

Table of contents

Introduction	1
Chapter 1 Introduction to Environmental Control and Life Support System	3
1.1 ECLS functions.....	3
1.1.1 ECLS subsystems and interfaces.....	3
1.2 General environmental control requirements.....	5
1.3 “Open-loop” vs. “closed-loop” ECLSS.....	6
1.4 Hierarchy of ECLS systems.....	9
1.5 Significance of forced ventilation in space.....	10
Chapter 2 CFD Simulation of Ventilation Flows – A Review	12
2.1 Ventilation methods.....	13
2.1.1 Mixing ventilation.....	13
2.1.2 Displacement ventilation.....	13
2.1.3 Plug-flow ventilation.....	14
2.2 The characteristics of ventilation flows.....	14
2.3 Numerical simulation of ventilation flows.....	15
2.4 General Problems in Modelling Ventilation Flows.....	16
2.4.1 The need of validation.....	16
2.4.2 Air flow velocity measuring problems.....	17
2.4.3 Main problems for indoor airflow simulation.....	18
2.5 Review of the validation data used in the present study.....	20
2.5.1 The IEA Annex 20 project.....	20
2.5.2 ASHRAE-1009.....	21
2.6 Review of CFD simulation of ventilation flows for space application.....	21
Chapter 3 Turbulence modelling	23
3.1 The characteristics of turbulence.....	23
3.2 Approaches in turbulence modeling and simulation.....	24
3.2.1 Fundamental equations of viscous fluid motion.....	24
3.2.2 Basic concepts in turbulence modeling.....	27
3.2.2.1 Direct Numerical Simulation (DNS).....	27
3.2.2.2 Large Eddy Simulation (LES).....	27
3.2.2.3 Reynolds Averaged Navier-Stokes models (RANS).....	27
3.3 Statistical turbulence models.....	30
3.3.1 Classification of turbulence closures.....	30
3.3.2 Algebraic turbulence models: zero-equation models.....	30
3.3.3 One-equation turbulence models.....	30
3.3.4 Two-equation turbulence models.....	31
3.3.4.1 The standard k- ϵ model.....	32
3.3.4.2 The RNG k- ϵ model.....	33
3.4 Turbulence modeling for ventilation flows.....	34
3.5 Remarks.....	36
Chapter 4 Numerical simulation for 2D and 3D isothermal ventilation flows	37
4.1 Validation study: IEA Annex 20 Test Case 2D (Forced convection in a 2D room).....	37
4.1.1 Numerical simulation with different k- ϵ models.....	38
4.1.1.1 Prediction with standard k- ϵ turbulence model.....	38
4.1.1.2 Prediction with RNG k- ϵ model and Realizable k- ϵ model.....	40
4.1.1.3 Prediction with low-Reynolds number (LRN) k- ϵ turbulence models.....	40
4.1.2 Prediction with k- ω turbulence models.....	40
4.1.3 Prediction with the RSM model.....	40

4.1.4	Remarks.....	40
4.2	Validation study: Forced convection in a partitioned 3D room.....	45
4.2.1	Prediction with two-equation models.....	46
4.2.1.1	Prediction with k- ϵ models.....	46
4.2.1.2	Prediction with low-Reynolds number (LRN) k- ϵ models.....	48
4.2.1.3	Prediction with two-equation k- ω models.....	49
4.2.2	Prediction with the RSM model.....	53
4.2.3	Large-eddy simulation.....	55
4.3	Validation study: IEA Annex 20 Test Case B (Forced convection, isothermal).....	59
4.3.1	Experiment setup.....	59
4.3.2	Modeling of the diffuser.....	61
4.3.2.1	Introduction.....	61
4.3.2.2	Experiment set-up.....	65
4.3.2.3	Modeling and numerical simulation.....	65
4.3.2.4	Remarks.....	79
4.3.3	Simulation of the IEA Annex 20 Test Cases B2 and B3.....	82
4.3.3.1	Turbulence modeling.....	82
4.3.3.2	Boundary conditions and numerical methods.....	82
4.3.3.3	Computation meshes.....	82
4.3.3.4	Velocity correction.....	83
4.3.3.5	Comparison of the predicted velocity profiles with measurements.....	83
4.3.3.6	Remarks.....	84
4.4	Conclusion.....	91
Chapter 5 3D Ventilation Flows with coupled Heat or Mass Transfer.....		92
5.1	Validation study: IEA Annex 20 Test Case E (Mixed convection, summer cooling).....	92
5.1.1	Experiment setup.....	92
5.1.2	Turbulence modeling.....	93
5.1.3	Boundary conditions and numerical methods.....	93
5.1.4	Computation meshes.....	94
5.1.5	Comparison of numerical predictions with experimental data for the Test Cases E2.....	94
5.1.6	Comparison of numerical predictions with experimental data for the Test Cases E3.....	95
5.1.7	Remarks.....	101
5.2	Validation study: IEA Annex 20 Test Case F (Forced convection, isothermal with contaminants).....	102
5.2.1	Problem description: The IEA Annex 20 Test Case F.....	102
5.2.2	Modeling and simulation of the IEA Annex 20 Test Case F.....	103
5.2.2.1	Boundary conditions and numerical schemes.....	104
5.2.2.2	Computation meshes.....	104
5.2.2.3	Test Case F1: contaminant transport with strong buoyancy.....	105
5.2.2.4	Test Case F2: contaminant transport by ventilation.....	125
5.2.2.5	Test Case F3: contaminant transport with stable stratification.....	132
5.2.3	Remarks.....	141
Chapter 6 3D Ventilation Flows with coupled Heat and Mass Transfer.....		143
6.1	Experiment setup of the test chamber.....	143
6.2	Displacement ventilation.....	144
6.2.1	Test conditions.....	144
6.2.2	Modeling and simulation.....	146
6.2.2.1	Boundary conditions.....	146
6.2.2.2	Turbulence modeling.....	147
6.2.2.3	Computation meshes.....	147
6.2.2.4	Numerical schemes.....	147
6.2.2.5	Simulation results.....	147
6.2.2.6	Remarks.....	148

6.3 Ceiling slot ventilation.....	148
6.3.1 Test conditions.....	157
6.3.2 Modeling and simulation.....	157
6.3.2.1 Boundary conditions.....	159
6.3.2.2 Turbulence modeling.....	161
6.3.2.3 Computation meshes.....	161
6.3.2.4 Numerical schemes.....	161
6.3.2.5 Simulation results.....	161
6.3.3 Simulation under normal g and zero g conditions.....	168
Chapter 7 General conclusions and perspective for future study	179
References	180
Appendix	A-1