# DECISION-MAKING MODEL FOR ENERGY EFFICIENT TECHNOLOGIES IN GREEN BUILDINGS

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198136T

Doctor of Philosophy

Department of Civil Engineering

Faculty of Engineering

University of Moratuwa

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July 2023

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree

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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: UOM Verified Signature Date: 08/09/2023

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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# DEDICATION

This thesis represents not only the culmination of academic achievements but also the culmination of the love, support, and belief that surrounded me throughout this transformative journey.

This dissertation is dedicated to the love and support given by my loving parents, my sister and her husband, and my loving mother-in-law.

To my loving husband, you deserve equal credit for this accomplishment, and I dedicate this thesis to you with heartfelt gratitude and love. This achievement is not solely mine, but a shared victory that we celebrate together.

With heartfelt appreciation, this dissertation is dedicated to Mother Sri Lanka - my source of knowledge, inspiration, and boundless opportunities that generously granted me free education. As I present this dissertation, I do so with profound gratitude for the doors Sri Lanka's education system has opened for me. This dedication is a tribute to the countless educators, administrators, and policymakers who work tirelessly to make education accessible to all.

To the relentless researchers, the tenacious souls who refuse to give up, the researchers who keep pushing forward, undeterred by failure and setbacks, I dedicate this thesis to you as a tribute to your incredible spirit and celebration of your remarkable accomplishments and the champions of perseverance.

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To everyone who played a role in this research endeavor, your contributions have not gone unnoticed and have left an indelible mark on my academic and personal growth. Thank you all for being an integral part of this remarkable achievement.

## ABSTRACT

Employee satisfaction is paramount as it directly impacts their productivity and health, particularly in the office environment, where thermal comfort plays a crucial role. Existing quantitative methods for evaluating thermal comfort satisfaction solely focus on building structural elements. To bridge this gap, a study was conducted, surveying 1091 staff members across 14 green office buildings to assess their satisfaction with indoor environmental quality (IEQ) comfort. The analysis introduced a proposed network of IEQ comfort features to aid in designing the questionnaire and measuring the environment. To address the issue of an imbalanced dataset, the study implemented various resampling methods along with feature selection techniques that integrated statistical analysis methods and machine learning algorithms. Developing predictive models using the Random Forest algorithm allowed for a comparison with Decision Tree, Lasso Regression and Support Vector Regression models. Three predictive models were created to assess thermal comfort, visual comfort and indoor air quality comfort separately, and one predictive model was created to assess the overall IEQ comfort. The study identified significant factors influencing IEQ comfort satisfaction, the share of the area served by AC, total window area, the thickness of the wall insulation, area served by lighting, and smart controlling. The predictive models achieved more than 75% accuracy, and interpretability supports their practical application in office design. By utilising this predictive model, building designers and managers can make informed decisions, uncovering situations where green building certifications may not meet employees' expected level of thermal comfort. Ultimately, optimising employee thermal comfort can lead to enhanced productivity.



**Keywords**: employee satisfaction evaluation, green office buildings, IEQ comfort, predictive modelling, random forest regression

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## LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| AC | Air Condition |
| ASHRAE | American Society of Heating, Refrigerating, And Air-Conditioning Engineers |
| BCA | Building and Construction Authority |
| BD & FM | Building Design and Facilities Management |
| BRE | Building Research Establishment |
| BREAM | Building Research Establishment Environmental Assessment Method |
| CDF | Cumulative Distribution Function |
| CFL | Compact Fluorescent Lamps |
| $CO_2$ | Carbon Dioxide |
| DGNB | Deutsche Gesellschaft Für Nachhaltiges Bauen (German Sustainable Building Council) |
| DT | Decision Tree |
| EDGE | Excellence In Design for Greater Efficiencies |
| Emp | Employee |
| ESE | Employee Satisfaction Survey |
| GBCA | Green Building Council of Australia |
| GBCSL | Green Building Council of Sri Lanka |
| GBDM | Green Building Decision Making Model |
| G-SEED | Green Standard for Energy and Environmental Design |
| $H_0$ | Null Hypothesis |
| $H_1$ | Alternative Hypothesis |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IAQ | Indoor Air Quality |
| IEQ | Indoor Environmental Quality |
| IFC | International Finance Corporation |
| IQR | Interquartile Range |
| ISO | International Organization for Standardization |
| IWBI | International Well Building Institute |
| K-S | Kolmogorov-Smirnov |
| KW test | Kruskal-Wallis Test |
| LED | Light-Emitting Diodes |
| LEED | Leadership In Energy and Environmental Design |
| MAE | Mean Absolute Error |
| NDA | Non Disclosure Agreement |
| NGBS | National Green Building Standard |

| | |
|---|---|
| NZEB | Net-Zero Energy Building |
| PM | Particulate Matter |
| PPM | Parts Per Million |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| QQ | Quantile-Quantile |
| r | Correlation Coefficient |
| RF | Random Forest |
| RMSE | Root Mean Squared Error |
| SHGC | Solar Heat Gain Coefficient |
| SVM | Support Vector Mechanism |
| SVR | Support Vector Regression |
| S-W | Shapiro-Wilk |
| U test | Mann-Whitney U Test |
| USA | United States of America |
| USGBC | United State Green Building Council |
| USGBC | U.S. Green Building Council |
| VAV | Variable Air Volume |
| VIF | Variance Inflation Factor |
| VOCs | Volatile Organic Compounds |
| VT | Visible Transmittance |
| WWR | Window-to-Wall Ratio |

## LIST OF APPENDICES