interesting air balancing methods will be introduced. From this tutorial, you will easy to understand why the ventilation system suffering un-air-balancing problem. From this tutorial, you will be familiar with the modelling of the ventilation system in theory. From this tutorial, you will learn the best air-balancing methods, which supported by advanced control technologies and artificial intelligent (AI) based data-driven technologies. From this tutorial, you will clearly feel that a better air balancing method is really a guarantee for energy saving of the green building. In addition, this tutorial provides clear guidelines for both the heating, ventilation, and air conditioning (HVAC) system designers and engineers as well as the scholars to design and balance the ventilation system to achieve better performance and higher energy efficiency.

- Duration:
Presentation duration:
- Totally 3 hours.
- The detailed duration allocation for each speaker is listed in the outline part.

- Outline:
1. Introduction of the air balancing technologies in super-low energy buildings
   (Speaker: Professor Cai Wenjian, 20 mins)
   1.1 Overview of HVAC systems and its role in super-low energy buildings
1.1 Background
1.1.2 Operation principle of HVACs
1.1.3 The role of the HVACs in super-low energy buildings.

1.2 Basic knowledge of the air balancing
1.2.1 Mathematical modelling of the air duct system
1.2.2 Theoretical analysis on energy consumption in air duct system caused by over ventilation
1.2.3 The concept and basic knowledge of the air balancing
1.2.4 Benefits of the air balancing

1.3 The existing air balancing technologies
1.3.1 Traditional Testing, Adjusting and Balancing (TAB)
1.3.2 Modern air balancing technologies

1.4 Flow measurements in air balancing
1.4.1 Common flow measurement approaches in air duct systems
1.4.2 Intelligent air flow control station

1.5 Conclusion

2. The proposed hierarchical proportional–integral–derivative (PID) control-based air balancing method
(Speaker: Professor Zhang Xin, 20 mins)

2.1 Introduction

2.2 The Proposed hierarchical control structure for the PID control-based air balancing method
2.2.1 Description of the test bed
2.2.2 The proposed hierarchical control structure

2.3 The proposed PID control strategy of the fan-duct system
2.3.1 Transfer function of the fan-duct system
2.3.2 Open loop step test with two points method
2.3.3 PID parameter estimation method based on the gain and phase margin method

2.4 The proposed PID controller of the damper in the duct system
2.4.1 Characteristic of the damper
2.4.2 Transfer function modelling of the damper
2.4.3 PID parameter estimation method

2.5 Experimental results
2.5.1 Experiments of the PID control of the fan-duct system
2.5.2 Experiments of the PID controller of the damper
2.5.3 Experiments of the dual loop PID strategy for the duct system

2.6 Conclusion
3. The proposed distributed cooperative control-based air balancing method
(Speaker: Professor Zhang Xin, 20 mins)

3.1 Introduction

3.2 Preliminary: modeling of the air duct system

3.3 Theory of the proposed distributed cooperative control-based air balancing method

3.3.1 Concept of distributed cooperative control: consensus algorithm
3.3.2 The proposed distributed cooperative control-based air balancing method

3.4 Design principle of the proposed distributed cooperative control-based air balancing method

3.4.1 $\beta = 0$, equal $q^*$
3.4.2 $\beta \neq 0$, equal $q^*$
3.4.3 $\beta \neq 0$, different $q^*$
3.4.4 $\beta \neq 0$, different $T_s$

3.5 Experimental validation

3.5.1 Experimental platform and experimental procedures
3.5.2 Validation of the proposed distributed cooperative control-based air balancing method on the test platform

3.6 Conclusion

4. The proposed gradient-based online adaptive air balancing method
(Speaker: Dr Cui Can, 20 mins)

4.1 Introduction

4.2 The proposed gradient-based online adaptive air balancing method

4.2.1 Objective function of the proposed gradient-based online adaptive air balancing method
4.2.2 Refinement of damper adjustment with consideration of energy conservation
4.2.3 Estimation of Jacobian matrix and online adaptation
4.2.4 Low-pass filter trick
4.2.5 Final form of the proposed gradient-based online adaptive air balancing method

4.3 Design principle of the proposed gradient-based online adaptive air balancing method

4.3.1 Base case of the gradient-based online adaptive air balancing method
4.3.2 Investigation into the initial damper angle $\theta_0$
4.3.3 Investigation into the refinement coefficient $\lambda$
4.3.4 Investigation into the step size $\alpha$

4.4 Experimental validation

4.4.1 Experimental platform and experimental procedures
4.4.2 Validation of the proposed gradient-based online adaptive air balancing method on the test platform

4.5 Conclusion

• (Coffee break: 10 mins)

5. The proposed physical model-based air balancing method via support vector machine (SVM) technology
   (Speaker: Professor Zhang Xin, 20 mins)
   5.1 Introduction
   5.2 Physical-based system model of the duct system
      5.2.1 Component model of the duct system
      5.2.2 Definition of the physical-based system model
      5.2.3 Computational model for duct system
   5.3 The proposed physical model-based air balancing procedure
      5.3.1 Parameter identification of the physical model of the duct system
      5.3.2 Damper position determination
   5.4 Data collection procedure for the proposed air balancing method
   5.5 Experiments validation
      5.5.1 Data sampling and pre-processing
      5.5.2 Parameter characteristics of SVM
      5.5.3 Results of Parameter identification
      5.5.4 Results of damper position determination
      5.5.5 Results of maximum absolute percentage error (MAPE)
   5.6 Conclusions

6. The proposed branch and black-box (B^2) model-based air balancing method
   (Speaker: Dr Cui Can, 20 mins)
   6.1 Introduction
   6.2 Problem description
      6.2.1 Review of the existing physical fitting grey-box (PFGB) model-based air balancing methods
      6.2.2 Limitations of the existing PFGB model-based air balancing methods
   6.3 The proposed B^2 model-based air balancing method
      6.3.1 Preliminary of the proposed B^2 model-based air balancing method
      6.3.2 Motivation of the proposed B^2 model-based air balancing method
      6.3.3 Advantages of the proposed B^2 model-based air balancing method
6.4 Experimental validation
   6.4.1 Experimental platform
   6.4.2 Practical considerations in the experiment
   6.4.3 Verification of the proposed $B^2$ model for the duct system
   6.4.4 Verification of the air balancing ability of the proposed $B^2$ model-based method on the test system

6.5 Conclusion

7. The proposed energy-saving oriented air balancing method with full data-driven duct system model
   (Speaker: Dr Cui Can, 20 mins)
   7.1 Introduction
   7.2 Review: energy-saving mechanism and challenges for air duct systems
      7.2.1 Energy-saving mechanism for air duct systems
      7.2.2 Challenges for energy-saving in air duct systems
   7.3 The proposed energy-saving oriented air balancing method with full data-driven duct system model
      7.3.1 The proposed energy-saving model with full data-driven duct system model
      7.3.2 Advantages of the proposed energy-saving oriented air balancing method
   7.4 Experimental validation
      7.4.1 Experimental platform
      7.4.2 Practical considerations in the experiment
      7.4.3 Verification of the proposed full data-driven duct system model
      7.4.4 Verification of the air balancing ability on the test system
      7.4.5 Verification of the energy-saving performance on the test system
   7.5 Conclusion

8. The proposed modeling, air balancing and optimal pressure set-point selection methods for the ventilation system with minimized energy consumption
   (Speaker: Professor Zhang Xin, 20 mins)
   8.1 Introduction
   8.2 Energy-saving-oriented (ESO) model of ventilation systems
      8.2.1 Definitions for ESO modeling the ventilation system
      8.2.2 ESO model of the ventilation system
      8.2.3 Parameter identification for the developed ESO model
   8.3 Damper position control method to achieve air balancing
8.4 Optimal static pressure set-point selection to minimize energy consumption of ventilation system

8.5 Operating steps for improved SPR control strategy

8.6 Experimental apparatus

8.7 Experimental validation
   8.7.1 Parameter selection for SVM regression machine learning algorithm
   8.7.2 Parameter identification for the developed model of the ventilation system
   8.7.3 Validation of relative error of airflow rate
   8.7.4 Validation through use of maximum absolute percentage error

Conclusion

9. Q&A (Speakers: Professor Cai Wenjian, Professor Zhang Xin, Dr Cui Can, 10 mins)

-Brief CV:

-Speaker 1: Cai Wenjian, ewjcai@ntu.edu.sg

Cai Wenjian received his B. Eng., M. Eng., and PhD from Department of Precision Instrumentation Engineering, Department of Control Engineering, Harbin Institute of Technology, P. R. China, and Department of Electrical Engineering, Oakland University, U. S. A., in 1980, 1983 and 1992, receptively. Currently, he is in the School of EEE, Nanyang Technological University, since 1999. He participated in many industry related research projects, and published more than one hundred technical papers, three books, two patents and received three national awards. He has been often invited as a technical committee member or referee and reviewer for a number of premier conferences and journals, including Journal of Process Control, Energy and Management etc. Prof Cai is a member of IEEE.

-Speaker 2: Zhang Xin, jackzhang@ntu.edu.sg

Zhang Xin received the Ph.D. degree in Automatic Control and Systems Engineering from the University of Sheffield, U.K., in 2016 and the Ph.D. degree in Electronic and Electrical Engineering from Nanjing University of Aeronautics & Astronautics, China, in 2014. Currently, he is an Assistant Professor at the School of Electrical and Electronic Engineering of Nanyang Technological University.
He services as the Associated Editor of IEEE Transactions on Industrial Electronics, IEEE Journal of Emerging and Selected Topics in Power Electronics, IET Power Electronics, IEEE open journal of power electronics, IEEE Access, Journal of Artificial Intelligent. He is IEEE senior member. He is also the TPC member in IEEE IA/PELS Singapore joint Chapter. Dr Xin Zhang has received the highly-prestigious Chinese National Award for Outstanding Students Abroad in 2016. He is generally interested in zero energy building, power electronics and advanced control theory, together with their applications in various sectors.

- Cui Can, can.cui@ntu.edu.sg

Cui Can received bachelor's degree in Control Science and Engineering (Automation) from Shandong University, China in 2014, and Ph.D. degree in Electrical and Electronic Engineering from Nanyang Technological University, Singapore in 2019. Currently, she works as a research fellow in the SJ-NTU Corporate Lab in NTU. She is interested in advanced control, data driven technology and the air balancing control in HVAC system. She participated in several projects related to zero energy building.

- Relevant publications and projects for this tutorial:

Book:

Journal Papers:


Conference Papers:


Projects:

[1] 2020.02-present, High-performance, High-energy-efficiency and High-reliability (H3) based Smart Air-Balancing System with Artificial Intelligence (AI), Internet of things (IoT) and Fault Detection & Diagnostics (FDD) Technologies, RT07/19, Tier 1, MOE, Singapore.


- Relevant invited talks for this tutorial:

