ENERGY SAVING MONITORING USING FUZZY LOGIC FOR GREEN ICT: A CASE STUDY OF IIUM COMPUTING LAB

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Computer Science

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ABSTRACT

It is important to protect our pure natural world from ecological problems for the present and future generations. Green Information and Communication Technology (GICT) is an innovative approach of using ICT for environmental safety and sustainability of our future. GICT consists of practices and new software techniques to achieve educational, corporate and social responsibilities by reducing energy consumption, ICT wastages, and carbon footprints. The issue with energy monitoring in educational institution is to examine energy consumption in computing labs and develop a model for energy saving monitoring using Fuzzy Logic for GICT implementation in an Educational Institution. Additionally, the study analyzes the needs, requirements as well as Green ICT practices in computing labs at educational institutions. With rising figures of Higher Educational Institutions (HEI), Green ICT practices at institutions have ended up as key factors to attain cost-effective consequences and commercial social duties. The universities and colleges are getting more long-term approaches to ICT use in an efficient way. Green ICT has been a dynamic research area that contemplates the productive utilization of ICT equipment. The research was carried out following the experimental research methodology. This involved doing the energy audit to collect data from two computing labs. A model developed using Fuzzy Logic technique and implemented in a prototype coded in MATLAB software used the data sets collected to measure the energy consumption of the computers in the labs. The model was then evaluated energy monitoring in ICT computing lab. Survey and interviews were conducted for the collection of energy data. The findings show the energy monitoring model in terms of its applicability to monitor energy consumption.

ملخص البحث

من المهم حماية عالمنا الطبيعي النقي من المشاكل البيئية للأجيال الحالية والمستقبلية. تقنية المعلومات والاتصالات الخضراء (**GICT**) هي نهج مبتكر لاستخدام تكنولوجيا المعلومات والاتصالات من أجل السلامة البيئية واستدامة مستقبلنا. يتكون **GICT** من ممارسات وتقنيات برمجية جديدة لتحقيق المسؤوليات التعليمية والمؤسسية والاجتماعية من خلال تقليل استهلاك الطاقة، وإهدار تكنولوجيا المعلومات والاتصالات، والبصمات الكربونية. تكمن مشكلة مراقبة الطاقة في المؤسسة التعليمية في فحص استهلاك الطاقة في مختبرات الحوسبة وتطوير نموذج لمراقبة توفير الطاقة باستخدام المنطق الضبابي لتنفيذ **GICT** في مؤسسة تعليمية. بالإضافة إلى ذلك، تحلل الدراسة الاحتياجات والمتطلبات وكذلك ممارسات تكنولوجيا المعلومات والاتصالات الخضراء في مختبرات الحوسبة في المؤسسات التعليمية. مع ارتفاع أرقام مؤسسات التعليم العالي (**HEI**)، انتهى الأمر بممارسات تكنولوجيا المعلومات والاتصالات الخضراء في المؤسسات كعوامل رئيسية لتحقيق نتائج فعالة من حيث التكلفة والواجبات الاجتماعية التجارية. تحصل الجامعات والكليات على مناهج طويلة المدى لاستخدام تكنولوجيا المعلومات والاتصالات بطريقة فعالة. كانت تكنولوجيا المعلومات والاتصالات الخضراء مجال بحث ديناميكي يفكر في الاستخدام المثمر لمعدات تكنولوجيا المعلومات والاتصالات. تم إجراء البحث باتباع منهج البحث التجريبي. تضمن ذلك القيام بمراجعة الطاقة لجمع البيانات من مختبرين للحوسبة. نموذج تم تطويره باستخدام تقنية **Fuzzy Logic** وتم تنفيذه في نموذج أولي مشفر في برنامج **MATLAB**استخدم مجموعات البيانات التي تم جمعها لقياس استهلاك الطاقة لأجهزة الكمبيوتر في المختبرات. ثم تم تقييم النموذج لمراقبة الطاقة في مختبر حوسبة تكنولوجيا المعلومات والاتصالات. تم إجراء استبيان ومقابلات لجمع بيانات الطاقة. تظهر النتائج نموذج مراقبة الطاقة من حيث قابليته للتطبيق لمراقبة استهلاك الطاقة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Computer Science.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Computer Science.

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……
Abdul Wahab Abdul Rahman
Dean, Kulliyyah of Information
CommunicationTechnology

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Fareeha Tariq

Signature ..... Date .....

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LIST OF ABBREVIATIONS

ICT	Information and Communication Technology
IT	Information Technology
GICT	Green Information and Communication Technology
EPA	Environment Protection Agency
GDP	Gross Domestic Product
US	United States
DG INFSO	Directorate General of Information Society and Media
EU	European Union
WEC	World Energy Council
CO2	Carbon Dioxide
CDW	Collision Damage Waiver
UK	United Kingdom
HEIs	Higher Education Institutions
CRC	Carbon Reduction Commitment
ES	Essential Studies
ECAR	Eligibility and Certificate Approval Report
AHP	Annalistic Hierarchy Process
FTUI	Faculty at the University of Indonesia
MW	Mega-Watt
UI	University Indonesia
EUM	End-Use Meter
CSI	Campbell Scientific, Inc.
WWW	Worldwide web
ECOIS	Experienced choosy obedient intuitive self-contented
FLS	Fuzzy Logic System
CPU	Central processor unit
GPU	Graphic processor unit
UNIX	Uniplexed information and computer system
LCD	Liquid crystal display
EMU	Energy Management Unit
HVAC	Heating ventilation and air conditioning
CS	Computer Science
IIUM	International Islamic University Malaysia
KICT	Kulliyyah of Information and Communication Technology
KW	Kilowatt
SPSS	Statistical Package for the Social Sciences
KWH	Kilowatt-hour
FIS	Fuzzy inference system
MATLAB	Matrix laboratory

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

The important issue for societies, enterprises, and governments is to improve energy efficiency and reduce huge energy demand consumed by a large number of computers and servers, which could have an extensive impact on the climate as well as the environment. Information and Communication Technology (ICT) creates many environmental issues such as high consumption of electrical energy from a large number of computers and Information Technology (IT) equipment, placing a heavy load on electric grid stations and causing emissions of Greenhouse gas (Steven and Patrick, 2015).

In the nineties, Green Information and Communication Technology (GICT) or Green Computing gained recognition when Energy Star Program was launched by the US Environment Protection Agency (EPA) "Energy Star" is a label awarded to notebooks, desktop computers, and other electronic devices to promote energy-efficient hardware. The main purpose of this labeling program is to design, recognize and promote the efficiency of energy in computer monitors, equipment that controls the climate and other IT technologies (Energy Star Overview, www.energystar.gov). This innovative technology increases the acceptance of "sleep mode" among consumer's electronics. Hence, many countries have now adopted the "sleep mode" technology.

Green usually means energy-efficient, environmentally friendly and sustainable. Green computing is an environmental science application that provides economically promising solutions to save the natural environment and its resources.

According to several researchers, lower energy software and efficient IT hardware can facilitate GICT to make a divergence in climate change management and can help in reducing electricity bills, as well as reducing energy consumption waste in the education sector (Murugesan and San, 2013).

The innovation of Green technology is the key to sustainable development on multiple aspects, such as sustainability of eco-friendly environment, energy efficiency economics, IT disposal, recycling, and cost (Azmi Zain Ahmed, 2015).

The use of smartphones, mobile phones, tablets, and appliances also contributes to environmental pollution if it is not handled in the right way. This is a common phenomenon; however, people do not realize it could cause a very bad influence on the efforts to save the environment as well as huge consumption of energy by the equipment (Azmi Zain Ahmed, 2015).

Hence, the growing alertness about the influence of computing on environment has resulted in Green technology to be increasingly gaining importance in different sectors. The idea of Green ICT and good practices for sustainable development is now widely taken into serious attention by several agencies, governments, and other private companies.

1.2 GREEN INFORMATION AND COMMUNICATIONS TECHNOLOGY

The main pillar of today's world is ICT. It has a major impact on our private and professional lives, and also plays a vital role in the world of IT that drives economic growth. Global energy consumption growth slowed down in 2019 (+0.6%) compared to an average 2%/year over the 2000-2018 period, in a context of slower economic growth. Energy consumption increased at a slower pace than in previous years in China (+3.2%), the world's largest consumer since 2009, in Russia (+1.8%) and in India

(+0.8% only). But the concept of green ICT was introduced in Malaysia quite recently and it is still at a nascent stage in Malaysia.

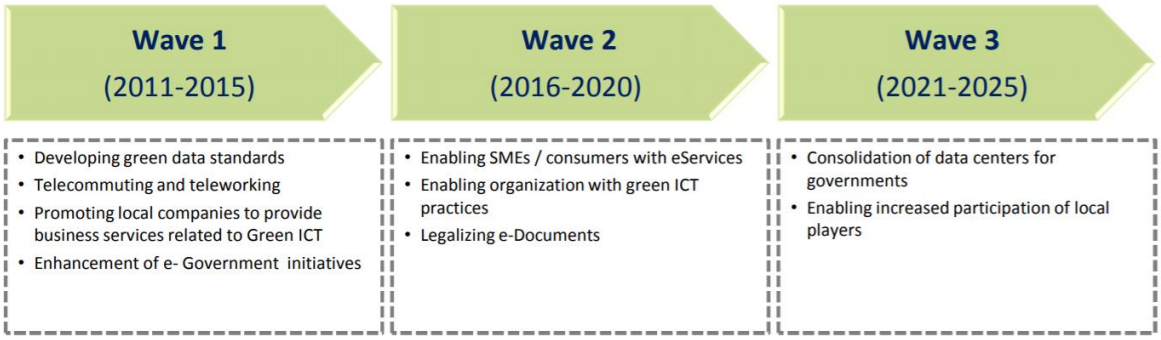

Figure 1 Green ICT – The Malaysia's Perspectives Implementation Approach

According to the International Energy Agency, ICT usage in 2012 has consumed 4.7% of electricity worldwide amounting to approximately 920 TWh (one equal to terawatt-hour or 1012 watt-hours). While overall energy consumption (around 19,000 TWh) is 15% of the total energy that is being produced around 150,000 TWh (International Energy Agency, 2012). In the United States (US), ICT's share of electricity consumption in 2008 was around 8% (European Commission DG INFSO, 2008).

Researchers have reported that the ICT sector is accountable for 2 percent of the Greenhouse gas emission into the atmosphere, with the prediction of 4 percent increment by the year 2020. In the year 2020, the figure for personal computers is also expected to increase from 1.2 billion to 4 billion. Hence, the ICT sector has a lot to do in helping to reduce further gas emission by 98% (Agarwal and Nath, 2013). In addition, ICT itself uses a huge amount of electricity. Some detailed analysis done by European Union (EU) in 2006 on the usage of energy and equipment efficiency also showed continuous rapid growth in recent years of energy consumption by computers

and end-user equipment. In 2008, CeBit forum present in Hanover, the world's biggest technology event has estimated that usage of the worldwide Internet through the important PCs and large servers need the equivalent of fourteen power grid stations, which produce the equivalent amount of carbon dioxide as the whole airline industry (Coroama and Hilty, 2010).

According to the Global Energy Statistical Yearbook 2019, global energy consumption has grown significantly in year 2018, due to economic and rising demand in China, since 2009, China is considered as the world's largest energy consumer. The highest ever growth of energy consumption in china were reordered in 2012, due to high power generation, high industrial demand and high consumption of transport fuel

Whereas, in 2018 total consumption of energy in U.S reached a high record of 2.3 Gtoe as compare to 3.5% from 2017.

In an addition, energy consumption has been decreased in the European Union (-1%) and in Germany as well (-3.5%) due to decreasing consumption in the sector of power and their improvements in energy efficiency (Enerdata, 2019).

In figure 1.1 country wise highest energy consumption has been shown in year 2018, in which China has consumed the highest energy consumption.

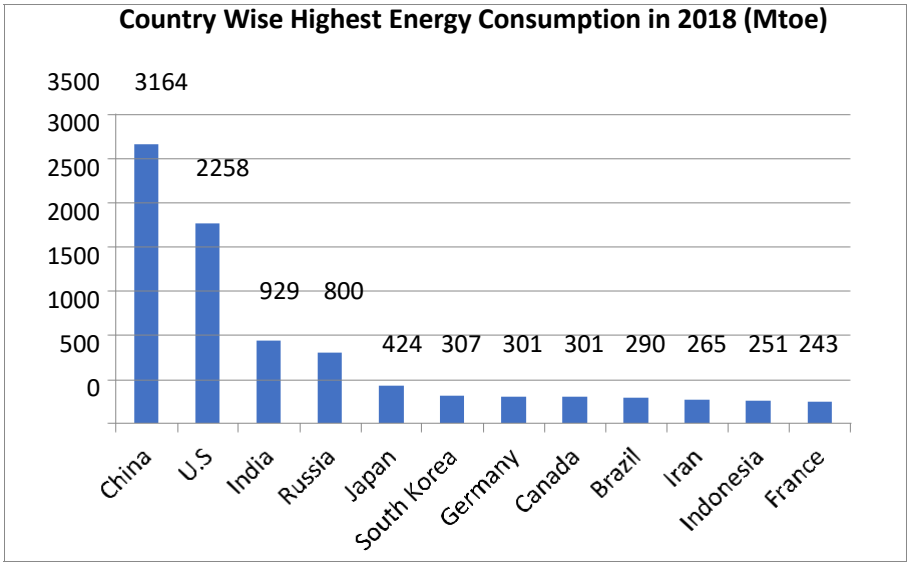

Figure 1.1 Country Wise Highest Energy Consumption (World Energy Consumption Statistics | Enerdata, 2019)

GICT is generally a good initiative to encourage individuals, groups, and organizations that are engaged in the use of ICT to face energy-related issues and find a good solution to them. (Green IT, 2010).

Green ICT is defined as:

> Green ICT is the study and practice of using computing (ICT) resources efficiently. The use of technologies and techniques to reduce the increasing rate of power consumption or carbon footprint of ICT function (Hankel, 2013).

Today, the computer is one of the most broadly used machines ever invented. Its wide usage requires extensive amounts of electrical energy whether to power the computer system unit and monitors, recharge large batteries, or to print. The rapid growth in the development of electronic information, electrical leads to the huge production of such products. The strong procurement power for such equipment is mainly due to a large number of announcements and advertisements in different media, as well as a decline in the prices of such products. This leads to the imprudent customer behavior of buying more products regardless of their actual needs. This action results in more consumption of energy in production, manufacturing and operation of ICT products, which in turn causes a number of significant problems related to environment and energy in different sectors (Osch and Avital, 2010).

The 21st century has so far seen considerable changes in the way we understand and use energy, especially when we compare the industrialization that has started in the countries that are today known as “urbanized” Today, the population growth of these countries accounts for 20 percent of the global population and is barely increasing; however, when compared to the developed countries, the growing rate of the residents is significantly higher (Brooks, Wangs and Sarker, 2010). People migrated to large urban areas, which results in the emergence of mega developed cities. The challenges faced by these countries to meet the global needs for energy, housing, mobility, as well as food are huge and none of thesechallenges can be obtained without energy (Osch and Avital, 2010). According to the World Energy Council (WEC), the consumption of energy is growing less rapidly than the economic activity in all world regions. This declining tendency for the energy intensity increase from 2004 is due to high oil prices, technological development and higher deployment of energy-efficient technologies in bulbs, motors and different appliances. More energy policies and efficiency measurements are required to realize available energy savings (Patrick, 2015).

1.3 GREEN ICT AT EDUCATIONAL INSTITUTIONS

The fastest growing emerging economy and ongoing technological advancement produce environmental issues due to the rapid increment of energy from the ICT systems. ICT has enhanced and improved the quality of education by giving a great variety of educational advanced resources, in which computer technologies are on top of the list. However, ICT power consumption devices, IT equipment, and Greenhouse emissions are now becoming serious issues among ICT professionals in education institutions (Suryawanshi and Narkhde, 2012). The local effects of ICT on the health of humans and the environment include; wastage of electronics, high health risk and

polluted air. The global effects of ICT on human health and the environment are global warming, changes in climate, rising of the ocean level, increase in temperature and ice cap to shrink (Mingay, 2007).

There is an increasing pressure on all educational institutions, such as schools, universities, colleges, to implement more sustainable eco-friendly approaches in the use of the environment from the hazard and ultimately the globe. In the education warming, which is mainly caused by carbon emission. Thus, it is very much required to save sector, the huge amount of ICT usage is the cause of C02 emission, high consumption of energy and harmful waste production. These problems have made educational institutions to adopt Green ICT so ICT. This pressure is expected as external stakeholders and governments become more aware of the environmental cost. Recently, a major challenge facing the environment is global that they minimize huge energy consumption, carbon dioxide as well as to reduce the cost of energy (Robert and Meurant, 2011). Thus, Green ICT implementation at educational institutions has become a key factor to gain less costly solutions due to the increasing number of educational institutions that are offering professional education (James and Hopkinson, 2009).

Therefore, this study focuses on how energy can be monitored and saved in educational institutions, and also identify Green ICT practices in order to improve and reduce energy consumption in educational institutions. A model for Green ICT Energy Saving Monitoring System is then proposed. Some of the Green ICT practices that must be implemented in computer Labs of education institutions include;

1. Reorganization management.
2. Removal of electronic waste.
3. Server resources Virtualization.

4. Efficient consumption of energy.
5. Personal computer replacement with energy-efficient thin clients.
6. Investment return.
7. Designing of energy-efficient chips and disk drives.

Green ICT is receiving more and more attention because of the high energy cost and growing environmental issues. This is basically because of the trend towards operating computer systems that are energy-efficient, and it can also reduce energy resource consumption and appropriate disposal of E-waste.

1.4 PROBLEM STATEMENT

The use of ICT in educational institutions causes carbon dioxide released, therefore, a higher amount of energy consumption and harmful E-waste production (Murugesan and San, 2012). Awareness of the environmental impact because of the usage of ICT has led the education sector to adopt Green ICT in their computer and research labs in order to minimize the huge energy consumption, ICT waste, carbon footprint, and also to promote reusability and recycling of IT products; and most importantly, to reduce cost of the energy.

Some of the main problems are highlighted here:

- **High Energy Consumption in ICT computing labs**

  Higher amount of energy consumption and harmful E-waste production in ICT labs.

- **Energy Wastage**
- Standby mode of computers and other electrical appliances is the main factor that contributes to the energy wastage mostly during the standby operation.
- **Energy Cost**

Energy cost is higher due to high consumption.

The primary goal behind Green ICT in the education sector is to reduce energy consumption, along with controlling the operating expenses and to manage the continuous increasing requirements for capacity and performance of resources (Paul, 2010).

It has been estimated that old computer system uses 60% of the power supply, and the other 40% is wasted (Erol Gelenbe, 2015), but green ICT technology has improved the efficiency of PC. Moreover, in the older technology, computer's components consume more energy because of no proper management to distribute power to all parts of the computer. Due to the high implementation cost, green ICT practices are not widely adopted and implemented in many industries. In 2012 according to the CDW (Collision Damage Waiver) surveyed different governmental agencies, from which it was observed that less than 40% had not such plans and strategies yet, 35% were implemented green IT and planning to implement green IT in next year's will be 26% and 39% have no plans yet on green IT in coming years (CDW Green IT survey, 2012).

Issues in GICT that needed for an effective energy monitoring mechanism:

1. Researchers have used high experimentation cost with complex algorithm for greening computer lab.
2. Previous researches identified energy related issues, however, the proactive justifications to forecast problems and failures are not present in the literature.
3. High implementation costs of Greening computer lab was also not discussed in past studies.
4. Most researchers investigated and presented Green ICT Energy Saving Monitoring Systems, where they mainly focused on Green ICT practices, Green

ICT adoption, and its techniques. Very few researches addressed the Green ICT energy monitoring issues in computer labs.

In light of the above, there is a need to monitor energy consumption in education institutes particularly in the computer labs to ensure healthy energy utilization. This study aims to investigate a way to monitor and measure computer energy consumption, and practices that can reduce energy consumption of computers in computer labs in educational institutions. A model-based prototype of energy saving monitoring using Fuzzy Logic for green ICT has been proposed to be implemented in computer labs with minimal cost.

1.5 SIGNIFICANCE OF THE RESEARCH

The research is significant to both practitioners and academicians for the following reasons:

An energy efficiency technique that helps offer feedback and measurement of energy consumption, patterns, trends with the aim of noting opportunity areas in order to reduce energy usage and costs. In most cases, the monitors are plugged directly into the breaker panel specifically on the areas of interest that need monitoring. If it is web based, the information is sent directly to a computer or smartphone. By monitoring energy, we can easily identify and explain excessive energy usage and detect instances when consumption is unexpectedly higher or lower than would usually have been the case, visualize energy consumption trends on daily, weekly, seasonal, operational basis. Determine future energy use and costs when planning changes in the business diagnose specific areas of wasted energy. Observe how changes to relevant driving factors impact energy efficiency