

LB/Don/103/2011 (iii)

# ENERGY SAVING OF VARIABLE AIR VOLUME SYSTEMS

LIBRARY  
UNIVERSITY OF MORATUWA, SRI LANKA  
MORATUWA

Basnayake Mudiyansele Buddhika Kalum Suchinthana Bandara

(07/8320)



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

Dissertation submitted in partial fulfillment of the requirements for the degree  
Master of Science

Department of Electrical Engineering

University of Moratuwa  
Sri Lanka

University of Moratuwa



100840

October 2011

100840

621.3 "11"  
696.6(043)

TH

100840

## DECLARATION OF THE CANDIDATE & SUPERVISOR

I declare that this is my own work and this dissertation does not incorporate without acknowledgment any material previously submitted for a Degree or Diploma in any other University or institution of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in whole or part in future work (such as articles or books).

Signature *UOM Verified Signature*

Date: 25/10/2011

Name of the Candidate



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
www.lib.mrt.ac.lk

B. M. B. K. S. Bandara

The above candidate has carried out research for the Masters Dissertation under my supervision.

Signature *UOM Verified Signature*

Date: 25/10/2011

Name of the Supervisor : Professor Lanka Udawatta

## Abstract

Air conditioning is very common in modern buildings. It was originally purposed to maintain thermally comfortable environments for people inside the building. So far, human thermal comfort is not only the criteria adapted to given the control and operation of a system. Most of the commercial buildings in Sri Lanka are sick buildings and having extremely high energy consumption of 50% to 65% of the total power consumption for air conditioning.

The main reasons to have less energy efficiency of central air conditioning systems are over selection of the equipments, poor maintenance and improper controlling. Although having over selected equipment such as chillers, pumps and air handling units of particular installation, the energy usage can be optimized by accommodating a proper control system.

The objective of this research is a conceptual development for air distribution cycle in order to improve the energy saving of existing variable air volume (VAV) system while maintaining the human comfort at a highest level.

This will be only a functional modification of the system (programming concept), any additional sensing elements and or controlling elements will not be required to achieve the results. Any Specialized Building Management System Contractor can use this programming concept in their system with own programming languages or functional blocks. Only the requirement is that the VAV controller shall be connected to air handling unit controller via a communication bus and the few parameters from VAV controllers shall be transmitted to the particular air handling unit (AHU) controller. Generally in VAV air distribution system, thought-out the running period of the AHU, the duct static pressure set point is constant and Variable Speed Drive will be modulated by Direct Digital Controller (DDC) in order to maintain the duct static pressure at the set point. The research describes about the concept of the duct static pressure set point to varying (resetting) according to the actual demand of the total VAV Units which are connected to the particular VAV AHU. This will be an adaptive control loop for pressure set point. At the end of the research (under the result), the actual site experimental data is given for the power consumption of "Fixed Duct Static Pressure Set Point VAV Control System" Vs "Proposed adaptive control of pressure set point VAV Control System". The conclusion and analysis of the dissertation shows 6% of the energy saving from the adaptive control system compare to the fixed duct static pressure set point.

**Key Words:** Duct Static Pressure, VAV Energy Efficiency, Static Pressure Set Point and VAV AHU.

## ACKNOWLEDGEMENT

I wish to acknowledgement and express my sincere thanks to my supervisor Prof. Lanka Udawatta for the technical support and advise he gave me to work on a research having a greater opportunity to save energy which in the Air Conditioning Industry of Sri Lanka. I am also grateful to Dr. Karunadasa and all other members of Department of Electrical Engineering, University of Moratuwa for the support given to me from the beginning of Electrical Installation Msc Class.

I would also like to thank all reviewers who attended in the progress review presentation for giving me their valuable comments and guidance.

Without the help and support given by my colleagues Nihal Silva, Nirosch Perera, and Priyantha Bernard, who worked with me on HNB Head Office Project, I would not have been to able to complete this research project in time and I am very thankful to them for their support.



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations

Finally I wish to thank my parents and my brother for unwavering and resolute support given while this dissertation is being prepared.

## TABLE OF CONTENTS

Declaration of the Candidate & Supervisor	i
Abstract	ii
Acknowledgement	iii
Table of Content	iv
List of Figures	vi
List of Tables	vii
List of Abbreviations	ix
1. Introduction	1
1.1 Type of Air Conditioning Systems	1
1.2 Constant Air Volume (CAV) System	2
1.3 Variable Air Volume (VAV) System	2
1.4 Motivation	5
1.5 Objective and Scope	6
2. Theoretical Background	8
2.1 Characteristics of Fan	8
2.2 Bernoulli's Equation	10
2.3 Duct Designing and Air Distribution	10
2.4 Variable Speed Drive	19
2.5 Insulation Class of Motor and Speed Limitation	21
2.6 Duct Layout of Variable Air Volume System	24
2.7 Direct Digital Controllers	26
3. Research Design	29
3.1 Selection of a Suitable Building	30
3.2 The System Architectures	31
3.3 Functional Description	34
3.4 Theory of Operations and VAV AHU Fan Characteristics (Calculation Basis) with the Existing Control Function (Fixed Duct Static Pressure Set Points)	38

3.5	Theory of Operations and VAV AHU Fan Characteristics (Calculation Basis) with the Proposed Adaptive Control Duct Static Pressure Set Point Function	42
3.6	Adaptive Control for Pressure Set Point Varied Function	44
4.	Actual Site Experimental Data	48
4.1	The selected 11kW VAV AHU Fan Characteristics (Experiment Basis)	48
4.2	Sample Calculation of Power Consumption	56
5.	Results and Calculation	58
5.1	Result	59
5.2	Calculation	69
6.	Analysis	71
6.1	Analysis	71
6.1.1	Human and Equipment Heat Load	71
6.1.2	Heat Load from Outside and Ventilation	71
6.1.3	Heat Load from Radiation via Glass & Windows	72
7.	Conclusion	77
	References List	79



## LIST OF FIGURES

	Page
Figure 2.1: General Fan Characteristics	9
Figure 2.2: Trunk and Branch System	15
Figure 2.3: Spider System	16
Figure 2.4: Radial System	17
Figure 2.5: Perimeter Loop System	17
Figure 2.6: Speed – Torque Curve for an Induction Motor	19
Figure 2.7: Typical Block Diagram of a VSD	20
Figure 2.8: Motor Insulation Class	23
Figure 2.9: Duct Layout of one Simple Run with Short Takeoffs	25
Figure 2.10: Duct Layout of Complex Duct Runs with Multiple Branches	25
Figure 3.1: The System Architecture of the Central Air Conditioning System	31
Figure 3.2: The System Architecture of Building Management System	33
Figure 3.3: Constant Volume Air Handling Unit	34
Figure 3.4: Variable Volume Air Handling Unit	38
Figure 3.5: Variable Volume Box	40
Figure 3.6: Physical Network Diagram of Adaptive Pressure Set Point Control Loop	46
Figure 3.7: Control Algorithm Block Diagram of Adaptive Pressure Set Point in DDC	47
Figure 4.1: Fan Characteristics for Fixed (Constant) Duct Pressure Values	54
Figure 4.2: Fan Characteristics for Different Duct Pressure Values (Fixed Speed)	55
Figure 6.1: Variation of Outdoor Condition during the Sampling Periods	74
Figure 6.2: Variation of Average Outdoor Enthalpy during the Sampling Periods	76

## LIST OF TABLES

	Page
Table 2.1: Temperature Class and Maximum Operation Temperature	22
Table 2.2: Minimum Speed Limitation Vs Temperature Tolerance Class	23
Table 2.3: DDC Contact Convention	28
Table 3.1: AHU On/Off Schedule	35
Table 3.2: Schedule of Adaptive Control	45
Table 4.1: Fan Characteristics for Fixed Speed of 100%	48
Table 4.2: Fan Characteristics for Fixed Speed of 90%	49
Table 4.3: Fan Characteristics for Fixed Speed of 80%	50
Table 4.4: Fan Characteristics for Fixed Speed of 70%	51
Table 4.5: Fan Characteristics for Fixed Speed of 60%	52
Table 4.6: Fan Characteristics for Fixed Speed of 50%	53
Table 4.7: The Power Consumptions of AHU Fan for Different Air Flow Rates	57
Table 5.1: Total Power Consumption for 400 Pa, on 26 <sup>th</sup> Oct 2009	59
Table 5.2: Total Power Consumption for 400 Pa, on 27 <sup>th</sup> Oct 2009	60
Table 5.3: Total Power Consumption for 400 Pa, on 28 <sup>th</sup> Oct 2009	61
Table 5.4: Total Power Consumption for 400 Pa, on 29 <sup>th</sup> Oct 2009	62
Table 5.5: Total Power Consumption for 400 Pa, on 30 <sup>th</sup> Oct 2009	63
Table 5.6: Total Power Consumption with Adaptive Control Duct Static Pressure Set point on 17 <sup>th</sup> Oct 2009	64
Table 5.7: Total Power Consumption with Adaptive Control Duct Static Pressure Set point on 18 <sup>th</sup> Oct 2009	65
Table 5.8: Total Power Consumption with Adaptive Control Duct Static Pressure Set point on 19 <sup>th</sup> Oct 2009	66
Table 5.9: Total Power Consumption with Adaptive Control Duct Static Pressure Set point on 20 <sup>th</sup> Oct 2009	67
Table 5.10: Total Power Consumption with Adaptive Control Duct Static Pressure Set point on 21 <sup>st</sup> Oct 2009	68



Table 5.11: Total Power Consumption for Five Days with Fixed Duct Static Pressure Set Point of 400 Pa	69
Table 5.12 Total Power Consumption for Five Days with Adapting Control Duct Static Pressure Set Point	69
Table 6.1: Variation of Outdoor Relative Humidity and Dry Bulb Temperature during the Data Gathering Period of Adaptive Control	72
Table 6.2: Variation of Outdoor Relative Humidity and Dry Bulb Temperature during the Data Gathering Period of Fixed Pressure Set Point	73
Table 6.3: Variation of Average Outdoor Air Enthalpy during the Data Gathering Period of Adaptive Control	74
Table 6.4: Variation of Average Outdoor Air Enthalpy during the Data Gathering Period of Fixed Pressure Set Point	75



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)



## LIST OF ABBREVIATIONS

Abbreviation	Description
A	Ampere
AC	Alternative Current
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BMS	Building Management System
CAV	Constant Air Volume
CFD	Computational Fluid Dynamics
Co2	Carbon Dioxide
DC	Direct Current
DDC	Direct Digital Control
DW/142	Specification for Sheet Metal Ductwork Addendum-A
DX	Direct Expansion
EMI	Electromagnetic Interference
g	Gravity Acceleration
HVAC	Heating Ventilation and Air Conditioning
Hz	Hertz
IAQ	Indoor Air Quality
kW	Kilo Watt
l/s	Liters per Second
m	Meter
m/s	Meters per Second
m/s <sup>2</sup>	Meters per Square Second
mA	Milliamp
N/m <sup>2</sup>	Newton per Square Second
NEMA	National Electrical Manufacturer Association
°C	Celsius



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

P	Pressure
Pa	Pascal
PI	Proportional-Integral (PI) control
RH	Relative Humidity
RPM	Revaluation per Minutes
SMACNA	Sheet Metal and Air Conditioning Contractors Association
V	Velocity, Voltage
VAV	Variable Air Volume
VFD	Variable Frequency Driver
VSD	Variable Speed Diver
z	Height



University of Moratuwa, Sri Lanka.  
 Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)