ASSESSMENT AND OPTIMISATION OF COOLING LOADS FOR OPTIMAL BUILDING ENERGY EFFICIENCY USING GREY-TAGUCHI AND ANOVA METHODS

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AUGUST 2023

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTER OF ENGINEERING (M.Eng) DEGREE IN MECHANICAL EBGINEERING IN THE DEPARTMENT OF MECHANICAL ENGINEERING, COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA, OGUN STATE, NIGERIA

AUGUST 2023

ACCEPTANCE

This is to attest that this dissertation is accepted in partial fulfilment of the requirements for the award of the degree of Master of Engineering (M.Eng) in the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Nigeria and has been accepted by the school of Postgraduate Studies, Covenant University, Ota, Ogun state, Nigeria.

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(Dean, School of Postgraduate Studies) **Signature and Date**

DECLARATION

I, **AKOMOLAFE, MARVELLOUS IREOLUWA (20PCM02098)**, declare that this dissertation was carried out by me under the supervision of Prof. Sunday O. Oyedepo, in the Department of Mechanical engineering, College of Engineering, Covenant University, Ota, Ogun state, Nigeria. I attest that this dissertation has not been presented, either wholly or partially for the award of any degree elsewhere. All sources of scholarly information used in this research work were duly acknowledged.

AKOMOLAFE, MARVELLOUS IREOLUWA

Signature and Date

CERTIFICATION

This is to certify that this dissertation titled "**ASSESSMENT AND OPTIMISATION OF COOLING LOADS FOR OPTIMAL BUILDING ENERGY EFFICIENCY USING GREY-TAGUCHI AND ANOVA METHODS**" is an original work carried out by **AKOMOLAFE MARVELLOUS IREOLUWA (20PCM02098)** in the Department of Mechanical Engineering, Covenant University, Ota, Ogun state, Nigeria under the supervision of Prof. Sunday O. Oyedepo. This dissertation has met the required standard for the award of Master of Engineering (M.Eng) in Mechanical Engineering.

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Prof. Akan B. Williams **Signature and Date**
(Dean, School of Postgraduate Studies)

DEDICATION

To God, the Almighty, the Father of all; for His unending Mercy and Grace.

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NOMENCLATURE

Abbreviations

ACH	Air Change per Hour
AI	Artificial Intelligence
AIC	Akaike's Information Criterion
ANOVA	Analysis of Variance
BIC	Bayesian Information Criterion
CIS	Commonwealth of Independent States
CLF	Cooling Load Factor
CLTD/TA	Cooling Load Temperature Difference/Time Averaging
DOE	Design of Experiments
EJ	Exajoules
EPED	Energy Performance of Building Directive
EPC	Energy Performance Certificates
EU	European Union
GHG	Greenhouse Gas Emissions
GRA	Grey Relational Analysis
GTM	Grey-Taguchi Method
HAP	Hourly Analysis Program
HEI	Higher Education Institution
HBM	Heat Balance Method
HVAC	Heating Ventilation and Airconditioning
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MAPE	Mean Absolute Percentage Error
MTCO	Million Tonnes of Carbon dioxide
P4P	Pay for Performance
PRESS	Predicted Residual Sum of Squares
RTSM	Radiant Time Series Method
Q	Heat gain by conduction
U/U-factor	Overall heat transfer coefficient
A	Area of the surface
S	Standard Deviation of the Residuals

S/N	Signal to Noise Ratio
Seq SS	Sequential Sum of Squares
SC	Shading Coefficient
SCL	Solar Cooling Load
SDGs	Sustainable Development Goals
SHGC	Solar Heat Gain Coefficient
TFM	Transfer Function Method
VIF	Variance Inflation Factor
ZEB	Zero Energy Building

Greek Letters

ΔT	Dry-bulb Temperature Difference Across the Surface
η	The Signal-to-Noise Ratio Coefficient
m	The Total Number of Observations

Superscript

R^2	Coefficient of Determination
Z_{ij}^2	The Noise component for the ith Observation and jth Variable

Subscript

A_w	Area of Wall
$Cooling\ load_{actual}$	The Actual Cooling Load of the Space
$Cooling\ load_{pred}$	The Predicted Cooling Load of the Space
F_{sa}	Light Special Allowance Factor
F_u	Usage Factor
F_r	Radiation Factor
F_{ul}	Light Use Factor
N_b	Number of Lighting Points
N_p	Number of Persons
P_e	Power Rating of Equipment
Q_{equip}	Sensible Heat Gain for Equipment
Q_{latent}^{infil}, Q_{il}	Latent Heat of Infiltration
$Q_{sensible}^{infil}$, Q_{is}	Sensible Heat of Infiltration

Q_{light}, Q_{li}	Heat Gain from Lighting
$Q_{latent}^{people}, Q_{l}$	Latent Heat Gain from People
$Q_{sensible}^{people}, Q_{s}$	Sensible Heat Gain from People
Q_{wall}	Heat Gain by Conduction Through the Wall
Q_{roof}	Heat Gain by Conduction Through the Roof
$Q_{radiated}^{window}, Q_{wr}$	Solar Radiation Through a Window
Q_{window}, Q_{wi}	Heat Conduction Through Windows
R_a	Roof Area
$R_{aluminium\ foil}$	Thermal Resistance of Aluminium Foil
$R_{ceiling}$	Thermal Resistance of Ceiling
$R_{cement\ plaster}$	Thermal Resistance of Cement Plaster
$R_{glasswool}$	Thermal Resistance of Glasswool
$R_{Gypsum\ plaster}$	Thermal Resistance of Gypsum Plaster
$R_{hollow\ cement\ block}$	Thermal Resistance of a Hollow Cement Block
$R_{moving\ air}$	Thermal Resistance of the Moving Air
$R_{still\ air}$	Thermal Resistance of Still Air
R_{zinc}	Thermal Resistance of Zinc
$S/_N\ ratio_{LTB}$	Signal to Noise Ratio (larger-the-better)
$S/_N\ ratio_{STB}$	Signal to Noise Ratio (smaller-the-better)
T_o	Outdoor Dry-bulb Temperature
T_i	Indoor Dry-bulb Temperature
V_s	Volume of Space
W_a	Window Area
W_b	Wattage of Lighting

ABSTRACT

Amid the escalating global energy usage and carbon dioxide (CO_2) emissions originating from buildings, energy efficiency has become a topmost concern for energy policies across various nations. The problem is further amplified by the rapid surge in the usage of air conditioning systems, predominantly in the developing countries' infrastructure, influenced by higher living standards, modern architectural designs, and a preference for cooler indoor environments. The central aim of this research is to devise a cooling prediction model utilizing Taguchi orthogonal array and ANOVA techniques to optimise cooling loads in buildings, using Covenant University as a case study. The study primarily targets the compelling issue of energy inefficiency in selected buildings in Covenant University, with a special focus on improving energy efficiency through cooling load optimisation. Results of the investigation offered a predictive model which accounted for an impressive 98.51% of the cooling load variation, underpinned by an R^2 value of 98.51% and an adjusted R^2 value of 98.08%. The study further illuminated that the application of the model to the selected buildings showcased mixed outcomes. The university library's cooling load, originally at 137582.31W, was refined to 136816.11W, reflecting a 0.56% MAPE. The university chapel, starting with a cooling load of 149224.61W, experienced an optimisation down to 143776.22W, showcasing a 3.65% MAPE. Cafeteria 1 underwent a transition from its 110380.99W to a lower 108323.48W, marking a 1.86% MAPE. For the university Guest House, its initial cooling load of 89953.43W was pruned to 85393.19W, translating to a 5.07% MAPE. However, the Health Centre's cooling load escalated from 52494.41W to 53748.80W, resulting in a 2.39% MAPE. Further illuminating the study, the influence of key factors on the cooling load was discerned. The area of the roof (R_a) emerged as the most potent influence, followed closely by the number of occupants (N_p), the wall area (A_w), and the power rating of equipment (P_e). Beyond pure statistics, the exploration extended into tangible engineering solutions conducive for energy conservation in the studied buildings. Techniques encompassed retrofitting with energy-efficient windows, the inclusion of dynamic building shading, optimisation of HVAC system operations, the integration of automated lighting and energy management systems, and the contemplation of alternative cooling mechanisms, such as evaporative cooling. Conclusively, this research not only furthers the understanding of building energy efficiency but also furnishes a blueprint for the effective application of energy conservation policies amidst the global urgency for sustainable practices. The data-driven insights presented here are crucial for energy planners, architects, and university authorities, laying a foundation for more energy-efficient building operations.