

**DATA-DRIVEN BENCHMARKING FOR LPG
CONSUMPTION IN RESIDENTIAL CONDOMINIUMS:
A GUIDE TO SUSTAINABLE ENERGY MANAGEMENT**

W. H. S. C. Silva

228466R

Degree of Master of Science in Building Services Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

June 2024

**DATA-DRIVEN BENCHMARKING FOR LPG
CONSUMPTION IN RESIDENTIAL CONDOMINIUMS:
A GUIDE TO SUSTAINABLE ENERGY MANAGEMENT**

Wellane Hewawasam Sajeewa Chandana Silva

228466R

Thesis submitted in fulfillment of the requirements for the degree of
Master of Science in Building Services Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

June 2024

DECLARATION OF THE CANDIDATE AND THE SUPERVISOR

I declare that this is my work and this thesis/dissertation does not incorporate without acknowledgment 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 acknowledgment is made in the text.

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

Signature:

Date: 22.06.2024

W.H.S.C. Silva

The above candidate has carried out research for the Master/MPhil/Ph.D. thesis/dissertation under my supervision.

Signature of the supervisor:

Date: 28.09.2024

Prof S. Witharana

ABSTRACT

Residential condominiums have become popular in Sri Lanka as a modern and handy housing option. Additionally, employing LPG as an energy source has become a viable option for energy-efficient and sustainable residential buildings. The optimization of resource usage has emerged as a critical frontier, particularly in the complex ecosystem of residential condominium structures. The goal was to establish a sustainable energy management paradigm that addressed the unique issues of residential condominiums, ushering in a new era of efficiency, environmental responsibility, and resilient community living. This included an assessment of current literature, regulations, and rules governing LPG use in Sri Lankan residential condominium complexes and other similar situations. The technical aspects of LPG use in residential condominium buildings were researched, including LPG use intensity, utilization rate, per capita energy consumption from LPG use, and carbon content of the LPG combustion process. This study's significance extends beyond academic exploration, connecting with the practical concerns of industry practitioners, building designers, facility managers, and other stakeholders involved in the condominium sector. As a result, the purpose of this thesis was to develop a benchmark for household LPG consumption in a Sri Lankan condominium complex by looking at technical, economic, and environmental factors.

Keywords: Sri Lanka, Residential condominium, Liquefied Petroleum Gas (LPG), Sustainable energy, Benchmark.

ACKNOWLEDGMENT

I want to express my warmest thanks to my supervisor Prof. S. Witharana made this work possible. His guidance and advice carried me through all the stages of writing my project. It also encouraged me to maintain my progress on track by directing me to a logical way of thinking to complete this project successfully. I would also like to thank my examining committee members for letting my defense be an enjoyable moment, and for your brilliant comments and suggestions, thanks to you.

Many thanks to Prof. J.G.A. Saliya Jayasekara for his advice at the very beginning, which was the turning point in my thesis. Also, many thanks to Dr. (Mrs.) M.M.I.D. Manthilake for her positive thoughts during the examination process.

I would also like to thank the general manager, Eng. K.P.R.H. Silva of the Condominium Management Authority assisted me in gathering data from condominium buildings in Sri Lanka; without his assistance, it would have been impossible; thank you.

Finally, I would like to acknowledge with much appreciation my family as a whole for their continuous support and understanding when undertaking my research and writing my project. Your prayer for me was what sustained me this far.

TABLE OF CONTENTS

DECLARATION OF THE CANDIDATE AND THE SUPERVISOR	i
ABSTRACT	ii
ACKNOWLEDGMENT	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vii
LIST OF TABLES	viii
LIST OF NOMENCLATURE	ix
CHAPTER 1	1
1. INTRODUCTION	1
1.1 Aim	2
1.2 Objectives	2
1.3 Methodology	2
CHAPTER 2	4
2. LITERATURE REVIEW	4
2.1 Liquefied Petroleum Gas	4
2.1.1 Conventional System of LPG Supply	5
2.1.2 Exhaust ingredient from LPG combustion	6
2.1.2.1 Understanding the Gas Explosions	6
2.1.3 Trend of LPG Consumption in Residential Buildings	7
2.2 LPG, Broadcast to the Condominium Buildings	8
2.2.1 LPG Supply Network in Condominium Buildings	9
2.2.1.1 Gas Meter	10
2.2.2 Advantages of LPG Piped Gas System	11
2.3 Legislation, Codes, and Safety Standards Related to LPG	12
2.3.1 Sri Lanka Standard Institute	13
2.3.2 Construction Industry Development Authority	13
2.3.3 Sri Lanka Sustainable Energy Authority	13
2.3.4 Public Utilities Commission of Sri Lanka	14
2.3.5 Municipal Councils and Local Authorities	14
2.3.6 Fire Service Department	14
2.4 Design Criteria for LPG Supply System in a Multi-Unit Building	14
2.4.1 Safety	15
2.4.2 Capacity and Demand	15
2.4.3 Pipe Sizing	15
2.4.4 Location and Installation	16
2.4.5 Storage Requirements	16
2.4.6 Pressure Regulation	16
2.4.7 Emergency Shut-Off Systems	16

2.4.8	Compliance with Standards	16
2.4.9	Documentation and Record-Keeping	17
2.5	Factors Affecting the Domestic LPG Consumption	17
2.5.1	Household Size	17
2.5.2	Cooking Habits.....	17
2.5.3	Efficiency of Appliances	17
2.5.4	Seasonal Variations.....	18
2.5.5	Income Levels	18
2.5.6	Cultural Practices	18
2.5.7	Urban vs. Rural Settings	18
2.5.8	Government Subsidies and Policies	19
2.5.9	Energy Efficiency Awareness.....	19
2.5.10	Availability and Accessibility	19
2.6	Benchmarking the Domestic LPG Consumption.....	19
2.6.1	A Benchmark.....	20
2.6.2	Requirement of a Benchmark for Domestic LPG Consumption	20
2.6.3	Advantages of Benchmarking the LPG Consumption.....	20
2.6.4	KPIs of Benchmarking the Domestic LPG Consumption	21
2.7	Benchmarking Techniques	21
2.7.1	Points-based Rating System Technique	21
2.7.2	Simulation Model-based Benchmarking Technique	22
2.7.3	Statistical Analysis Benchmarking Technique	22
2.7.4	Hierarchical and End-use Metrics Technique.....	23
2.7.5	Advisable Technique for Benchmarking Domestic LPG Consumption	23
2.8	Energy Management and Sustainable Approach in LPG Usage.....	23
2.8.1	Sustainable Energy Management by Benchmarking the Domestic LPG Consumption.....	24
2.9	Research Gaps	24
CHAPTER 3		26
3	METHODOLOGY	26
3.1	Data Collection	27
3.1.1	Scrutinizing the Dataset.....	28
3.2	Data Analysis	32
3.3	Modeling a Benchmark.....	35
3.3.1	Benchmark for LPG Consumption	37
3.3.2	Validation of the Benchmark	38
3.4	Outcomes.....	38
CHAPTER 4		39
4	RESULTS.....	39
4.1	Determination of “Best-In-Class” Performance in KPIs	39

4.2	Compatibility to the Determination of Benchmarks	42
4.3	Benchmark for Domestic LPG Consumption	51
4.4	Per Capita LPG and LPG Energy Consumption	55
4.5	Carbon Content of LPG Combustion Process	55
4.6	Gas Cylinder Change Frequency Based on the Per Capita LPG Consumption	58
CHAPTER 5		59
5	DISCUSSION.....	59
5.1	Problems Identified During the Survey.....	59
5.1.1	Non-compliance to the Country Law	59
5.1.2	Lack of Implementation of Modern Techniques	60
5.2	Selecting KPI 3 for the Benchmarking Purpose	60
5.3	Spread of Data Sets	61
5.4	The Numerical Benchmark of Domestic LPG Consumption	61
5.5	Sustainable Achievements through Energy Efficiency.....	62
5.6	Improving Maintenance Practices	63
CHAPTER 6		64
6	CONCLUSION.....	64
6.1	Recommendations and Future Works.....	65
REFERENCES.....		67
ANNEXURE - I		81
Gas Explosion in Sri Lanka.....		81
ANNEXURE - II.....		85
Specifications of Gas Meters		85

LIST OF FIGURES

Figure 1: Conventional System of Gas Cylinder Connection	5
Figure 2: Trend of LPG Consumption in Sri Lanka	8
Figure 3: LPG Piped Gas System.....	9
Figure 4: LPG gas flow meters	10
Figure 5: Flowchart of the Benchmarking Process	27
Figure 6: Average Annual Temperatures	29
Figure 7: Annual Rainfall in Sri Lanka	30
Figure 8: KPI 1 against the Type of Apartment	40
Figure 9: KPI 3 against the Type of Apartment	41
Figure 10: KPI 4 against the Type of Apartment	41
Figure 11: Average LPG Consumption Trend per Apartment	43
Figure 12: Average daily LPG consumption in 1BR apartments	44
Figure 13: Average daily LPG consumption in 2BR apartments	45
Figure 14: Average daily LPG consumption in 3BR apartments	45
Figure 15: Average daily LPG consumption in 4BR apartments	46
Figure 16: Average daily LPG consumption in 5BR apartments	46
Figure 17: Histogram for 01-bedroom residential apartments	48
Figure 18: Histogram for 02-bedroom residential apartments	48
Figure 19: Histogram for 03-bedroom residential apartments	49
Figure 20: Histogram for 04-bedroom residential apartments	49
Figure 21: Histogram for 05-bedroom residential apartments	50
Figure 22: Behavior Pattern of the Benchmarks	54

LIST OF TABLES

Table 1: Specifications of Gas Meters	10
Table 2: LPG Consumption in Residential Apartments	32
Table 3: Classification of Apartment Units.....	33
Table 4: Comparison of LPG Consumption in Residential Apartments	34
Table 5: Summary of the 10 KPIs	39
Table 6: Behavior of KPIs 1, 3, & 4 against the Type of Apartments.....	42
Table 7: Average LPG Consumption of 5 Types of Residential Apartments	43
Table 8: Statistical Analysis of Average Daily LPG Consumption	47
Table 9: Properties of the Gaussian Distribution Curves in the Histograms	50
Table 10: LPG consumption benchmarks for different types of residential apartments	53
Table 11: Comparison of derived LPG consumption benchmarks and values of trendline equation...	54
Table 12: Per Capita LPG Consumption and Per Capita LPG Energy Consumption	55

LIST OF NOMENCLATURE

Subscripts	Description
BTU	Amount of Energy needed to Cool or Heat
MJ	Energy
R^2	Coefficient of Determination
kW	Power
kg	Weight
g	Weight
mm	Length
m^2	Area
ft^2	Area
m^3	Volume
h	Time
°C	Temperature
%	Percentage
Abbreviation	Description
BMS	Building Management System
BR	Bed-Room
C	Carbon
CIDA	Construction Industry Development Authority
CMA	Condominium Management Authority
EC	Elemental Carbon
EMSI	Extra-Metabolic Scholander-Irving model
Eq.	Equation
H	Hydrogen
HC	Hydrocarbon
HVAC	Heating, Ventilation, Air conditioning, and Cooling
KPIs	Key Performance Indicators
LPG	Liquefied Petroleum Gas
LPGN	Liquefied Petroleum Gas Network
NFPA	National Fire Protection Association
PM	Particular Matter
RB+	Randomized Benchmarking
SLS	Sri Lanka Standard
SLSI	Sri Lanka Standards Institution
SLSEA	Sri Lanka Sustainable Energy Authority
#N/A	Not Available