

**ENERGY EFFICIENT BUILDING MODEL: A Case
study for Proposed SL ARMY Headquarters**

Godakumbura Watte Asiri Sanjeewa Bandara Muhandiramge

(108888P)



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Degree of Master of Science

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

April 2015

ENERGY EFFICIENT BUILDING MODEL: A Case study for Proposed SL ARMY Headquarters

Godakumbura Watte Asiri Sanjeewa Bandara Muhandiramge

(108888P)



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Dissertation submitted in partial fulfillment of the requirements for the
degree Master of Science

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

April 2015

ABSTRACT

The Sri Lankan Tri forces Headquarters with Ministry of Defence office complex are scheduled to be located in one place at Akuregoda Baththaramulla. This building complex will be one of the largest office complexes in Sri Lanka and to be accommodated for different nature functions except routine official duties. Therefore more attention has been given to improve the architectural view of the entire complex. In the mean time less attention has been given for energy optimizations issues. When the proposed design is thoroughly studied, many possibilities are available to improve energy efficiency of entire complex with some simple modifications. In order to optimize the energy use for illumination system and HVAC system, this case study has been done for selected building area of the total complex. The part of the building complex is selected to do the research and selected area is developed as a separate building model.

The research is mainly based on the finding of best wall to window ratio to optimize the energy consumption for illumination system and HVAC system of the selected building model. The calculation stages are done, maintaining the initial building parameters in human comfort zone as ASHRAE stranded and sun path over the location. The best orientation of the building model is obtained according to the north alignment. Then the condition of the building model is improved as an energy efficient model by replacing illumination system with LED luminaire, window glass with energy efficient low-e window glass and developing a building envelop.

Financial evaluation is done to all proposed building models with compare to the existing design for energy consumption. Then the lighting power density (LPD) is calculated for each building model and made a comparison with the maximum LPD values published by Sustainable Energy Authority.

The research methodology can be practiced in designing stage of any kind of a building to improve the energy efficiency effectively. It gives more opportunity for designers to develop more energy saving building environment, while maintain the human comfort in the same time.

DECLARATION

I declare that this is my own work and this thesis/dissertation¹ 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.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

.....

G.W.A.S.B. Muhandiramge

Date:  University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

The above candidate has carried out research for the Masters Dissertation under my supervision.

.....

Dr. Asanka Rodrigo

ACKNOWLEDGEMENT

First and foremost I offer my sincerest gratitude to my supervisor, Dr Asanka S. Rodrigo, who supported me by stimulating suggestions and encouraging throughout my dissertation with his patience and knowledge. Also, I wish to convey my sincere gratitude to Professor. J. P. Karunadasa, Former Head of the Department of Electrical Engineering, and the other members of the academic staff of the Department of Electrical Engineering, for valuable suggestions and comments given throughout my study. In the same time, I offer my gratitude to Professor R A Attalage, Department of Mechanical Engineering, Dr Muzathik, ITUM, and Eng Chandana Dalugoda who gave me guidance in the special event of my study.

In addition I would like to thank the staff of the Post Graduate Office of the Faculty of Engineering of University of Moratuwa for helping in various ways to clarify the things related to my academic work in time with excellent cooperation and guidance. My sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering office.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

I must extended my gratitude to Commander of the Army, Colonel Commandant Cops of Engineer Services, Brigadier J A M R Jayasundara Director Engineer Services, Colonel (Engineer Services) and all of my superior staff and my subordinate staff to the opportunities given me to complete my studies successfully. Specially, I must thankful to computer section of Directorate of Engineer services for the grate support given me in all the way, during my study.

I would like to offer my special thanks to my colleagues and friends for giving their fullest co-operation throughout the time of research and writing of this dissertation.

I express my thanks and appreciation to my family for their understanding, motivation and patience. Lastly, but in no sense the least, I am thankful to all.

Table of Contents

ABSTRACT.....	i
DECLARATION	ii
ACKNOWLEDGEMENT	iii
List of Figures.....	viii
List of Tables	x
Abbreviations	xiii
List if Appendices.....	xv
1 INTRODUCTION.....	1
1.1 Background	1
1.2 Energy Efficiency and Conservation	2
1.3 Bioclimatic architecture	6
1.4 Background	14
1.5 Preliminary statement	15
1.6 Problem identification.....	15
1.7 Long term problem identification	16
1.8 Objectives.....	16
2 LITRETUER REWIEV	18
2.1 Descriptions of main parameters - Lighting	18
2.1.1 Illumination.....	18
2.1.2 Luminous Flux	18
2.1.3 Luminous Intensity	19
2.1.4 Illuminance (Illumination)	19
2.1.5 Luminance.....	20
2.2 Dialux light building software	20
2.2.1 Daylight Integration	21
2.2.2 Daylight factors.....	21
2.2.3 Recommended illuminance level.....	22
2.3 Descriptions of main parameters - HVAC.....	23



2.3.1 HVAC System	23
2.4 Theoretical details	23
2.4.1 Relative Humidity (RH).....	23
2.4.2 Dry-bulb temperature (DBT)	24
2.4.3 Wet-bulb temperature	25
2.4.4 R-Value	25
2.4.5 U-factor	25
2.4.6 Sensible Heat	26
2.4.7 Latent Heat.....	26
2.4.8 Shading coefficient	26
2.4.9 The Psychrometric Chart	27
2.4.10 Properties on the Chart.....	29
2.5 CLTD method	33
2.6 Human comfort and productivity improvement.....	33
2.6.1 Thermal comfort.....	33
2.6.2 Comfort Conditions	34
2.6.3 The Comfort Chart.....	35
2.6.4 ASHRAE's Thermal Comfort Standard	36
3 METHODOLOGY	39
3.1 Methodology for case study.....	39
3.1.1 Collection of data	39
3.1.2 Calculation process	40
4 MODELING FOR POWER CONSUMPTION; CASE STUDY FOR PROPOSED ARMY HEADQUARTER OFFICE	43
4.1 Selection of the building model	43
4.1.1 Condition of the selected building model	44
4.1.2 Geographical setup of the location	44
4.1.3 Sun path over the location.....	45

4.2 Calculation methodology	45
4.3 The illumination system.....	45
4.3.1 Details of the selected luminaire.....	46
4.3.2 Consideration to the time duration for calculations	46
4.3.3 The enclosed model	47
4.3.4 The first stage calculation	47
4.4 Second stage calculation	50
4.4.1 Lumon Method.....	51
4.4.2 At site readings	51
4.4.3 Model comparison	52
4.5 Third Stage calculation	54
4.6 Fourth Stage Calculation.....	55
4.7 Fifth Stage Calculation	57
4.8 Sixth Stage Calculation.....	59
3.9 Seventh stage Calculation.....	61
4.10 HVAC System.....	63
4.10.1 Heat load calculation – CLTD, CLF Method.....	64
4.10.2 Second Stage Calculation.....	65
4.10.3 Third Stage Calculation.....	67
4.10.4 Fourth Stage Calculation.....	68
4.10.5 Fifth Stage Calculation.....	70
5 ANALYSIS	73
5.1 Total energy consumption.....	73
5.1.1 Total energy consumption for first stage calculation.....	73
5.1.2 Total energy consumption for second stage calculation	76
5.1.3 Total energy consumption for third stage calculation.....	79
5.1.4 Total energy consumption for fourth stage calculation	81
5.2 Evaluation	86

5.2.1 Power consumption for a month	86
5.2.3 Payback period.....	87
5.2.4 Comparison for the LPD for each building model.....	89
6 ANALYSIS FOR OTHER LOCATIONS	90
6.1 Power consumption for illumination	90
Chapter: 7	101
7 DISCUSSION	101
8 CONCLUSION	104
Reference List	106
Appendices.....	109



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Figures

Figure 1 5 An eco-house with a turf roof and solar panels	4
Figure 1 6 Trias Energetica concept	5
Figure 1 7 Approchers of Trias Energetica concept	6
Figure 2 1 Illustration for lighting properties	18
Figure 2 2 Illustration for luminous flux	19
Figure 2 3 Illustration for illuminance	20
Figure 2 4 Illustration for luminance	20
Figure 2 5 Illustration for DB Temp and WB Temp	24
Figure 2 6 The Psychrometric Chart	28
Figure 2 7 Dry Bulb temperature line	29
Figure 2 8 Wet Bulb temperature line	29
Figure 2 9 Relative humidity line	29
Figure 2 10 Dew Point temperature lines	30
Figure 2 11 Moisture content lines	30
Figure 2 12 Enthalpy lines	31
Figure 2 13 Specific volume lines	31
Figure 2 14 Comfort zones	32
Figure 2 15 Comfort zones in Psychrometric Chart	32
Figure 2 16 Comfort chart	35
Figure 2 17 Comfort range	36
Figure 4 1 Graphical representation of data in Table 4.1.....	73
Figure 4 2 Enlarge view of the summation (Energy (kJ) Total).....	74
Figure 4 3 Gradient of the graphs in Figure 4.1.....	75
Figure 4 4 Graphical representation of data in Table 4.5	78
Figure 4 5 Graphical representation for Energy-Avg Vs W/W Ratio.....	79
Figure 4 6 Graphical representation of Table 4.8	80
Figure 4 7 Graphical representation of Table 4.9	81
Figure 4 8 Graphical representation of Table 4.10	82

Figure 4 9 Graphical representation of Table 4.11	83
Figure 4 10 Graphical representation of Table 4.12	84
Figure 4 11 Graphical representation of Table 4.13	84
Figure 4 12 Graphical representation of Table 4.14	85
Figure 5 1 Graphical representation of data in Table 5.1.....	73
Figure 5 2 Enlarge view of the summation (Energy (kJ) Total)	74
Figure 5 3 Gradient of the graphs in Figure 5.1.....	75
Figure 5 4 Graphical representation of data in Table 5.5.....	78
Figure 5 5 Graphical representation for Energy-Avg Vs W/W Ratio.....	79
Figure 5 6 Graphical representation of Table 5.8	80
Figure 5 7 Graphical representation of Table 5.9	81
Figure 5 8 Graphical representation of Table 5.10	82
Figure 5 9 Graphical representation of Table 5.11	83
Figure 5 10 Graphical representation of Table 5.12	84
Figure 5 11 Graphical representation of Table 5.13	84
Figure 5 12 Graphical representation of Table 5.14	85



List of Tables

Table 1 1 Allocation for electricity for last five years	11
Table 1 2 Lighting Power Densities	13
Table 2 1 Recommended daylight levels	22
Table 2 2 Recommended lux level for office environment	22
Table 3 1 Power consumption for lighting (W/W ratio Vs time)	48
Table 3 2 Power consumption for lighting as per the W/W ratio.	50
Table 3 3 At site readings	52
Table 3 4 Simulated building model data at calculation point	52
Table 3 5 Power consumption Vs North alignment	54
Table 3 6 Energy consumption Vs North alignment	54
Table 3 7 Power consumption for lighting Vs W/W ratio as 21/06/2011	56
Table 3 8 Power consumption for lighting Vs W/W ratio as 21/12/2011	56
Table 3 9 Energy consumption Vs W/W ratio as to sun path.....	56
Table 3 10 Power consumption for lighting Vs North Alignment as to sun path.....	57
Table 3 11 Energy for lighting Vs North Alignment as to sun path	58
Table 3 12 Average of the values in Table 3.10	58
Table 3 13 Power consumption for lighting Vs W/W ratio on 21/06/2011	59
Table 3 14 Energy consumption for lighting Vs W/W ratio on 21/06/2011	59
Table 3 15 Power consumption for lighting Vs W/W ratio on 21/12/2011	60
Table 3 16 Energy consumption for lighting Vs W/W ratio on 21/12/2011	60
Table 3 17 Power consumption for lighting against W/W ratio on 21/06/2011	62
Table 3 18 Power consumption for lighting against W/W ratio on 21/12/2011	62
Table 3 19 Energy consumption for lighting on 21/06/2011 and 21/12/2011	62
Table 3 20 Power consumption for AC Vs W/W ratio	66
Table 3 21 Energy for HVAC system Vs W/W ratio	66
Table 3 22 Power Consumption for HVAC system as to North Alignment	67
Table 3 23 Energy Consumption for HVAC system Vs North Alignment	68

Table 3 24 Electricity Consumption Vs W/W ratio as 21/06/2011	69
Table 3 25 Electricity Consumption Vs W/W ratio as 21/12/2011	69
Table 3 26 Energy Consumption Vs W/W ratio as to sun path	69
Table 3 27 Power Consumption Vs North Alignment as to sun path.....	71
Table 3 28 Energy Vs North Alignment as to sun path	71
Table 3 29 Energy (Average) Vs North alignment as to sun path	72
Table 4 1 Energy (Lighting + A/C) Vs W/W ratio (calculation done 21/03/2011)	73
Table 4 2 Gradient of the each graph in Figure 4.1	74
Table 4 3 Comparison for low energy consuming areas	75
Table 4 4 Total energy consumption as 21/06/2011	76
Table 4 5 Total energy consumption as 21/12/2011	77
Table 4 6 Energy consumption against W/W Ratio as to Sun path.	77
Table 4 8 Average values of Energy consumption against W/W Ratio as to Sun path	78
Table 4 9 Energy (Lighting + HVAC) Vs North alignment as to sun path	79
Table 4 10 Energy (Summarized) Vs North alignment Sri Lanka	80
Table 4 11 Average values of data in Table 4.8	80
Table 4 12 Energy Vs W/W ratio for improved model	82
Table 4 13 Average values of data in Table 4.10	82
Table 4 14 Energy Vs W/W ratio (North Alignment 180°)	83
Table 4 15 Average value of data in Table 4.12	84
Table 4 16 Comparison of each calculated model, Energy Vs W/W ratio.	85
Table 4 17 Cost for electricity for a month.....	87
Table 4 18 Average values of the data in Table 5.14.....	98
Table 5 1 Power consumption for lighting against W/W ratio for building model at Jaffna	90
Table 5 3 Power consumption for lighting against W/W ratio for building model in Mannar	91
Table 5 4 Power consumption for lighting against W/W ratio for building model in Mullativu	91

Table 5 5 Power consumption for lighting against W/W ratio for building model in Trincomalee	92
Table 5 6 Power consumption for lighting against W/W ratio for building model in Anuradhapura	92
Table 5 7 Power consumption for lighting against W/W ratio for building model in Puttalam	93
Table 5 8 Power consumption for lighting against W/W ratio for building model in Kandy.....	93
Table 5 9 Power consumption for lighting against W/W ratio for building model in Rathnapura	94
Table 5 10 Power consumption for lighting against W/W ratio for building model in Badulla	94
Table 5 11 Power consumption for lighting against W/W ratio for building model in Galle	95
Table 5 12 Power consumption for lighting against W/W ratio for building model in Matara	96
Table 5 13 Power consumption for lighting against W/W ratio for building model in Hambantota	96
Table 5 14 Energy consumption vs North Alignment as to sun path	97
Table 5 15 Energy consumption Vs W/W ratio as to sun path	99
Table 5 16 Average values of the data in Table 5.16	99



Abbreviations

Abbreviation	Description
AC	Air Condition
AHQ	Army Head Quarters
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Avg	Average
BF	By Pass Factor
C	Celsius
COP	Coefficient of performance
DB	Dry Bulb
DES	Directorate of Engineer Service
DP	Dew Point
ENE	East-northeast
F	Fahrenheit
GMT	Greenwich Mean Time
HQ	Head quarters
Hrs	Hours
HVAC	Heating ventilation and Air Conditioning
J	Joule
K	Kelvin
Lat	Latitude
LED	Light Emitting Diode
LHG	Latent Heat Gain
MOD	Ministry of Defence.
N/A	North alignment
NNW	North-North-West
RH	Relative Humidity
s	Seconds



SC	Shading Coefficient
SHG	Sensible Heat Gain
SHGF	Solar Heat Gain Factor
SSE	South-southeast
TR	Ton (Cooling load)
W	Watt
WB	Wet bulb
WSW	West-South-West
W/W ratio	Wall to window ratio



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Appendices

Appendix A: Sample Calculations of Dialux Software	109
Appendix B: Cooling Load Temperature Difference for Calculating Load from Flat roof	110
Appendix C: Cooling Load Temperature Difference for Calculating Cooling Load from Sunlit Walls	110
Appendix D: Cooling Load Temperature Differences for conduction through Glass.....	110
Appendix E: Maximum Solar Heat Gain Factor, W/m ² for Sunlit Glass, North Latitudes	110
Appendix F: Cooling Load Factors for Glass without Interior Shading, North Latitudes	110
Appendix G: Cooling Load Factors for Glass with Interior Shading, North Latitudes	110
Appendix H: Shading Coefficients for Single Glass with Indoor Shading by Venetian Blinds or Roller Shades	110
Appendix I: Cooling Load Factors When Lights Area on for 8 Hours	110
Appendix J: Rates of Heat Gain from Occupant of Conditioned Spaces and Sensible Heat Cooling Load Factors for People	110
Appendix K: Overall Coefficient of Heat Transmission(U-Factor) of Windows, Shading Patio Doors and Skylights for User in Peak Load Determination and Mechanical Equipment Sizing only and not in Any Analysis of Annual Energy Usage, W/m ² °C	110
Appendix L: Glass Performance Data	110
Appendix M: Data for Cooling Load	110
Appendix N: Minimum Ventilation Rates in Breathing Zone	110