HYBRID FIRELY AND PARTICLE SWARM OPTIMISATION ALGORITHM FOR OPTIMAL DIMMING LEVEL AND ENERGY SAVING IN LECTURER'S ROOM

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To my beloved parents, family-in-law, siblings and husband: Thank you.

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ABSTRACT

The lighting system is one of the main systems in buildings and contributes to the usage of a considerable amount of energy. Therefore, the daylight harvesting system (DHS) is vital in lighting systems to control and minimise energy consumption from artificial lighting. The main factor for employee comfort in workplaces is the lighting system, where it can provide productivity and reduce stress when employees are working if they are getting enough lighting. There are many types of lighting systems and these systems have different performances in terms of energy efficiency, radiated heat, power consumption and lifetime. The optimisation of artificial lighting is required in order to achieve the optimal dimming level for minimising the energy consumption in buildings. To achieve the optimisation, a good, efficient and fast simulation algorithm is required. Thus, this research proposed a hybrid firefly and particle swarm optimisation (HFPSO) algorithm to solve the energy consumption and visual comfort problem by dimming-level minimisation. In order to identify the optimal dimming level, energy consumption, simulation time and luminaire performance, this research work presents the comparison between light-emitting diode (LED) and fluorescent luminaires using the HFPSO algorithm and using the particle swarm optimisation (PSO) algorithm and the firefly algorithm (FA). The comparison results showed that the superior performance of the HFPSO algorithm for the LED luminaire compared with that for existing luminaires, with significant energy savings of up to 64.2% and fully satisfying the average illuminance according to the Malaysian Standard MS-1525. The average simulation time for the LED luminaire was faster by up to 4.9% compared with the fluorescent luminaire. The average simulation time using the proposed HFPSO algorithm for the LED luminaire was faster by up to 7.6% than that for the fluorescent luminaire, compared with 4% and 3.6% faster using the PSO and FA methods, respectively. Therefore, the LED luminaire had the lowest dimming level and better performance in energy savings compared with those of the fluorescent luminaire by using the proposed method.

ABSTRAK

Sistem pencahayaan adalah salah satu sistem utama di bangunan dan menyumbang sejumlah besar tenaga. Oleh itu, sistem penuaian siang hari (PSH) sangat penting dalam sistem pencahayaan untuk mengawal dan meminimumkan penggunaan tenaga dari pencahayaan buatan. Faktor utama keselesaan pekerja di tempat kerja adalah sistem pencahayaan, di mana ia dapat memberikan produktiviti dan mengurangkan tekanan semasa melakukan kerja jika pekerja mendapat pencahayaan yang mencukupi. Terdapat banyak jenis sistem pencahayaan dan masing-masing mempunyai prestasi yang berbeza dari segi kecekapan tenaga, haba yang dipancarkan, penggunaan kuasa dan jangka hayat yang panjang. Pengoptimuman pencahayaan buatan diperlukan untuk mencapai tahap pemalapan optimum untuk meminimumkan penggunaan tenaga di bangunan. Pengoptimuman ini memerlukan algoritma simulasi yang menghasilkan keputusan yang baik, cekap dan pantas. Oleh itu, penyelidikan ini mencadangkan algoritma gabungan kunang-kunang dan pengoptimuman kumpulan zarah (HFPSO) untuk menyelesaikan masalah penggunaan tenaga dan keselesaan penglihatan dengan pengurangan tahap pemalapan. Untuk mengenal pasti tahap pemalapan, penggunaan tenaga yang optimum, masa simulasi dan prestasi lampu, kerja penyelidikan ini menunjukkan perbandingan antara diod pemancar cahaya (LED) dan lampu kalimantang menggunakan algoritma HFPSO dibandingkan dengan algoritma pengoptimuman kumpulan zarah (PSO) dan algoritma kunang-kunang (FA). Hasil perbandingan menunjukkan prestasi algoritma HFPSO yang unggul untuk lampu LED, dengan purata penjimatan tenaga yang ketara hingga 64.2% dan menepati nilai pencahayaan piawaian Malaysia (MS-1525) berbanding pencahayaan sedia ada. Purata masa simulasi untuk lampu LED adalah lebih cepat hingga 4.9% berbanding dengan lampu kalimantang. Purata masa simulasi oleh algoritma HFPSO yang dicadangkan untuk lampu LED adalah sehingga 7.6% lebih cepat daripada purata masa simulasi untuk lampu kalimantang, berbanding sebanyak 4% lebih cepat dengan PSO dan 3.6% lebih cepat dengan FA. Oleh itu, lampu LED mempunyai tahap pemalapan yang terendah dan prestasi yang lebih baik dalam penjimatan tenaga berbanding dengan lampu kalimantang dengan menggunakan kaedah yang dicadangkan.

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LIST OF SYMBOLS AND ABBREVIATIONS

C_1 and C_2	–	Value for Acceleration Constant
d_k	–	Dimming Level of *kth* Lamps
D_{min} and D_{max}	–	Minimum and Maximum Value of the Dimming Level
E_{ave}	–	Average Illuminance Level
EC	–	Energy Consumption
$EC_{existing}$	–	Energy Consumption for Existing Lamps
$EC_{proposed}$	–	Energy Consumption for Proposed Lamps
ES	–	Energy Saving
E_s	–	Standard of Average Illuminance Level
GBest	–	Best Global
$Iter_j$	–	Current Number of the Iteration
Max_{iter}	–	Maximum Number of the Iteration
N_k	–	Number of Luminaires
PBest	–	Best Position
PC	–	Power Consumption
P_k	–	Power Consumed for Each Luminaires
$Rand_1$ and $Rand_2$	–	Value of The Random Number
$V_{id}^{(t)}$	–	Current Value for Velocity on *ith* Each Particle at *dth* the Dimension
$V_{id}^{(t+1)}$	–	New Value for Velocity on *ith* Each Particle at *dth* the Dimension
W_{min} and W_{max}	–	Minimum and Maximum Number of Initial Weight
$X_{id}^{(t)}$	–	Current Position on *ith* Each Particle at *dth* the Dimension
$X_{id}^{(t+1)}$	–	New Position on *ith* Each Particle at *dth* the

		Dimension
ABC	–	Artificial Bee Colony
ACO	–	Ant Colony Optimization
AIS	–	Artificial Immune System
ANN	–	Artificial Neural Network
ANN-IMC	–	Artificial Neural Network based Internal Model Controller
BBB	–	Bundle Branch Block
BBMOPSO-A	–	Bare-Bones Based on Multi-Objective PSO Algorithm
CCT	–	Correlated Color Temperature
CEC	–	Congress on Evolutionary Computation
CEED	–	Combined Economic Emission Dispatch
CO	–	Convex Optimization
CRI	–	Color Rendering Index
DHS	–	Daylight Harvesting Systems
EP	–	Evolutionary Programming
EPSO	–	Evolutionary Particle Swarm Optimization
FA	–	Firefly Algorithm
FLC	–	Fuzzy Logic Controller
GA	–	Genetic Algorithm
HFPSO	–	Hybrid Firefly Particle Swarm Optimization
HVAC	–	Heating, Ventilation and Air Conditioning
IEA	–	International Energy Agency
IEP	–	Immune Evolutionary Programming
LED	–	Light-Emitting Diode
LMNN	–	Levenberg Marquardt Neural Network
LP	–	Linear Programming
MDs	–	Mobile Devices
MIMO	–	Multi-Input Multi-Output
NSGA II	–	Non-Dominated Sorting Genetic Algorithm II
OPE	–	Optimal Power Flow
PI	–	Proportional Integral

PSO	–	Particle Swarm Optimization
PWM	–	Pulse Width Modulation
RBFNN	–	Radial Basis Function Neural Networks
SI	–	International System of Units
US	–	United State
VLC	–	Visible Light Communication
WSN	–	Wireless Sensor Network

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The recent growth in building constructions in Malaysia has added more energy demand. The demand for electricity in Malaysia has increased by 10.4% in 2018, in line with the rapidly rising urbanisation and industrialisation [1]. Consequently, there is an increasing energy demand in buildings, especially for heating, ventilation, air conditioning (HVAC) and others. In 2018, the three major sectors that contributed to energy consumption were the industrial, commercial and residential sectors, which contributed to the energy usage of 50%, 30% and 20%, respectively, as presented in Figure 1.1 [2]. Consequently, this can cause the waste of energy and produce greenhouse gas emissions with serious impacts on the environment, such as global warming, climate change and the depletion of the ozone layer [3].

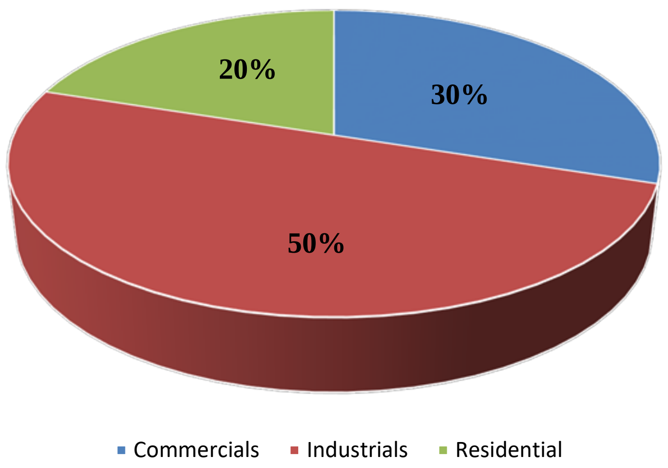

Figure 1.1: Major sectors of energy consumption of Malaysia in 2018 [2]

In European Union countries, the building sector contributes to 40% of the total energy consumption and 36% of carbon dioxide emissions [4], [5]. Buildings worldwide consume a substantial amount of energy, which is about a third of the total primary energy supply. Electric lighting is estimated to be between 20% to 40% of the total electricity consumption in buildings [6]. Therefore, this has caused concerns regarding adequate energy supplies and the fast depletion of energy resources with the rising demand for building services, improved lifestyle comforts, as well as people spending more time in buildings; as a consequence, rising energy demand has become apparent in the near future [7]. Moreover, lighting systems contributed about 25% to 35% of the energy consumption of buildings to provide enough lighting for the occupants [8], especially in workplaces, where adequate and appropriate lighting will result in more efficient productivity for the occupants.

The lighting system can be divided into two, which are artificial lighting and natural illumination. Examples of artificial light sources are lamps and light fixtures. According to the statistical data provided by the International Energy Agency (IEA), the percentage of the electrical usage of artificial lighting recorded about 19% of the global electricity consumption [9]. The energy used by artificial lighting constitutes a significant amount of overall energy consumption in buildings. Natural illumination is by capturing daylight through windows, skylights, light shelves and others. Natural illumination has been used to reduce the use of artificial lighting in buildings, and this process is called daylight harvesting [10].

One of the latest optimisation algorithms, called hybrid firefly particle swarm optimisation (HFPSO), is inspired by observation in nature [11]. The HFPSO is a combination of two algorithms, which are the firefly algorithm (FA) and the particle swarm optimisation (PSO) algorithm. Most researchers in previous studies considered minimising the dimming level of artificial lighting to decrease energy consumption. Based on a recent review [12] on optimising the power consumption of lighting systems, no researchers used the HFPSO algorithm and no comparison has been carried out in terms of the performance of the optimisation method and the Malaysian Standard (MS-1525). In order to reduce energy consumption, the dimming level of artificial lighting needs to be optimised. This research proposed an optimisation method to optimise the dimming level by using the HFPSO algorithm. The performance of the hybrid algorithm would be compared with those of the PSO and FA methods in order to find the optimal dimming level, simulation time, energy consumption and performance of the luminaires.

1.2 Problem statement

There are two main keys of the lighting system in buildings, which are energy savings and energy efficiency [13]. Reduced energy consumption in buildings results in lower electricity bills and, as a result, lower greenhouse gas emissions. Besides that, the technology of the luminaire in the lighting system plays a role in reducing energy consumption. In fact, proper lighting is needed to improve the performance of employees and the appearance of the interior area and has a positive psychological effect on the occupants in the building. Excessive use of lighting can cause an increase in electrical energy consumption. Daylight harvesting in buildings also plays a main role in reducing energy consumption from artificial lighting. For that reason, various types of luminaires and sky conditions need to consider in order to investigate the performance of lighting systems in terms of energy savings. In lighting systems, the minimised dimming level needs to be maintained in order to use less energy from artificial lighting and achieve better efficiency. Solving the problem of optimising the dimming level requires a good and fast algorithm that is able to give the best solution and strong stability. Therefore, an optimisation method called the hybrid firefly and particle swarm optimisation (HFPSO) algorithm was proposed in this research to optimise the dimming level and consequently reduce energy consumption. The performance of the proposed HFPSO algorithm was compared with those of other algorithms, which were the firefly algorithm (FA) and the particle swarm optimisation (PSO) algorithm, in order to investigate the performance of the proposed algorithm towards the optimal dimming level of the lighting system by considering daylight harvesting. A good and fast algorithm that is able to give the best solution and strong stability would solve the problem of optimising the dimming level.

1.3 Hypothesis

In this study, the designing of the models of illuminance level to obtain the illuminance matrix data depended on the types of luminaires and sky conditions. The daylight-adaptive behaviour varies according to the time of day. If a lot of light is received from the sunlight, then the artificial lighting system can reduce its electrical usage. Therefore, the HFPSO algorithm can optimise the dimming level efficiently.

1.4 Aim

This study aimed to optimise the dimming level, and hence the energy savings, of the lighting system in the lecturer's room at the QA Block of the Faculty of Electrical and Electronic Engineering (FKEE), Universiti Tun Hussein Onn Malaysia (UTHM), by proposing a novel approach of using the hybrid firefly and particle swarm optimisation (HFPSO) algorithm.

1.5 Objectives

The objectives of this research are as follows:

i. To design illuminance matrix model using different types of luminaires by considering different types of sky conditions.

ii. To develop a proposed hybrid algorithm for minimising the summation of the dimming level of artificial lighting by considering different types of sky conditions.

iii. To compare the performance of a proposed hybrid algorithm with those of other meta-heuristic methods and validate the proposed method in terms of the summation of the dimming level, average illuminance level, simulation time, energy consumption and luminaire performance.

1.6 Scope of study

The research is carried out within the scopes as follow:

i. The lighting system's design and simulation were implemented using DIALux software. The algorithms of PSO, FA and HFPSO were implemented in MATLAB software.

ii. The average illuminance level was considered as the parameter in this research and followed the lighting standard, which was the Malaysian Standard (MS-1525).

iii. The lecturer's room was considered as the case study. The lecturer's room is located at the QA Block, FKEE, UTHM. The dimensions of the lecturer's room are 5.6 m in length, 3 m in ceiling height and 4 m in width.

iv. Two different types of luminaires were considered in this research, which were LED and fluorescent lamps.

v. Performance evaluations were considered in terms of the summation of the dimming level, average illuminance level, simulation time, energy consumption and luminaire performance.

1.7 Research contribution

This dissertation presents the optimal dimming level performance based on daylight harvesting using the HFPSO algorithm to optimise the dimming level of artificial lighting. This thesis introduced an optimisation method to optimise the dimming level based on the daylighting illuminance in the lecturer's room. The optimisation method to optimise the dimming level of artificial lighting is the foundation of this thesis. In this study, the values of daylight and artificial light in the lecturer's room were captured to develop the optimisation method using the HFPSO algorithm.

The proposed HFPSO algorithm outperformed the PSO and FA methods in minimising the dimming level of artificial lighting. The result demonstrated that the HFPSO algorithm can optimise the dimming level of artificial light efficiently. The proposed method can give efficiency in energy use, the optimal dimming level of artificial light and faster simulation of the algorithm with various sky conditions, which were clear and average skies. Therefore, the comparative results showed that performance of the HFPSO algorithm for the LED luminaire compared with fluorescent luminaires are superior, with significant energy savings of up to 64.2% and fully satisfying the average illuminance according to the Malaysian Standard MS-1525.

1.8 Outline of thesis

This thesis is organised into five chapters as stated below.

Chapter 1 is about the introduction of research studies, problem statement, hypothesis, objectives, scope of study and research contribution.

Chapter 2 is about the literature review that reviewing on lighting system design such as daylight harvesting, lighting system characteristics, type of electrical light sources, the concept of the lighting control system, lighting energy performance and Malaysian Standard MS-1525. The next part reviewing on optimization method includes conventional, meta-heuristic and hybrid methods. Rather than that, it also reviewing about the overview of the HFPSO algorithm on the different applications and summary of previous researches.

Chapter 3 is about the methodology of this research work. This chapter discusses the methods used to execute the research. This methodology is very important in developing the project. It contains the whole process from the start until the project end.

Chapter 4 present the results and discussion for this research works. In this chapter, includes the result of the simulation, analysis, and discussion to solve optimal dimming level in the lighting system.

Chapter 5 present the conclusions and recommendation for future works to this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter provides the literature review of the theories and previous studies related to this research. Section 2.2 presents a review of lighting system designs by providing the concept of lighting design based on standards and requirements. In Section 2.3, the optimisation methods widely used in electrical and building engineering fields are explained and the different applications of the HFPSO algorithm are reviewed. Then, previous research studies related to the dimming level of lighting systems are presented in Section 2.4. Section 2.5 presents the research gap for this research. This chapter ends with the summary in Section 2.6.

2.2 Lighting system designs

In designing the model of a lighting system in a building, after the building design is completed, the designs of the wiring and electrical equipment will be carried out. The designs of the electrical wiring required are the electrical circuits and the installation of the lighting and HVAC systems. Lighting system designs have several criteria that need to be considered [14], such as daylight harvesting, the lighting system's characteristics, the types of electric light sources, the lighting control system, the lighting system's energy performance and the lighting standard.

2.2.1 Review of daylight harvesting

Daylight harvesting can be defined as reducing energy consumption by using daylight, in addition to artificial lighting, to illuminate an interior space [15]. The presence of daylight can reduce the lighting system's reliance on artificial lighting. This has been shown to help reduce the cooling load and the building's energy demand and to create a visually stimulating and productive environment for the building's occupants.Furthermore, the daylight harvesting system is a combination of direct and indirect sunlight during the daytime. It includes direct sunlight and diffused sky radiation. Daytime can be defined as the period of time each day when daylight is available.

The most effective energy-saving system is the automatic daylight harvesting system, which can monitor the lighting of natural light at any time. In an automatic daylight harvesting system, when the intensity of natural light is higher than the setpoint, the artificial light is reduced to the predetermined point for the system, and when the intensity of natural light is lower than the setpoint, the system will increase the intensity of the artificial light to maintain brightness. Figure 2.1 shows the concept of daylight harvesting and the lighting control of natural light and artificial light. For the space where natural light produces 80% light intensity, the electric light source only needs to produce 20% light intensity. However, for the space that does not use natural light, the electric light source will produce 100% light intensity.

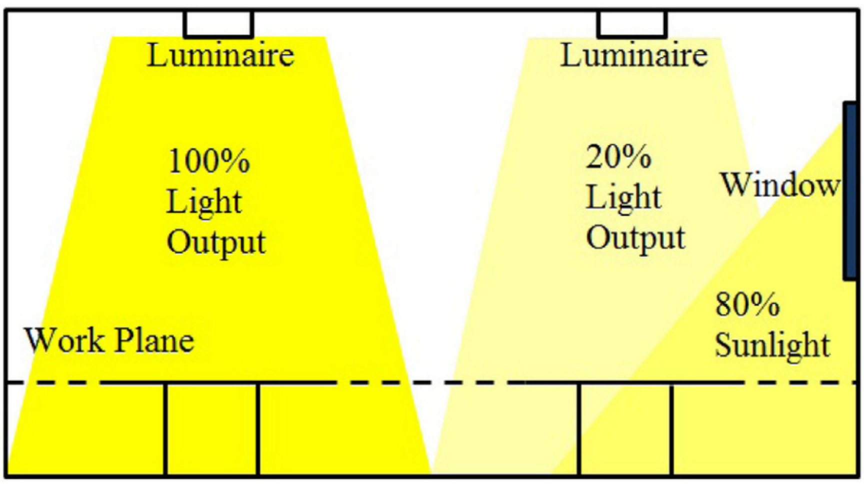

Figure 2.1: Concept of daylight harvesting [15]

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