A PERFORMANCE BASED APPROACH FOR THE PREDICTION OF INDOOR THERMAL COMFORT OF NATURALLY VENTILATED BUILDINGS IN THE TROPICS

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Degree of Doctor of Philosophy

Department of Mechanical Engineering
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DECLARATION

I declare that this is my own work, and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute 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. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date: 05.02.2025

The above candidate has carried out research for the PhD/~~MPhil~~/~~Masters~~ thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

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Signature of the Supervisor: Date: 05.02.2025

Name of Supervisor: Prof. K.K.C.K. Perera, Senior Professor, Department of Mechanical Engineering, Faculty of Engineering, University of Moratuwa, Sri Lanka

Signature of the Supervisor: Date: 05.02.2025

DEDICATION

To my parents, brothers and wife for their unconditional love, endless support and encouragement

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ABSTRACT

Natural ventilation is a key strategy for achieving energy-efficient and thermally comfortable indoor environments, particularly in tropical climates. This thesis presents a comprehensive framework for evaluating and optimizing natural ventilation performance in buildings by integrating computational modeling, optimization techniques, and empirical validation. The research focuses on assessing airflow distribution and thermal comfort while developing a performance-based approach to guide the design of naturally ventilated buildings.

The study begins by investigating the impact of various Reynolds-Averaged Navier-Stokes turbulence models on airflow distribution and thermal comfort prediction using computational fluid dynamics (CFD). Among the tested models, the Standard k-ε turbulence model demonstrated the highest accuracy in predicting indoor airflow fields and thermal comfort indices. Validation of computational results against wind tunnel experiments revealed that existing turbulence models have limitations in capturing transient flow phenomena, such as Kelvin-Helmholtz instabilities, highlighting the need for improved model selection strategies. The deviation in the predicted thermally comfortable area for the Renormalization Group k-ε and Standard k-ω models was within ±5.0% of the Standard k-ε model, while the Realizable k-ε model showed deviations within the same range only in horizontal planes at y/H = 0.375 and 0.5. Additionally, the incoming jet angle was found to be within 17.1°-23.7°, with the Renormalization Group k-ε model exhibiting the highest value (23.7°) and the Rk-ε model the lowest (17.1°).

Building on these findings, an optimization framework was developed using Artificial Neural Networks and Central Composite Design to refine turbulence model coefficients. This novel integration significantly enhanced prediction accuracy and computational efficiency. The fraction of CFD predictions falling within a factor of two of the corresponding wind tunnel measurements improved from 0.68 to 0.84 for velocity predictions and from 0.48 to 0.81 for kinetic energy predictions, confirming the effectiveness of the optimized model. When applied to a real residential building in Sri Lanka, the optimized turbulence model demonstrated strong agreement with validation metrics across multiple ventilation scenarios. The factor of acceptance increased to 0.92, indicating that 92% of CFD predictions fell within a factor of two of the measured wind speeds. The correlation coefficient of 0.89 confirmed strong agreement between simulated and experimental values, while the normalized mean squared error of 0.35 and fractional bias of -0.06 highlighted a slight underprediction tendency, ensuring a conservative yet reliable model. These results validate the effectiveness of the CFD framework in accurately capturing indoor airflow distribution and guiding ventilation design decisions.

A key contribution of this research is the development of a performance-based guideline for evaluating natural ventilation potential and thermal comfort during the

building design phase. The guideline incorporates site-specific climatic data, Predicted Mean Vote based thermal comfort assessments, and systematic airflow evaluations to optimize building orientation and the placement of ventilation openings. The findings underscore the influence of wind direction, opening configurations, and building orientation on ventilation performance, providing actionable insights for architects and engineers.

This research also addresses critical gaps in computational model validation, emphasizing the need for distributed and three-dimensional measurement points in wind tunnel experiments. Additionally, it highlights the importance of non-isothermal conditions, internal layouts, and surrounding structures in future studies to enhance the applicability of the developed methodology.

The proposed framework offers practical tools for designing energy-efficient, naturally ventilated buildings, aligning with global sustainability goals. By bridging computational simulations, optimization techniques, and real-world applications, this thesis establishes a robust foundation for advancing natural ventilation studies and contributing to the development of thermally comfortable and sustainable built environments.

Keywords: ANN, CFD, Natural ventilation, Thermal comfort, RANS turbulence models

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LIST OF ABBREVIATIONS

Abbreviation	Description
ACH	Air Changes per Hour
ANN	Artificial Neural Network
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CCD	Central Composite Design
CFD	Computational Fluid Dynamics
DBT	Dry Bulb Temperature
FAC2	Factor of Two of the Observations
FB	Fractional Bias
IAQ	Indoor Air Quality
MRT	Mean Radiant Temperature
NMSE	Normalized Mean Square Error
Opt-U	Optimized Turbulence Model
PMV	Predicted Mean Vote
PMVe	Extended Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
RANS	Reynolds-Averaged Navier-Stokes

Abbreviation	Description
ACH	Air Changes per Hour
RH	Relative Humidity
Sk-ε	Standard k-epsilon Model
RNG k-ε	Renormalization Group k-epsilon Model
Rk-ε	Realizable k-epsilon Model
Sk-ω	Standard k-omega Model
TKE	Turbulent Kinetic Energy
ISO	International Organization for Standardization