



UNIVERSITI PUTRA MALAYSIA

**INFLUENCE OF AIR EXCHANGE EFFECTIVENESS ON THERMAL
COMFORT IN MALAYSIA**

ROONAK DAGHIGH

FK 2008 6



**INFLUENCE OF AIR EXCHANGE EFFECTIVENESS ON THERMAL
COMFORT IN MALAYSIA**

By

ROONAK DAGHIGH

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science**

March 2008



In dedication to:

My dear, loving and supporting mother, Mehri
And my beloved husband and brother, Jalil and Zhian

For all their encouragement, patience and support

With Love and gratitude

My precious father, Ghobad

Peace to his departed spirit

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

INFLUENCE OF AIR EXCHANGE EFFECTIVENESS ON THERMAL COMFORT IN MALAYSIA

By

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March 2008

Chairman : Associate Professor Ir. Nor Mariah Adam, PhD

Faculty : Engineering

Influence of air exchange rate and air exchange effectiveness on thermal comfort has not been investigated in the world at all and are, therefore, not well understood. The main objective of this research is to investigate effects of ventilation parameters on thermal comfort and assessing these influences through the variable windows-door opening arrangements. To determine the windows-door opening performance in terms of ventilation air flow rate 28 opening configurations have been considered. The combination of windows-door opening arrangements was carried out in office room.

Thermal comfort field experiments and ventilation study were conducted in both naturally ventilated and air conditioned office. Age of air, Air exchange rate (ACH), Air exchange effectiveness (AEE), Predicted Mean Vote (PMV) and predicted Percentage of Dissatisfied (PPD) for each condition were calculated. Apart from common thermal comfort factors such as air dry bulb temperature, relative humidity,

mean radiant temperature, air velocity, metabolic rate and thermal resistance, two new factors were considered, i.e., ACH and AEE.

The subjective survey involved questions on the thermal environmental perception and indoor air quality for office occupants. The results yielded from subjective and objective approach were used to formulate a method for simulation of office buildings to include the effects of opening arrangements and ventilation parameters on thermal comfort.

These results showed that for naturally ventilated and air conditioned office room twelve linear regression equations of PMV versus ACH and AEE can be derived. Through those yielded equations it has been determined that the Coefficient of Correlation (R^2) obtained for PMV average, maximum and minimum versus ACH are 96.5, 93.9, 97.3% and 94.3, 89.9, 86.6%, respectively. The Coefficient of Correlation (R^2) obtained for PMV average, maximum and minimum versus AEE are 74.9, 70.7, 76.9% and 88.7, 76.5, 86.7%, respectively for naturally and mechanically ventilated office room. P values (significance levels) for ANOVA test and t-test are less than 0.05, which means that the variation explained by these equations not due to chance and there are significant correlation between PMV and ACH and high correlation between PMV and AEE in naturally and mechanically ventilated office room.

It has been observed that with increment in ACH in order to meet ASHRAE Standard 62 requirements, PMV values are closed to ISO 7730 comfort range, and

by approaching the AEE to value of one, PMV values are again closed to ISO 7730 comfort range in naturally and mechanically ventilated office room.

This study has shown that there are relationship between ACH, AEE and thermal comfort. Thermal comfort is to a great extent influenced by ACH and AEE which go beyond the six factors which have been taken into account in PMV modeling. It is believed that they have contributed in some positive ways to the higher level of thermal comfort.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN KEBERKESANAN PERTUKARAN UDARA PADA KESELESAAN TERMA DI MALAYSIA

Oleh

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Kajian berkenaan kesan dari kadar pertukaran udara dan keberkesanan pertukaran udara pada keselesaan terma belum pernah dikaji di dunia ini dan oleh itu, ia kurang difahami. Objektif utama bagi penyelidikan ini ialah untuk menyiasat kesan dari parameter pengudaraan ke atas keselesaan terma dan menilai pengaruhnya melalui penyusunan bagi pembukaan tingkap-pintu secara pembolehubah. Bagi menentukan prestasi pembukaan tingkap-pintu dari aspek pengaliran pengudaraan, konfigurasi pada kadar 28 pembukaan telah dipertimbangkan. Kombinasi penyusunan bagi pembukaan tingkap-pintu telah dijalankan di dalam bilik pejabat.

Fail kajian eksperimen bagi kesesuaian terma dan pengudaraan telah dijalankan pada kedua-dua keadaan pejabat iaitu pada pengudaraan semula jadi dan pengudaraan penghawa dingin. PMV dan PPD bagi setiap keadaan telah dikira. Selain dari faktor keselesaan terma yang biasa seperti suhu udara kering mentol, kelembapan relatif, min suhu sinaran dan halaju udara, tiga faktor baru telah dipertimbangkan iaitu kadar pertukaran udara, umur udara dan keberkesanan pertukaran udara.

Tinjauan subjektif melibatkan soalan berkenaan persepsi terma persekitaran dan kualiti udara dalaman bagi penghuni pejabat. Hasil keputusan dari pendekatan subjektif dan objektif telah digunakan untuk membentuk satu kaedah bagi simulasi bangunan pejabat dengan termasuk kesan oleh penyusunan bagi pembukaan tingkap-pintu dan parameter pengudaraan bagi keselesaan terma.

Keputusan ini menunjukkan bahawa bagi bilik pejabat dengan pengudaraan semula jadi dan pengudaraan penghawa dingin, duabelas persamaan regresi linear bagi PMV lawan Kadar Pertukaran Udara dan Keberkesanan Pertukaran Udara boleh diterbitkan. Melalui hasil persamaan tersebut bagi pengudaraan bilik pejabat secara semula jadi dan mekanikal, telah ditentukan bahawa nilai Pekali Kolerasi (R^2) yang diperolehi bagi purata PMV, maksimum dan minimum lawan kadar pertukaran udara adalah 96.5, 93.9.8, 97.3% dan 94.3, 89.9, 86.6% masing-masing. Nilai Pekali Kolerasi (R^2) yang diperolehi bagi purata PMV, maksimum dan minimum lawan keberkesanan pertukaran udara adalah 74.9, 70.7, 76.9% dan 88.7, 76.5, 86.7% masing-masing bagi bilik pejabat dengan pengudaraan semula jadi dan mekanikal. Untuk ujian Anova dan T, nilai P (tahap penting) adalah kurang daripada 0.05, bermaksud variasi di dalam persamaan ini menjelaskan bahawa terdapatnya kaitan yang penting di antara PMV dan ACH, di mana terdapat kaitan yang tinggi antara PMV dan AEE untuk pengudaraan bilik pejabat secara semulajadi dan mekanik.

Ianya telah diperhatikan bahawa kenaikan di dalam ACH (selagi mana ianya memenuhi keperluan "ASHRAE Standard 62" nilai PMV menjadi semakin dekat dengan kadar keselesaan ISO 7730. Untuk memperoleh ISO 7730 bagi pengudaraan

bilik pejabat secara semulajadi dan mekanik, nilai PMV mestilah mendekati nilai 1 di mana kecekapan pengaliran udara akan dicapai.

Kajian ini telah menunjukkan bahawa terdapat perhubungan diantara kadar pertukaran udara, keberkesanan pertukaran udara dan keselesaan terma. Keselesaan terma dipengaruhi secara meluas oleh kadar pertukaran udara dan keberkesanan pertukaran udara dimana ia melibatkan lebih dari enam faktor yang telah diambil kira dalam pembentukan model PMV. Adalah dipercayai bahawa ACH dan AEE telah menyumbang sedikit kearah positif untuk keselesaan peringkat terma yang lebih tinggi.

ACKNOWLEDGEMENTS

All the praise to Allah the Al-Mighty for his blessing and benevolence

I wish to express my sincere gratitude and appreciation to the numerous individuals who have contributed towards the completion of this thesis:

- To my supervisor, Associate Professor Ir. Dr. Nor Mariah bt. Adam, and supervisory committee member: Professor Ir. Dr. Barkawi Sahari for their invaluable advice, supervision and assistance during this research. Their encouragement, moral and technical support have made this work possible.
- To Prof. Dr. Kamaruzzaman Sopian, of the Faculty of Engineering Universiti Kebangsaan Malaysia (UKM) for all of his invaluable expert guidance throughout the research.
- To Dr. Yupiter HPManurung of the Faculty of Engineering Universiti Institute Technology MARA (UiTM) for his assistance.
- To all the Malaysian people, UPM staff especially all staff in the Department of Mechanical and Manufacturing Engineering, UPM for their cooperation given to me throughout this research.
- To all my friends in UPM for all their moral support.
- To my dear mother and brother, for their warm encouragement, love and support.
- And last but not least, my heartfelt gratitude and utmost love to my husband, for his support, understanding and patience.

Thank you for all your contributions.

May Allah bless you all.

I certify that an Examination Committee has met 4th of March 2008 to conduct the final examination of Roonak Daghigh on her Master of Science thesis entitled “Influence of Air Exchange Effectiveness on Thermal Comfort” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Master of Science.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

ROONAK DAGHIGH

Date: 11 March 2008

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	ix
APPROVAL	x
DECLARATION	xii
LIST OF TABLES	xvii
LIST OF FIGURES	xix
LIST OF ABBREVIATIONS	xxii
CHAPTER	
1 INTRODUCTION	1
1.1 Introduction	1
1.2 Problem Statement	4
1.3 Research Objectives	6
1.4 Scope and Limitation	7
1.5 Expected Outcome	7
1.6 Layout of Thesis	8
2 LITERATURE REVIEW	10
2.1 Thermal Comfort	10
2.1.1 The Effect of Dry Bulb Temperature(Air Temperature) on Thermal Comfort	11
2.1.2 The Effect of Mean Radiant Temperature on Thermal Comfort	11
2.1.3 The Effect of Air Velocity on Thermal Comfort	12
2.1.4 The Effect of Relative Humidity on Thermal Comfort	12
2.1.5 The Effect of Clothing Thermal Resistance on Thermal Comfort	13
2.1.6 The Effect of Metabolic Rate on Thermal Comfort	13
2.2 Models for Thermal Comfort	13
2.2.1 The Heat Balance Approach	14
2.2.2 The Adaptive Approach	16
2.2.3 ASHRAE Comfort Charts	17
2.2.4 Thermal Comfort Criteria for MALAYSIA	18
2.3 Thermal comfort studies in Malaysia and the Surrounding Regions	20
2.3.1 Thermal comfort studies in Malaysia	21
2.3.2 Thermal comfort studies in South East Asia	23
2.4 Ventilation	26
2.5 Tracer Gas Technique	29
2.6 Air Exchange Rate	31



2.7	Age-of-Air	31
2.7.1	Room Air Movement	32
2.8	Air Exchange Effectiveness	33
2.9	Window-Door opening arrangements	33
2.9.1	Introduction	33
2.9.2	The effects of Windows, Door Opening studies on Ventilation and thermal comfort	35
2.10	Previous IAQ and Ventilation Effectiveness Researches in Malaysia and South East Asia	39
2.11	Closure	40
3	THEORETICAL EQUATIONS	42
3.1	Introduction	42
3.2	Thermal Comfort Equations	42
3.3	Useful Equations for PMV and PPD Calculation	44
3.4	The Adaptive Approach	45
3.5	Air Exchange Rate	46
3.6	Age-of-Air	48
3.6.1	Air Exchange Effectiveness	51
3.7	Sample Calculation to Obtain Air Exchange Rate (ACH)	53
3.7.1	Air Exchange Rate Calculation Using Equation	53
3.7.2	Air Exchange Rate Calculation Using Graph	54
3.7.3	Air Exchange Rate Calculation Using Data Analysis by Multiple Regressions	55
3.8	Calculation of Age-of-Air	57
3.9	PMV and PPD Calculation	59
4	METHODOLOGY	61
4.1	Introduction	61
4.2	Walkthrough Inspection	66
4.3	Arrangement of Experimental Series	67
4.4	Description of Experimental Study	67
4.5	Tracer Gas Selection	68
4.5.1	Source of Tracer Gas	68
4.5.2	Tracer Gas Injection	69
4.5.3	Experimental Procedures	70
4.5.4	Experimental Set Up	74
4.5.5	Measurement Techniques	74
4.5.6	Instrumentation	76
4.6	Thermal Comfort Measurements	77
4.6.1	Experimental Procedures	78
4.6.2	Experimental Set Up	78
4.6.3	Measurement Techniques	78
4.6.4	Instrumentation	80
4.7	Subjective Approach	83
4.7.1	Design of Survey and Questionnaire	83
4.7.2	Distribution and Collection of Questionnaires	84
4.8	Data Analysis	85
4.8.1	Statistical data analysis on Measured Parameters	86
4.8.2	Statistical data analysis on survey	86

5	RESULTS AND DISCUSSION	87
5.1	Introduction	87
5.2	Variable Windows-Door Combinations for Office	87
5.3	Ventilation Study for Naturally Ventilated Office Room	87
5.3.1	Evaluation of Air Exchange Rates	88
5.3.2	Evaluation of Age of Air and Local Air Exchange Effectiveness	93
5.3.3	Assessment of Amount of Fresh Air	94
5.3.4	Evaluation of Air Exchange Effectiveness	98
5.4	Thermal Comfort Filed Experiments-Naturally Ventilated Office Room	100
5.4.1	Evaluation of Thermal Comfort Parameters	100
5.4.2	Results with reference to ASHRAE 55 – 1992 using Psychometric Chart	101
5.4.3	Neutral Temperature	101
5.5	Evaluation of the thermal comfort	102
5.5.1	Data Analysis Based on Simulation with Reference to the ISO 7730 and ASHRAE 55-1992	102
5.5.2	Discussion Based on ASHRAE 55 – 1992 using Psychometric Chart	110
5.5.3	Discussion With Respect to Neutral Temperature	111
5.6	Subjective Assessment	112
5.6.1	Type of Clothing Worn	112
5.6.2	Analysis of Votes on ASHRAE Scale	113
5.6.3	Adaptive Behavior	113
5.6.4	Assessment of Air Quality	116
5.6.5	Assessment of Subjective Approach	117
5.6.6	Verification of Results	118
5.7	Correlation between Air Exchange Rate and Predicted Mean Vote	120
5.7.1	Simple Linear Regression for 14 Windows-Door Opening Arrangements	120
5.7.2	Analysis of Variance (ANOVA) for PMV and ACH	122
5.8	Effect of Predicted Mean Vote on Air Exchange Effectiveness	123
5.8.1	Simple Linear Regression for 14 Windows-Door Opening Arrangements	123
5.8.2	Analysis of Variance (ANOVA) for PMV and AEE	125
5.9	Air-Conditioned Office Room -Ventilation Study	126
5.9.1	Evaluation of Air Exchange Rates and the Amount of Fresh Air	126
5.9.2	Evaluation of Age of Air and Local Air Exchange Effectiveness	127
5.10	Air Conditioned Office Room-Thermal Comfort Filed Experiments	127
5.10.1	Assessment of Thermal Comfort Parameters	127
5.10.2	Results with reference to ASHRAE 55 – 1992 using Psychometric Chart	127
5.10.3	Neutral Temperature	128

5.11	Subjective Assessment	131
5.11.1	Analysis of Votes Based on ASHRAE Scale	131
5.11.2	Type of Clothing Worn	131
5.11.3	Adaptive Behavior	131
5.11.4	Assessment of Air Quality	132
5.12	Discussions	133
5.12.1	Evaluation of Ventilation Study	133
5.12.2	Evaluation of the thermal comfort - Data Analysis Based on Simulation with Reference to the ISO 7730 and ASHRAE 55-1992	136
5.12.3	Evaluation of the thermal comfort - Discussion Based on ASHRAE 55 - 1992 Using Psychometric Chart	137
5.12.4	Evaluation of the thermal comfort - Discussion With Respect to Neutral Temperature	137
5.12.5	Assessment of Subjective Approach	138
5.12.6	Verification of Results	139
5.13	Relationship between Air Exchange Rate and Predicted Mean Vote	140
5.13.1	Simple Linear Regression for 14 Windows-Door Opening Arrangements	140
5.13.2	Analysis of Variance (ANOVA) for PMV and ACH	142
5.14	Effect of Predicted Mean Vote on Air Exchange Effectiveness	143
5.14.1	Simple Linear Regression for 14 Windows- Door Opening Arrangements	143
5.14.2	Analysis of Variance (ANOVA) for PMV and AEE	144
5.15	Closure	145
6	CONCLUSIONS AND RECOMMENDATIONS	147
6.1	Conclusions	147
6.2	Recommendations for Future Research	152
	REFERENCES	153
	APPENDICES	163
	BIODATA OF THE AUTHOR	201

LIST OF TABLES

Table		Page
2.1	Thermal comfort research for naturally ventilated buildings and air-conditioned buildings in Malaysia and the South East Asia Region	28
3.1	Age of Air Measurement Equations	50
3.2	Regression Analysis of Natural Logarithm of Tracer Gas Concentration vs. Time	55
3.3	Concentration and Natural Logarithm of Tracer Gas Concentration vs. Time for Condition (AC1)	56
3.4	Thermal Comfort Parameters for Condition C1	58
4.1	Variable Conditions of Windows-Door arrangements	65
5.1	Variable Conditions of Windows-Door Arrangements for Naturally and Mechanically Ventilated Office Room	88
5.2	Measurements of Air Changes per hour (ACH) Age of Air, Air Exchange Effectiveness and Outside Air Quantities for Naturally Ventilated Office	90
5.3	Measurements of Thermal Comfort, Outside Air Parameters, Neutral Temperatures (Mean Values)	103
5.4	Distribution of individual thermal sensation votes for different values of mean vote. Source: ISO/WD 7730	104
5.5	Distribution of PMV for 14 Windows-Door Opening Arrangements	106
5.6	Demographic data of respondents	112
5.7	PMV Equations vs. ACH for Naturally Ventilated Office	121
5.8	PMV Equations vs. AEE for Naturally Ventilated Office	124
5.9	Measurements of Air Changes per hour (ACH) Age of Air, Air Exchange Effectiveness and Outside Air Quantities for Mechanically Ventilated Office	129

5.10	Measurements of Thermal Comfort, Outside Air Parameters, Neutral Temperatures (Mean Values) and PMV	130
5.11	PMV Equations vs. ACH for Mechanically Ventilated Office	140
5.12	PMV Equations vs. AEE for Mechanically Ventilated Office	143
6.1	PMV equations in Naturally and Mechanically Ventilated Office	151



LIST OF FIGURES

Figure		Page
2.1	Predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (ISO Standard 7730, 1994)	16
2.2	Kuala Lumpur psychrometric chart: Comfort zone and climatic data with boundaries of the control potential zone shown. Solid lines denote 1 m/s (ISO Standard 7730, 1994). (Source: Sh Ahmad, 2006)	20
3.1	Plot of the tracer-gas concentration as a function of time (Grieve, 1989)	48
3.2	Logarithmic plot of decay rate data (Grieve, 1989)	49
3.3	Variation of Local Tracer Gas Concentration vs. Time for Condition F1	53
3.4	Local Decay for for Condition F1	53
3.5	Ln CO ₂ vs. Time & Trend Line	54
3.6	Concentration-decay Profile of Tracer-gas at the Office & Line Fit Plot	55
3.7	Variation of Local Tracer Gas Concentration vs. Time, Condition (AC1)	57
3.8	Ln CO ₂ vs. Time & Trend Line, Condition (AC1)	57
3.9	Concentration-decay Profile of Tracer-gas at the Office & Line Fit Plot (AC1)	57
4.1	Flowchart of the Research	61
4.2	Flowchart of the Objective Study	62
4.3	Flowchart of the subjective Approach	63
4.4	Layout of building	64
4.5	Sketch of Office Room	64

4.6	Source of Tracer Gas	68
4.7	Location of office room	70
4.8	View of office room and windows	70
4.9	Test Office Room	71
4.10	View of window area and windows	71
4.11	View of office room during experiments with BABUCA in place	72
4.12	IAQ meter and BABUCA in test room	72
4.13	IAQ Meter	76
4.14	BABUCA, A portable instrument for acquisition, display, storage and processing of environmental data	81
4.15	Air Velocity Meter	82
4.16	Staff during conducting survey	84
5.1	Variation of Local Tracer Gas Concentration vs. Time for Control Condition (A)	89
5.2	Ladies wearing baju kurong	101
5.3	Thermal Comfort Range Based on Psychometric Chart – ASHRAE 55 – Controlled Condition	104
5.4	Variation of Thermal Comfort Parameters and Air Exchange Rate vs. PMV for Control Condition	105
5.5	Control Condition -Predicted Percentage of Dissatisfied (PPD) as a Function of Predicted Mean Vote (PMV) .Source: ISO 7730	106
5.6	Type of Clothing Worn	113
5.7	Relative Frequency of ASHRAE Thermal Votes	113
5.8	Adaptive Behaviour (control condition A)	114
5.9	Adaptive Behaviour in Naturally Ventilated Office	115
5.10	Complaints from staff on physical parameters (Control condition)	116
5.11	Complaints from staff on physical parameters	116

5.12	Distribution of Air Quality for Naturally Ventilated Office	117
5.13	Predicted Mean Vote (Ave.) vs. Air Exchange Rate	121
5.14	Predicted Mean Vote (Min.) vs. Air Exchange Rate	121
5.15	Predicted Mean Vote (Max.) vs. Air Exchange Rate	122
5.16	Predicted Mean Vote (Ave.) vs. Air Exchange Effectiveness	124
5.17	Predicted Mean Vote (Min.) vs. Air Exchange Effectiveness	124
5.18	Predicted Mean Vote (Max.) vs. Air Exchange Effectiveness	125
5.19	Variation of Local Tracer Gas Concentration vs. Time for Condition (AC1)	126
5.20	Thermal Comfort Range Based on Psychometric Chart – ASHRAE 55 – Air Conditioned Office	128
5.21	Relative Frequency of ASHRAE Thermal Votes	131
5.22	Adaptive Behaviour	132
5.23	Complaints from staff on physical parameters	132
5.24	Distribution of Air Quality	133
5.25	Predicted Mean Vote (Ave.) vs. Air Exchange Rate	141
5.26	Predicted Mean Vote (Min.) vs. Air Exchange Rate	141
5.27	Predicted Mean Vote (Max.) vs. Air Exchange Rate	141
5.28	Predicted Mean Vote (Ave.) vs. Air Exchange Effectiveness	143
5.29	Predicted Mean Vote (Min.) vs. Air Exchange Effectiveness	144
5.30	Predicted Mean Vote (Max.) vs. Air Exchange Effectiveness	144

LIST OF ABBREVIATIONS

A	Two Windows Closed, Door Closed- without air-conditioner
AB	Two Windows Opened, Door Opened- with air-conditioner
AC	Air Conditioned
AC1	Windows No.1 and No.2 Half Opened, Door Opened- with air-conditioner
ACH	Air Exchange Rate
ACS	Adaptive Comfort Standard
AEE	Air Exchange Effectiveness
ANOVA	Analysis of Variance
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
B	Two Windows Closed and Door Closed, with air-conditioner
C	Concentration of tracer-gas in room
C1	Two Windows Closed, Door Opened- without air-conditioner
CFD	Computational Fluid Dynamic
C_j	Concentration Measurement
CLO	Thermal Resistance of Clothing
C_M	Final Concentration Measured
C_{oa}	Concentration of tracer-gas in outside air
D	Two Windows Closed and Door Opened- with air-conditioner
DBT	Dry Bulb Temperature
DOSM	Department of Standards Malaysia
DV	Displacement Ventilation
E	Windows No.1 Fully Opened, Windows No.2 Closed, Door Closed- without air-conditioner

ET	Effective Temperature
F	Introduction rate of tracer-gas into room
F1	Windows No.1 Half Opened, Windows No.2 Closed, Door Closed- without air-conditioner
f _{cl}	Clothing Area Factor
FEC	Field Environmental Chamber
G	Windows No.2 Fully Opened, Windows No.1 Closed, Door Closed- without air-conditioner
GNP	Gross National Product
H	Windows No.2 Half Opened, Windows No.1 Closed, Door Closed- without air-conditioner
h _c	Convective Heat Transfer Coefficient
HCHO	Formaldehyde
HVAC	Heating, Ventilating and Air Conditioning
I	Windows No.1 Fully Opened, Windows No.2 Closed, Door Closed- with air-conditioner
IAQ	Indoor Air Quality
I _{cl}	Clothing Insulation
IPSI	Indoor Pollutant Standard Index
ISO	International Standards Organization
J	Windows No.1 Half Opened, Windows No.2 Closed, Door Closed- with air-conditioner
K	Windows No.2 Fully Opened, Windows No.1 Closed, Door Closed- with air-conditioner
L	Windows No.2 Half Opened, Windows No.1 Closed, Door Closed- with air-conditioner
LEO	Low Energy Office
LTS	Local Thermal Sensation
M	Metabolic Rate of Body Surface Area
M1	Windows No.1 Fully Opened, Windows No.2 Closed, Door Opened- without air-conditioner

Met	Metabolic Rate
MRT (t_r)	Mean Radiant Temperature
MSRB	Multi-Storey Residential Building
N	Windows No.1 Half Opened, Windows No.2 Closed, Door Opened- without air-conditioner
N/a	Not Available
NV	Naturally Ventilated
O	Windows No.2 Fully Opened, Windows No.1 Closed, Door Opened- without air-conditioner
P	Windows No.2 Half Opened, Windows No.1 Closed, Door Opened- without air-conditioner
p_a	Water Vapour Particle Pressure
Q	Windows No.1 Fully Opened, Windows No.2 Closed, Door Opened- with air-conditioner
q_v	Air-flow through room
R	Windows No.1 Half Opened, Windows No.2 Closed, Door Opened- with air-conditioner
RH	Relative Humidity
S	Windows No.2 Fully Opened, Windows No.1 Closed, Door Opened- with air-conditioner
SBS	Sick Building Syndrome
T	Windows No.2 Half Opened, Windows No.1 Closed, Door Opened- with air-conditioner
T_a	Ambient Temperature
T_{ao}	Outdoor Air Temperature
t_{cl}	Clothing Surface Temperature
T_g	Indoor Globe Temperature
T_n	Neutral Temperature
T_o	Operative Temperature