# ASSESSMENT AND MODELING OF LUMINOUS EFFICACY OF THE DAYLIGHT IN TROPICAL CLIMATE

MR. LITTHANOULOK LASPHO
ID: 52910419

A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING
IN ENERGY TECHNOLOGY AND MANAGEMENT

THE JOINT GRADUATE SCHOOL OF ENERGY AND ENVIRONMENT
AT KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI

2ND SEMESTER 2010

# ASSESSMENT AND MODELING OF LUMINOUS EFFICACY OF THE DAYLIGHT IN TROPICAL CLIMATE



MR. LITTHANOULOK LASPHO
ID: 52910419


A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING
IN ENERGY TECHNOLOGY AND MANAGEMENT

THE JOINT GRADUATE SCHOOL OF ENERGY AND ENVIRONMENT
AT KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI

2ND SEMESTER 2010

Assessment and Modeling of Luminous Efficacy of the Daylight in Tropical Climate

Mr. Litthanoulok Laspho
ID: 52910419

A Thesis Submitted as a Part of the Requirements
for the Degree of Master of Engineering
in Energy Technology and Management

The Joint Graduate School of Energy and Environment
at King Mongkut's University of Technology Thonburi

2nd Semester 2010

Thesis Committee

| | |
|---|---|
| ( Dr. Pipat Chaiwiwatworakul ) | Chairman |
| ( Prof. Dr. Surapong Chirarattananon ) | Member |
| ( Dr. Pattana Rakkwamsuk ) | Member |
| ( Prof. Dr. Somsak Chaiyapinunt ) | External Examiner |

**Thesis Title:** Assessment and Modeling of Luminous Efficacy of the Daylight in Tropical Climate

**Student's name, organization and telephone/fax numbers/email**

Mr. Litthanoulok Laspho
The Joint Graduate School of Energy and Environment (JGSEE)
King Mongkut's University of Technology Thonburi (KMUTT)
126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand
Telephone: 0-8533-56103
Email: litthanoulok@gmail.com

**Supervisor's name, organization and telephone/fax numbers/email**

Dr. Pipat Chaiwiwatworakul
The Joint Graduate School of Energy and Environment (JGSEE)
King Mongkut's University of Technology Thonburi (KMUTT)
126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand
Telephone: 0-8979-84204 or 02-8729014-5 ext 4128
Email: pipat@jgsee.kmutt.ac.th

**Topic:** Assessment and Modeling of Luminous Efficacy of the Daylight in Tropical Climate.

**Name of student**: Mr. Litthanoulok Laspho **Student ID:** 52910419

**Name of Supervisor**: Dr. Pipat Chaiwiwatworakul

## ABSTRACT



This thesis aims to study the characteristics of daylight efficacy in a tropical climate. With solar irradiance and daylight illuminance measurements at a station in Thailand, the statistical data of the hourly mean values and the standard deviations of the efficacy of global, diffuse horizontal and beam normal components were derived. This study explores the variations of daylight efficacy with climate conditions as well as the correlations with some insolation parameters of Perez's clearness ($\varepsilon$), brightness index ($\Delta$), and Solar zenith angle ($\phi_s$). The Mean Bias Difference (MBD) and Root Mean Square Difference (RMSD) are used for evaluation of prediction performances of the efficacy models proposed by various authors. The results of MBD and RMSD illustrated that no model is suitable for tropical climates. In this study, two models were proposed for global efficacy and diffuse efficacy. The models are capable of determining the efficacy for all sky conditions. As observed from a number of plots of variations of the efficacy with sky conditions, the models chose Perez's clearness ($\varepsilon$) for the model input. The less effective brightness index ($\Delta$) was excluded from the models. Solar zenith angle ($\phi_s$) in radian is also the input of the models. Therefore, this thesis proposes new efficacy models for tropical climates and the models are obtained by fitting the values of the relative luminous efficacy as a function of Perez's clearness ($\varepsilon$) and Solar zenith angle ($\phi_s$), which are expressed as follows:

Global efficacy: $K_{Geff} = (101.65 + 13.92\varepsilon^{-3.49})(\cos\phi_s)^{(-0.18+0.19\varepsilon^{-1.25})}$

Diffuse efficacy: $K_{Deff} = (107.14 + 12.59\varepsilon^{0.24}) + (30.35 - \frac{30.1}{\varepsilon^{1.5}})\phi_s$

Keywords: Global efficacy, diffuse efficacy, Mean Bias Difference (MBD), Root Mean Square Difference (RMSD), Clearness index and Brightness index.

# ACKNOWLEDGEMENTS

First of all, I would like to thank my advisor, Dr. Pipat Chaiwiwatworakul, for his support and suggestions on this study, and showing me how to approach a research problem and the need to be persistent to accomplish any goal. He gave insightful comments, explored and reviewed my work. Besides my advisors, I would like to thank the rest of my thesis committee in advice me for broadening my view and knowledge.

His sincere gratefulness to Prof. Dr. Surapong Chirarattananon, who supported wide knowledge and logical way throughout this work and this has been the great value for me. Furthermore, his understanding, encouraging and personal guidance have provided a good basis for the entire thesis study.

I also would like to express my deep and sincere gratitude to Dr. Pattana Rakkwamsuk, who has been very helpful for this study, his valuable advice and extensive discussions around my work and interesting explorations on this study.

I wish to express my warm and sincere thanks to Prof. Dr. Somsak Chaiyapinunt, who collaborated and gave very important guidance for overall steps into this study. His ideals and concepts have had a remarkable influence on my entire career in the field of solar study.

Special thanks to Thailand International Development Cooperation Agency (TICA) and in particular, to The Joint Graduated School of Energy and Environment (JGSEE) for the opportunity to study in Thailand.

Lastly, I also extend my sincere thanks to my family, friends and colleagues for encouraging me to pursue my interests. During this work I had the great relation with all my friends and colleagues, for whom I have great regard, and I wish to extend my warmest thanks to all those who have helped me with my work.

# CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# NOMENCLATURES

| SYMBOL | DESCRIPTION | UNIT |
|---|---|---|
| $a_i$, $b_i$ | Coefficients in the Perez model. | |
| $c_i$, $d_i$ | Coefficients in the Perez model. | |
| $c_1$ | First plank's constant ($3.7405 \times 10^{-16}$ W.m$^2$) | |
| $c_2$ | Second Plank's constant (0.0143879 m.K) | |
| $D$ | Cloud ratio (ratio of diffuse to global irradiance) | |
| $E$ | Horizontal global illuminance | lux |
| $E_b$ | Horizontal beam illuminance | lux |
| $E_d$ | Horizontal diffuse illuminance | lux |
| $E_\lambda$ | Solar spectral sensitivity of the eye | |
| $E_{eo}$ | Extraterrestrial irradiance | |
| $G$ | Horizontal global irradiance | W m$^{-2}$ |
| $G_b$ | Normal beam or direct irradiance | W m$^{-2}$ |
| $G_d$ | Diffuse horizontal irrariation | W m$^{-2}$ |
| $K_m$ | Maximum luminous efficacy | lmW$^{-1}$ |
| $K$ | Luminous efficacy | lmW$^{-1}$ |
| $K_g$ | Global Luminous efficacy | lmW$^{-1}$ |
| $K_d$ | Diffuse Luminous efficacy | lmW$^{-1}$ |
| $K_b$ | Beam Luminous efficacy | lmW$^{-1}$ |
| $k_t$ | Clearness index | |
| $m$ | Optical air mass | |
| $T$ | Temperature of the emitting surface | K |
| $V(\lambda)$ | C.I.E photopic spectral sensitivity of the eye. | |
| $W$ | Precipitable water | cm |
| $\varepsilon$ | Clearness index of Perez model | |
| $\square_s$ | Solar zenith angle | radian |
| $\Delta$ | Brightness index | |
| $\lambda$ | Wavelength | nm |
| $\alpha_s$ | Solar altitude angle | radian |

# ABBREVIATIONS

| | | |
|---|---|---|
| AIT | : | Asian Institute of Technology |
| CIE | : | Commission Internationale de l'Eclairage |
| DEDP | : | Department of Energy Development and Promotion |
| JGSEE | : | Joint Graduated School of Energy and Environment |
| KMUTT | : | King Mongkut's University of Technology Thonburi |
| MBD | : | Mean Bias Deviation |
| RMSD | : | Root Mean Square Deviation |
| TICA | : | Thailand International Development Cooperation Agency |