ENERGY EFFICIENCY AND THERMAL COMFORT: A CASE STUDY IN IRAQI GOVERNMENT HOSPITALS

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To my beloved family, thank you

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ABSTRACT

One of the largest energy consumers in the building sector are hospitals. In hospitals, many buildings tend to operate 24-hours daily throughout the year, among them are the wards, operation theatre and emergency department and hence require a balance between energy efficiency and thermal comfort among its occupants. The present work is a pioneering case study on energy efficiency and thermal comfort carried out at three hospitals in Iraq, designated as Hospital A, Hospital B, and Hospital C. The main objective of this study was to evaluate the present energy consumption, propose relevant active energy efficiency strategies and to evaluate thermal comfort among these Iraqi hospitals. The energy efficiency study includes walk-through and detailed energy audit while the thermal comfort study involves quantitative and qualitative measurements. From the energy audits, it was found that the average electricity consumed annually from 2016 to 2018 were 19,574,967 kWh, 12,100,426 kWh, and 4,317,093 kWh for Hospitals A, B, and C respectively with a corresponding building energy index (BEI) of 532, 484 and 260 kWh/m^2/year. The energy consumption by the air conditioning system was between 62% to 65% for these hospitals, followed by lighting system consuming 17% and plug-loads at about 20%. The ambient temperature and the hospitals'-built area were found to be major factors affecting energy use. The proposals for energy efficiency result in potential energy savings of 16%, 15% and 12% for HVAC system and 14% to 21% for lighting system and plug-load for these hospitals. As for the thermal comfort study, the predicted mean vote (PMV) and predicted percentage of dissatisfaction (PPD) were evaluated based on ASHRAE Standard at 60 locations in the hospitals. A good relationship between predicted mean vote (PMV) and thermal sensation vote (TSV) was observed, with correlation coefficient, R^2 of 0.69 from the linear regression analysis. It was also found that many slightly cooler than the acceptable thermal comfort range, indicating opportunities for energy efficiency in line with the proposed strategies.

ABSTRAK

Salah satu pengguna tenaga elektrik terbesar dalam sektor bangunan adalah hospital. Di dalam sebuah hospital, banyak bangunan beroperasi 24 jam sehari sepanjang tahun, di antaranya adalah wad, dewan bedah dan jabatan kecemasan maka penggunaan tenaga yang cekap di samping keselesaan terma di kalangan penghuninya adalah amat penting. Kajian ini adalah kajian rintis mengenai kecekapan tenaga dan keselesaan terma yang telah dijalankan di tiga buah hospital di Iraq, yang dinamakan sebagai Hospital A, Hospital B dan Hospital C. Objektif utama kajian ini adalah untuk menilai penggunaan tenaga semasa, mencadangkan yang strategi kecekapan tenaga aktif dan menilai keselesaan terma di kalangan penghuni di hospital-hospital tersebut. Kajian kecekapan tenaga yang merangkumi audit tenaga menyeluruh dan audit tenaga terperinci, manakala kajian keselesaan terma melibatkan pengukuran secara kuantitatif dan kualitatif. Daripada audit tenaga, didapati purata elektrik yang telah digunakan dari tahun 2016 hingga 2018 ialah 19,574,967 kWj, 12,100,426 kWj, dan 4,317,093 kWj bagi Hospital A, B, dan C masing-masing dengan indeks tenaga bangunan (BEI) adalah 532, 484 dan 260 kWj/m^2/tahun. Penggunaan tenaga oleh sistem penghawa dingin adalah yang tertinggi iaitu di antara 62% hingga 65%, diikuti oleh sistem pencahayaan yang menggunakan 17% dan beban palam sekitar 20%. Suhu persekitaran dan luas tapak bangunan hospital didapati menjadi faktor utama yang mempengaruhi penggunaan tenaga. Cadangan kecekapan tenaga menunjukkan potensi penjimatan tenaga sebanyak 16%, 15% dan 12% untuk sistem penghawa dingin dan 14% hingga 21% untuk sistem pencahayaan dan beban palam untuk hospital-hospital yang dikaji. Kajian keselesaan terma pula telah dinilai berdasarkan Piawaian ASHRAE di 60 lokasi di hospital kaedah undian ramalan min (PMV) dan ramalan peratusan ketidakpuasan hati (PPD) yang. Hubungan yang baik antara undian ramalan min (PMV) dan undian sensasi terma (TSV) telah diperolehi dengan pekali korelasi, R^2 sebanyak 0.69 daripada analisis regresi linear. Kajian juga mendapati sebahagian besar kawasan hospital berada dalam zon agak sejuk berbanding julat keselesaan haba yang boleh diterima. Ini menunjukkan potensi untuk kecekapan tenaga, selaras dengan strategi yang dicadangkan melalui audit tenaga.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ECMs	–	Energy Conservation Measures
IEQ	–	Indoor Environmental Quality
EMOs	–	Energy Management Opportunities
PMV	–	Predicted Mean Vote
PPD	–	Predicted Percentage of Dissatisfied
ESL	–	Energy Savings Lamps
SEU	–	Significant Energy User
TSV	–	Thermal Sensation Vote
EMM	–	Energy management matrix
EMA	–	Energy Management Assessment
EEI	–	Energy Efficiency Index
IERs	–	Information Exchange Requirements
IED	–	Information Exchange Description
IDM	–	Information Delivery Manual
HSE	–	Health and Safety Executive
PET	–	Physiological effective Temperature
SET	–	Standard effective temperature
AMV	–	Actual Mean Vote
HVAC	–	Heating, Ventilation, and Air-conditioning
TPES	–	Total Primary Energy Supply
GDP	–	Domestic Product
LED	–	Light-Emitting Diode
IQD	–	Iraqi dinar

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Energy is used in the buildings to provide users with a sequence of services, and inclusive environmental control for the occupancy conditions(Borgstein, Lamberts, & Hensen, 2018). Light, heat, and mobility are all dependent on energy. Moreover, power is required to sustain infrastructure and industries in developing economies. The way energy is provided is rapidly evolving, and thus the upcoming energy mix will be progressively low in carbon. Nevertheless, energy consumption proceeds to rise, mostly due to growing wages in emerging nations and a predicted world population of nine billion by 2040 as shown in Figure 1.1 An increase in energy efficiency is somewhat easing the magnitude of the energy consumption growth since there is a greater focus on utilising energy more efficiently globally.

Oil and gas now contribute to about 60% of total energy use. Oil and gas might contribute roughly 40% of all energy consumed by 2040 (British Petroleum, 2017), albeit in a situation congruent with the Paris Agreement in 2015 with aim of restricting global warming to less than 2°C. Therefore, steps should be taken to limit emissions associated with their production and utilization. Gas provides a considerably cleaner option than coal for power generation in a low-carbon environment, and a crucial backup for renewables, for instance, whenever the wind and sun are not present. Gas also serves as a source of heat for industry and households, as well as a source of fuel for ships and trucks.

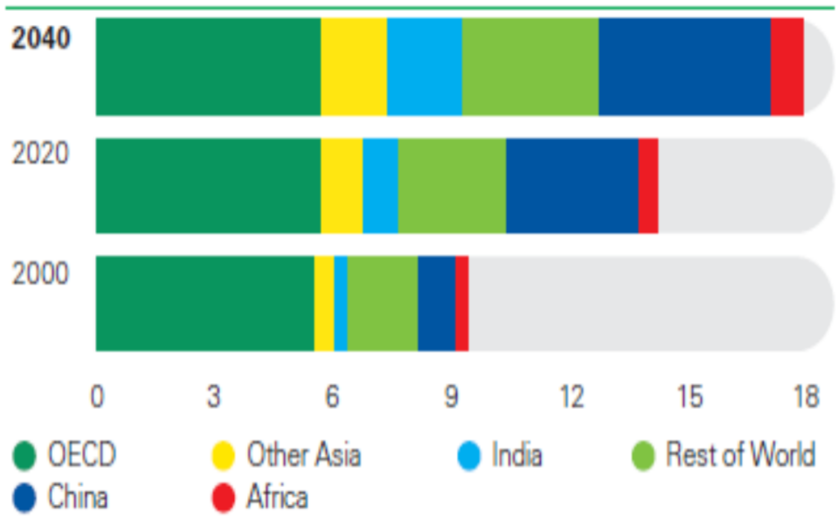

Figure 1.1: Energy consumption by region (billion tonnes of oil equivalent)(British Petroleum, 2017)

With increased worries about climate change, world energy is shifting towards lower carbon sources with technological advancements as well as geopolitical developments as shown in Figure 1.2. As a result, governments are establishing carbon trading schemes, taxes, and other measures to restrict greenhouse gas (GHG) emissions as part of emerging greenhouse gas policy and regulation. Carbon pricing systems currently encompass a fifth of global GHG emissions, more than double the coverage of just five years ago.

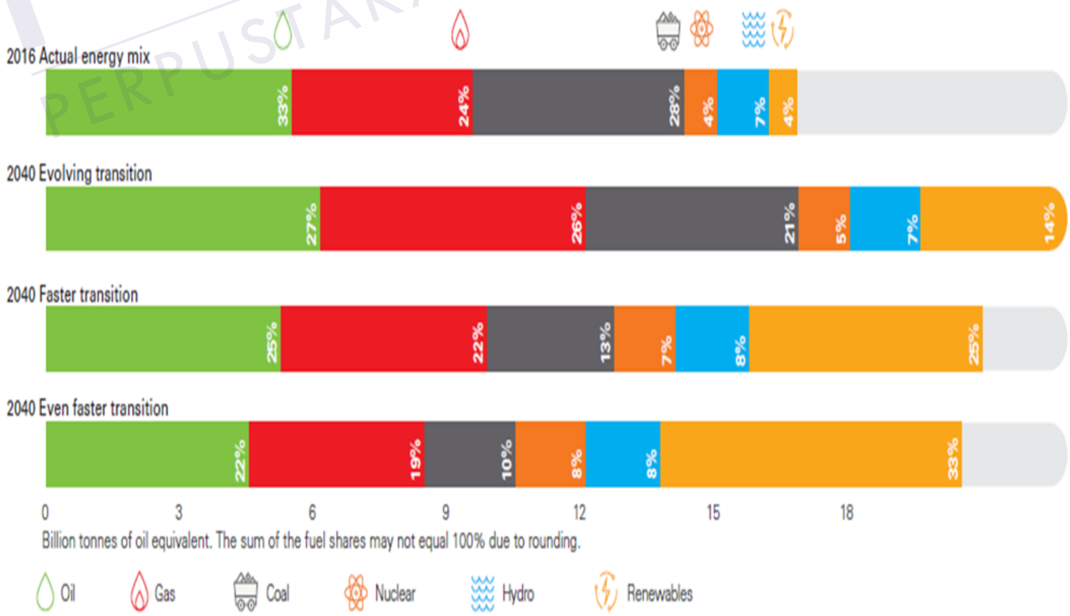

Figure 1.2: Energy consumptions – 2040 projection (British Petroleum, 2017)

The far more rapid transformation of this scenario suits carbon emissions close to the sustainable development scenario of the International Energy Agency, which attempts to reduce worldwide temperature rise to less than 2°C. Optimizing building energy performance is a critical component of attaining greater sustainable energy management. Buildings absorb 40% of the energy utilized in the US, as well as a comparable amount, is depicted in Europe.

As a result, stakeholders, including the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the European Performance of Buildings Directive (EPBD), have imposed impressive goals for the upcoming 15 years. ASHRAE, for instance, is working to create a target of producing market-viable Net Zero Energy Buildings (NZEBs) by 2030. Likewise, the EPBD expects new buildings to exceed the NZEB standard by 2020.

To accomplish the tasks, a thorough knowledge of building physics is required, as upgrading a design gets increasingly challenging as buildings become increasingly energy-efficient. Buildings are complex systems, with mass and heat movement via the envelope, internal gains, HVAC system efficiency, solar radiation, ventilation strategy, occupant decision-making, window characteristics, and so forth, all contributing to their energy performance. Thus, determining the best efficient techniques to cut energy consumption in buildings is not easy.

Healthcare is delivered in complex and energy-intensive environments, from medical office buildings to critical care hospitals. Given the significant hospitals' energy intensity levels as well as other inpatient care facilities, they constitute a significant portion of the energy consumption in the utility buildings sector, generally. High energy consumption is primarily attributable to constant usage patterns and operations in hospitals, which need significantly fluctuating energy demands based on the specialized services supplied. To provide precise management of the hospital's indoor environment, sophisticated air conditioning, ventilation, and heating systems are also required. Simultaneously, operations, intensive care units, white rooms, and outpatient clinics necessitate significant infiltrations and air changes to meet tight indoor air quality standards. Because hospitals have special clinical requirements that should be adhered to ensure that health services may be appropriately provided. Hence, hospitals are among the most complicated buildings (Abd Rahman et al., 2022).

As a result, continual demands for heating and cooling energy, including electricity (for electrical equipment and artificial lighting), result in significant energy consumption, which is considerably greater in contrast to other forms of buildings.

Power stations in Iraq are mainly reliant on either diesel or natural gas to generate electrical energy. In Iraq, buildings are the primary consumers of energy for cooling and heating. Around 50–60% of energy is used by air conditioners. Despite an increase in electricity production, there is not enough electricity to meet the growing demand. The Ministry of Electricity reports that only 9,000 of the 13,000–15,000 megawatts needed to supply Iraq's demands were produced in 2016 in Iraq. The energy consumption in Iraq was divided into many sectors such as agricultural (4%), commercial (6%), government (13%), industry (29%), and domestic (48%) of the total energy consumption (Mohamed et al., 2015).

Buildings in Iraq are neither designed with energy efficiency in mind nor are they administered to minimise energy consumption, resulting in the energy performance being poorer than that of the counterparts in nations with comparable climates. Building energy management is regarded as a low-cost source of energy. Energy conservation and energy efficiency in the construction industry align with an Iraqi target of signing a Memorandum of Understanding on Strategic Partnership in Energy between the Iraqi government and the European Union in 2010.

1.2 Problem statement

Due to the absence of comprehensive energy policies on the demand-side energy management in Iraq, energy efficiency and energy conservation are still alien to most of Iraqi people. Although building energy consumption was estimated to be around 40% of the total energy consumption in Iraq especially in government buildings like hospitals, little has been in terms of research and implementation.

Hospitals consist of many buildings with various roles, such as the emergency department, patient examination and consultation building, wards, operation theatre area, administrative office, and cafeteria. Each of these structures has distinct operational characteristics affecting total energy consumption. The 24 hours of operation result in high energy intensity in hospital buildings and it has been a challenge for the hospital operators to meet the arising energy efficiency requirements while sustaining the thermal comfort requirements. Therefore, a comprehensive energy analysis is essential to assist hospital administration in overcoming these challenges particularly in Iraq. On this basis, the present study has been carried out.

1.3 Objectives

The objectives of this study are:

i. To determine the present energy consumption profile and establish their corresponding load apportioning for three (3) Iraqi hospitals with different capacities.

ii. To establish a correlation between energy consumption in the hospitals with major factors affecting energy use.

iii. To provide relevant energy conservation and energy efficiency measures based on active strategies in the hospitals.

iv. To evaluate the thermal comfort in the hospitals based on ASHRAE Standard.

1.4 Scopes of Study

Energy efficiency in buildings can be implemented either via passive or active strategies. The building energy performance can be improved by Heating, ventilation, and air conditioning (HV AC) systems, electrical equipment, lighting, etc. can be categorized under active processes, whilst an enhancement to the envelope of the building such as walls, windows, roof, etc may be classified as passive strategies. The present study focuses on active design strategies. Hence the following are the scopes of the study:

1- The study was carried out in three selected hospitals with different capacities in Iraq, namely Imam Hussein Educational Hospital (400 beds), Bint Alhuda Educational Hospital (200 beds), and Nasiriyah Heart Center (100 beds). These hospitals were designated as Hospital A, Hospital B and Hospital C.

2- Two types of energy audit to be carried out: walk-through audit and detailed energy audit based on plug-in equipment, lighting systems, and HVAC systems.

3- Thermal comfort evaluation via indoor air properties measurement followed by a survey.

4- The electrical energy characteristics were based on annual energy consumption in 2019.
5- Determination of building energy index (BEI) for the hospitals and benchmarking with values from the literature.
6- Economic analysis of the proposed energy efficiency measures based on simple payback period (SPP).

1.5 Thesis layout

This thesis is orderly into five chapters as detailed below:
Chapter 1: Presents an introduction to the research and discusses the research background, problem statement, objectives, and scope of the study.
Chapter 2: Entails a review of the energy consumption in the hospital and buildings and examines the literature on critical aspects of the project; energy efficiency, energy audit, and thermal comfort. Implications are discussed, and research gaps are highlighted.
Chapter 3: Describe the methodologies utilized and discuss the main strategies used to achieve the research objectives in this research, as well as the quantitative and qualitative study, and survey methods utilized to gather data.
Chapter 4: Presents the research results and discussion of the proposed method to reduce energy consumption in hospitals without affecting thermal comfort.
Chapter 5: Presents the conclusion of the main findings of this study and recommendations for future work are mainly focused on the study's limitations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Fossil fuel consumption has resulted in worrying increases in greenhouse gas emissions, which is causing global warming. Over the last few centuries, the global average temperature has increased by 0.8°C, which is anticipated to increase by 1.1°C to 6.4°C over the next hundred years. This corresponds to huge, possibly alarming fluctuations in weather patterns as well as climate, which can result in extreme weather. The biggest concern is the rate of increase in emissions which is between 1971 and 2004, carbon dioxide (CO_2) emissions, such as those from the energy utilization in buildings, increased at 2.5% rate per year for commercial buildings whereas 1.7% per year for residential structures (Ramachanderan et al., 2017).

At the United Nations Conference on the Human Environment in Stockholm in 1972, an energy policy to minimise emissions was first addressed. In 1992, a conference commemorating the twentieth anniversary of the Stockholm meeting was held in Rio de Janeiro, Brazil, under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC). Furthermore, the UNFCCC's principal goal is to keep greenhouse gases (GHG) concentrations in the atmosphere at a safe level (Kusumadewi and Limmeechokchai, 2017). At the third Conference of the Parties (COP3) in Kyoto, Japan in the year 1997, the Kyoto Protocol, which was drafted under the UNFCCC, was adopted (Ki-moon, 2008). This protocol lays out the specific procedures that must be taken and that can be done by different nations that ratify it in order to fulfill the United Nations (UN) climate change policy objectives.

Since 2000, global energy savings have decreased a little over 4 billion tonnes of CO_2 equivalent ($GtCO_2$-eq) in GHG emissions as shown in Figure 2.1. Emissions in 2016 would have been 12.5% higher if these efficiency improvements had not been made. Furthermore, 45% of the emissions reductions came from IEA member nations, while 47% came from big emerging economies. Fuel combustion is avoided due to efficiency gains, which minimizes local air pollutants, and improves public health and air quality (Agency, 2017).

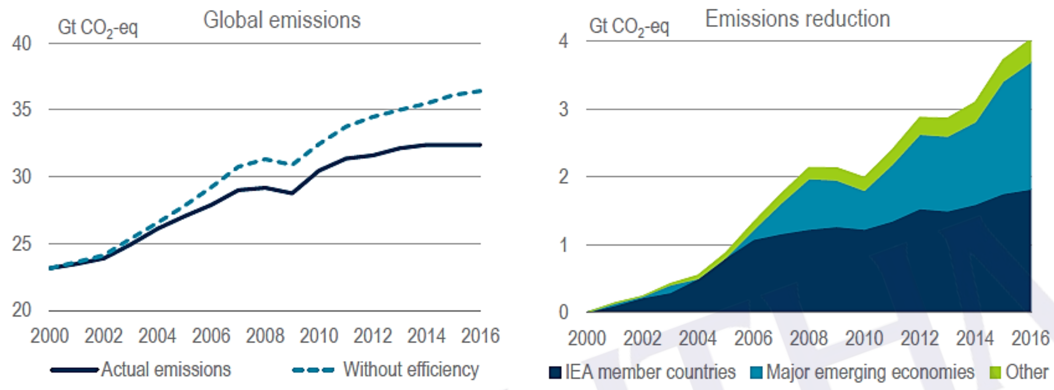

Figure 2.1: Avoided global GHG emissions from energy efficiency improvements (Agency, 2017)

Energy usage has drawbacks, such as contribution to city pollution as well as depletion of available energy resources, both of which contribute to disastrous climatic changes. Creating alternative energy resources, and methods for effective energy utilisation, is a time-consuming process that requires a strong emphasis on establishing alternative energy resources.

Climate change may be a worldwide concern brought on by human activity such as fossil fuel employment as well as land-use change, both releasing GHGs, mainly CO_2. GHG emissions are produced by fossil fuel combustion, which can range from cooking to electricity generation. The GHGs concentrations will also rise in tandem with the growth in population (Kusumadewi and Limmeechokchai, 2017). In addition, significant amounts of fossil fuel energy are used in the health sector in both industrialised and many developing countries, even though accurate numbers for many of the countries are lacking(Prada et al., 2020).

In order to scale back the utilization of fossil fuels, the ECU Commission has adopted two directives, particularly the Directive on Energy Efficiency (EED) and the Directive on the Energy Performance of Buildings (EPBD).

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