

**TECHNO-ECONOMIC COMPARISON OF COLD
STORAGE CONFIGURATIONS FOR SUMMER AIR
CONDITIONING OF HIGH-RISE COMMERCIAL
BUILDINGS**

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ABSTRACT

This research investigates the application of thermal energy storage (TES) systems for air conditioning in office buildings located in tropical climates with high cooling demands. While integrating cold storage systems with air conditioning offers benefits such as reduced peak demand electricity costs, the ability to leverage the electricity demand to get time-based electricity tariff benefits, enhanced chiller plant efficiency, and improved condenser performance during nighttime operation, the adoption of TES technology remains limited. This is primarily due to the lack of comprehensive assessments and cost analysis related to local electricity tariff structures in various regions.

The study provides guidelines and a decision-making tool for selecting the most suitable thermal energy storage (TES) system for buildings, with a focus on load-shifting strategies to off-peak hours. It includes a literature survey to explore the fundamentals and characteristics of thermal storage systems and media for air conditioning, review software tools for cooling load calculations and system simulations, and investigate cost analysis methods and applicable electricity tariff structures for high cooling demand buildings in tropical climates. Following this, the report presents a detailed examination of TES integration with chiller plants, assessing various configurations based on factors such as energy consumption, maximum demand variations, daily energy distribution, space requirements, and implementation costs. Among the four configurations assessed, including a conventional chiller plant, a chiller plants with TES for full capacity (full storage), and two configurations with partial TES for load leveling and demand limiting, the configuration 2-2, which uses TES for partial storage-load leveling, was found to be the most cost-effective. This configuration demonstrated substantial operational savings, reduced peak demand, and required minimal space.

Payback periods for Configuration 2-2 varied by region: approximately 14 years under Sri Lanka's July 2024 electricity tariffs, 3.28 years under Sri Lanka's August 2022 tariffs, 1.49 years under Singapore's current tariffs, and 6.21 years under Kerala, India's current tariffs. The extended payback period under Sri Lanka's latest tariffs is attributed to the reduction of the differences among daytime, peak, and off-peak electricity rates. Despite this,

Configuration 2-2 remains financially favorable compared to other tariff structures evaluated.

Keywords: Peak Energy Demand; Thermal Energy Storage; Cold Storage System; Air-Conditioning; Building Cooling Load; Energy Efficiency; Office Building; Tropical Country

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TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGMENT	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	x
LIST OF TABLES	xii
1. INTRODUCTION.....	1
1.1 Background	1
1.2 Energy Consumption of Air Conditioning Systems	1
1.2.1 Maximum Demand.....	2
1.2.2 Reducing the maximum demand charge	2
1.2.3 Thermal Storage for Chiller Plants.....	2
1.3 Introduction to Chapters	3
1.4 Aim.....	4
1.5 Objectives.....	4
1.6 Methodology	5
CHAPTER 2.....	7
2.1 Cooling Load of Building.....	7
2.2 Cold Storage Technology	7
2.3 Thermal Storage System Classification.....	9
2.3.1 Sensible Heat Storage (SHS).....	9
2.3.2 Latent Heat Storage (LHS).....	9
2.3.3 Thermochemical Heat Storage	9
2.4 Direct and Indirect Type Thermal Storage	10
2.5 Chilled Water Thermal Storage.....	10
2.6 Ice Thermal Storage	12
2.6.1 Ice Thermal Storage Classification.....	12
2.6.2 Applications of Ice Thermal Storages	13
2.7 Phase Change Material (PCM) Thermal Storage	15
2.7.1 Classification of PCMs.....	15
2.7.2 Selection of PCM media.....	16
2.7.3 Salt Hydrates and Eutectic.....	19
2.7.4 Paraffin Waxes and Fatty Acids	21

2.7.5	Refrigerant Hydrates	23
2.7.6	PCMs on the Market.....	23
2.8	Super Cooling Water Cold Storage	25
2.9	Cooling Water Cold Storage	25
2.10	Technical Parameters for Thermal Energy Storage Systems	25
2.10.1	Nominal Power.....	25
2.10.2	Response Time	25
2.10.3	Energy Efficiency	26
2.10.4	Total Energy Storage Capacity (ESC).....	26
2.10.5	Energy Storage Capacity of TES Media.....	27
2.11	Software Tools	29
2.11.1	TRACE 700.....	29
2.11.2	Hourly Analysis Program (HAP)	30
2.11.3	eQUEST	31
2.12	TES Applications.....	31
2.12.1	PCM Storage based chiller plant with Glycerin Cold Storage Media	31
2.12.2	PCM Storage in Working Lab Office Building-Johannesburg Science Park	32
2.12.3	CM Storage Integrated with a Chilled Water System at University of Bergen	33
2.13	Electricity Data and Tariff Structure in Sri Lanka	35
2.13.1	Electricity Data in Sri Lankan Contest	36
2.13.2	Peak and Off –Peak Hours	38
2.13.3	Maximum Demand Charge	38
2.13.4	Local Electricity Tariff Structure	38
2.14	Life Cycle Cost (LCC) Analysis	41
2.14.1	Economic Indicators	41
2.14.2	Simple Payback Period (SPBP).....	41
2.14.3	Net Present Value (NPV)	42
2.14.4	Cost-Benefit Ratio (B/C).....	43
2.14.5	Equivalent Uniform Annual Costs (EUAC).....	43
2.14.6	Internal Rate of Return (IRR).....	44
2.14.7	Costs	44
2.14.8	Methodology for the LCC Analysis	45
2.15	Research Gap.....	45

CHAPTER 3.....	47
3. METHODOLOGY.....	47
3.1 Analyze the Cooling Load Paten of Office Buildings	47
3.2 Selection of Chilled Water System for the Study.....	50
3.3 Chilled Water System Design Configurations.....	50
3.4 Design Selection and Cooling Load Calculation.....	52
3.4.1 Introduction to the Selected Design.....	52
3.4.2 Cooling Load Simulation	54
3.4.3 Indoor Design Conditions.....	55
3.4.4 Weather and Outdoor Parameters.....	55
3.4.5 Design Temperatures.....	56
3.5 On- and Off-Peak Schedule.....	56
3.6 Design Considerations for Chiller and Thermal Energy Storage	57
3.6.1 Sizing of Chiller	57
3.6.2 Sizing of Thermal Energy Storage	58
3.6.3 Chiller and TES requirement for Full Storage system.....	58
3.6.4 Chiller and TES requirement for Partial Storage for Load Leveling.....	59
3.6.5 Chiller and TES requirement for Partial Storage for Demand Limiting.....	59
3.7 Sizing of the Chiller Plant and TES System.....	60
3.7.1 Chiller Plant Room Load - Configuration 1	60
3.7.2 Chiller & Thermal Storage Capacities - Configuration 02 -1.....	61
3.7.3 Chiller & Thermal Storage Capacities - Configuration 02 -2.....	63
3.7.4 Chiller & Thermal Storage Capacities - Configuration 02 -3.....	65
3.8 Heat Transfer Fluid Selection for TES-Based Chiller Systems.....	67
3.9 Plant Room Schematics for Different Configurations.....	67
3.9.1 Key Components and Their Functions	68
3.9.2 Operational Modes and Piping Network	68
3.9.3 Detailed Equipment Arrangement	69
3.9.4 Control logic for different configurations	70
3.10 Selection of Suppliers.....	71
3.11 Installation Guidelines for Thermal Storage Units.....	71
3.12 Chiller Plant Simulation and Energy Consumption	73
3.13 Maximum Electricity Demand of the Building	78

3.14	Evaluation of the Bill of Quantity (BOQ)	79
3.14.1	BOQ Items.....	79
3.14.2	Price of Chiller and TES for Selected Configurations.....	81
CHAPTER 4.....		87
4.	RESULTS AND DISCUSSIONS	87
4.1	Cooling Load Patterns and Potential for Load Shifting in Office Buildings.....	87
4.2	Cooling Load Distribution of Selected Building.....	87
4.3	Details of Selected TES.....	91
4.4	Requirement for TES for - Configuration 02 -1	92
4.4.1	Product Summary	92
4.4.2	Typical Tank Arrangement Layout	93
4.4.3	Technical Requirements	93
4.5	Requirement for TES for - Configuration 02 -2	95
4.5.1	Product Summary	95
4.5.2	Typical Tank Arrangement Layout	96
4.5.3	Technical Requirements	97
4.6	Requirement for TES for - Configuration 02 -3	98
4.6.1	Product Summary	98
4.6.2	Typical Tank Arrangement Layout	99
4.6.3	Technical Requirements	99
4.7	Summary of Chiller & Thermal Storage Capacities.....	101
4.8	Chiller Selection.....	102
4.8.1	Chiller Selection Based on Capacity Calculations	102
4.9	TES Selection	103
4.10	Energy Consumption of the Selected Configurations	103
4.10.1	Annual Energy Consumption for Chiller Plants.....	103
4.10.2	Annual Energy Consumption	107
4.10.3	Maximum Demand.....	107
4.11	Cost Evaluation of Systems.....	109
4.12	Operational Cost.....	110
4.13	Comparison of the Cost Impact.....	115
4.14	Comparison of the Cost Impact with Different Tariff Structures.....	119
4.14.1	Comparison with Electricity Tariff 2022-August Revision - CEB	120

4.14.2	Comparison with Singapore Electricity Tariff Structure.....	121
4.14.3	Comparison with India Electricity Tariff Structure.....	122
CHAPTER 5.....		125
5.	CONCLUSION	125
REFERENCES		127

LIST OF FIGURES

Figure 1 : Expected Global Electricity Demand Growth from 2018 to 2050 [1]	1
Figure 2 : A typical HVAC system integrated with active cold storage [4].....	8
Figure 3 : Different strategies of operating of CTES system [5].....	9
Figure 4 : Types of energy storage [6]	10
Figure 5 : Two diffuser types used in Stratified storage tank [7]	11
Figure 6 : Two diffuser types most commonly used in Stratified storage tank [7]	13
Figure 7 : Plant structure of the HVAC system [3]	13
Figure 8 : Ice thermal storage temperature and normalized stored energy [3].....	14
Figure 9 : Classification of PCMs [7].....	15
Figure 10 : Melting points and heat of fusion for existing PCMs [7].....	16
Figure 11 : Melting temperature and fusion heat by mass [7].....	17
Figure 12 : Comparison of thermal properties for various PCMs [7].....	19
Figure 13 : Paraffin compounds and salt hydrates' PMC material costs [15].....	23
Figure 14 : Example of the Response time in a real system [18].....	26
Figure 15 : Schematic of the chiller plant combined with Glycerin based cold storage [22].....	31
Figure 16 : Actual installation of the Glycerin based cold storage [22]	32
Figure 17 : TES system integrated in to the AHU [23]	32
Figure 18 : Detailed scheme diagram of the chilled water system at University Bergen [6]	34
Figure 19 : PCM thermal energy storage tanks at University Bergen (at 2014) [6].....	34
Figure 20 : Electricity consumption, World 1990-2019 [1]	36
Figure 21 : Electricity consumption, Sri Lanka 1990-2019 [1].....	36
Figure 22 : Change in Daily Load Curve Over Year [26]	37
Figure 23 : Electricity Tariff 2024-July Revision _Ceylon Electricity Board (CEB) [28].....	39
Figure 24 : Electricity Tariff 2022-August Revision _Ceylon Electricity Board (CEB) [29]	40
Figure 25 : Building 01- Chiller Load (kW) vs Hour of Day	48
Figure 26 : Building 02 - Chiller Load (kW) vs Hour of Day	49
Figure 27 : Building 03 - Chiller Load (kW) vs Hour of Day	50
Figure 28 : Chiller Plant Operating Period - Configuration 1	51
Figure 29 : Cross-Section of the Proposed Building	53
Figure 30 : Chiller & TES Capacity Distribution for Full Storage - Load Shifting	62
Figure 31 : Chiller & TES Capacity Distribution for Partial Storage - Load Leveling	64
Figure 32 : Chiller & TES Capacity Distribution for Partial Storage - Demand Limiting	66
Figure 33 : Proposed Schematic Diagram for the Plant Room Combining Chiller and TES	67

Figure 34 : Layout Guidelines for the Selected Thermal Storage Units.....	72
Figure 35 : Recommended Overhead Clearance for the Thermal Storage Tank Units	72
Figure 36 : Hourly cooling load profile of the plant.....	90
Figure 37 : Chiller Load Profiles for Month of July.....	91
Figure 38 : Typical Tank Arrangement Layout for Configuration 02 -1	93
Figure 39 : Hourly Load Profile for Full Storage for Load Shifting	95
Figure 40 : Typical Tank Arrangement Layout for Configuration 02 -2	96
Figure 41 : Hourly Load Profile for Partial Storage - Load Leveling	98
Figure 42 : Typical Tank Arrangement Layout for Configuration 02 -3	99
Figure 43 : Hourly Load Profile for Partial Storage - Load Leveling	101
Figure 44 : Total Power Consumption of Chiller Plant.....	105
Figure 45 : Daytime Power Consumption of Chiller Plant	105
Figure 46 : Off-peak Power Consumption of Chiller Plant.....	106
Figure 47 : Maximum Electricity Demand Variation of the Building.....	108
Figure 48 : Distribution of Annual Electricity Cost	114

LIST OF TABLES

Table 1 : Thermal and physical properties of organic phase change materials [3] [11].....	17
Table 2 : Thermal and physical properties of inorganic phase change materials [3] [11].....	18
Table 3 : Comparative analysis of different thermal storage systems [7]	20
Table 4 : Thermal characteristics of eutectic salts and salt hydrates [7] [12].....	21
Table 5 : Thermal characteristics of paraffin waxes and fatty acids [7] [13]	22
Table 6 : Phase change material cost and Vendor details [15].....	24
Table 7 : Process Description of the Glycerin Cold Storage Based Application [6] [24]	33
Table 8 : Process Description of University College Bergen Application [6] [6].....	35
Table 9 : Summary of Statistics 2022, CEB [25]	36
Table 10 : Details of Building Construction.....	54
Table 11 : Monthly Minimum and Maximum Temperatures from Software Data Base	56
Table 12 : Chiller & TES Capacities for Full Storage - Load Shifting	61
Table 13 : Chiller & TES Capacities for Partial Storage - Load Leveling	63
Table 14 : Chiller & TES Capacities for Partial Storage - Load Leveling	65
Table 15 : Control logic for full storage for load shifting	70
Table 16 : Control logic for partial storage for load shifting and demand limiting.....	70
Table 17 : Chiller plant energy consumption results – Configuration 1.....	73
Table 18 : Chiller plant total energy consumption results – Configuration 2-1	74
Table 19 : Chiller plant off-peak energy consumption results – Configuration 2-1.....	74
Table 20 : Chiller plant total energy consumption results – Configuration 2-2	75
Table 21 : Chiller plant off-peak energy consumption results – Configuration 2-2.....	75
Table 22 : Chiller plant daytime energy consumption results – Configuration 2-2	76
Table 23 : Chiller plant total energy consumption results – Configuration 2-3	76
Table 24 : Chiller plant off-peak energy consumption results – Configuration 2-2.....	77
Table 25 : Chiller plant daytime energy consumption results – Configuration 2-2	77
Table 26 : Air-Side Electrical Load over Time and Month.....	78
Table 27 : BOQ items and affect when combine the TES to the chiller plant.....	79
Table 28 : Associated Cost for Chillers.....	81
Table 29 : Associated Cost for TES systems.....	82
Table 30 : Associated Cost for Cooling Towers.....	82
Table 31 : Associated Cost for Pipe Network – Configuration -1.....	84
Table 32 : Associated Cost for Pipe Network – Configuration -2-1	84
Table 33 : Associated Cost for Pipe Network – Configuration -2-2	85

Table 34 : Associated Cost for Pipe Network – Configuration -2-3	85
Table 35 : Associated Cost for Chilled Water Pumps	86
Table 36 : Associated Cost for Condenser Water Pumps.....	86
Table 37 : Maximum cooling capacity of air-conditioned spaces	88
Table 38 : Plant room cooling capacity	89
Table 39 : Chiller Load Distribution for Month of July	90
Table 40 : TES Load Profile Details for TES: Full Storage - Load Shifting.....	94
Table 41 : Chiller Capacities requirement for TES: Full Storage - Load Shifting	95
Table 42 : TES Load Profile Details for TES: Partial Storage - Load Leveling	97
Table 43 : Chiller Capacities requirement for TES: Partial Storage - Load Leveling.....	98
Table 44 : TES Load Profile Details for TES: Partial Storage – Demand Limiting	100
Table 45 : Chiller Capacities requirement for TES: Demand Limiting.....	100
Table 46 : Chiller and TES Capacity requirements	101
Table 47 : Chiller Selections Data.....	102
Table 48 : TES Selections Data.....	103
Table 49 : Annual energy consumption for the chiller plant -Total	104
Table 50 : Annual energy consumption for the chiller plant - Off-peak (22:30 – 05:30)	104
Table 51 : Annual energy consumption for the chiller plant – Daytime (05:30 – 18:30)	104
Table 52 : Annual Energy Usage of the Building	107
Table 53 : Maximum Electricity Demand Distribution.....	108
Table 54 : Summary of Initial Investment for Each Configurations	110
Table 55 : Total Annual Electricity Cost – Configuration -1	111
Table 56 : Total Annual Electricity Cost – Configuration - 2-1	111
Table 57 : Total Annual Electricity Cost – Configuration - 2-2.....	112
Table 58 : Total Annual Electricity Cost – Configuration - 2-3.....	113
Table 59 : Summary of Total Annual Electricity Cost.....	114
Table 60 : Simple Payback Period (SPBP).....	116
Table 61 : Net Present Value (NPV) - Configuration-1	116
Table 62 : Net Present Value (NPV) – Configuration - 2-1	117
Table 63 : Net Present Value (NPV) – Configuration - 2-2	118
Table 64 : Net Present Value (NPV) – Configuration - 2-3	118
Table 65 : Summary of Net Present Value (NPV)	119
Table 66 : Simple Payback Period (SPBP) – with Tariff 2022-August Revision, CEB.....	120
Table 67 : Summary of Net Present Value (NPV) – with Tariff 2022-August Revision, CEB ...	120

Table 68 : Singapore Electricity Tariff Revision - Published by March 28, 2024 [34].....	121
Table 69 : Simple Payback Period (SPBP) – with Singapore Electricity Tariff	121
Table 70 : Summary of Net Present Value (NPV) – with Singapore Electricity Tariff	122
Table 71 : Proposed Tariff from July 1, 2024, by Kerala State Electricity Board Limited [37] ..	123
Table 72 : Simple Payback Period (SPBP) – with Kerala -India Electricity Tariff	123
Table 73 : Summary of Net Present Value (NPV) – with Kerala -India Electricity Tariff	123

LIST OF NOMENCLATURE

Abbreviation	Description
AHU	Air Handling Unit
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
CEB	Ceylon Electricity Board
COP	Coefficient of Performance
CTES	Cold Thermal Energy Storage
ChD	Daytime Chiller
ChN	Nighttime Chiller
ESC	Energy Storage Capacity
FCU	Fan Coil Unit
HVAC	Heating Ventilation and Air Conditioning
PCM	Phase Change Material
TES	Thermal Energy Storage
TRNSYS	Transient System Simulation Tool
VA-TES	Diverting Valve of Thermal Energy Storage
VA-CD	Modulating Control Valve of Chiller Plant
Notations	Description
$\epsilon_{\text{sys.xt}}$	Energy efficiency of the TES system
ΔH_{pc}	Enthalpy of phase change
$ \Delta H_{\text{n} \rightarrow \text{m}}^0 $	Reaction enthalpy
ΔT_{l}	Temperature difference of the material in the liquid phase
ΔT_{s}	Temperature difference of the material in the solid phase
ΔT_{sys}	Design temperature difference of the system
C_{p}	Specific Heat Capacity
$C_{\text{p.mat}}$	Specific heat of the media/material
$C_{\text{p.mat.l}}$	Specific heat of the media/material in liquid phase
$C_{\text{p.mat.s}}$	Specific heat of the media/material in solid phase
$C_{\text{p.comp}}$	Specific heat of the component
ESC_{sys}	Energy storage capacity of the system
$ESC_{\text{sys.sens}}$	Energy storage capacity for sensible heat TES media

$ESC_{sys.lat}$	Energy storage capacity of latent heat TES media
$ESC_{mat.TCM}$	Energy storage capacity of media for sorption and chemical reactions (thermochemical)
ESC_{comp}	Energy Storage capacity of the components
M_n	Molar mass of the highest hydrate
m	Hydration state of the lower hydrate
m_{comp}	Mass of the component [kg]
m_{mat}	Mass of the material in the highest hydrate state
n	Hydration state of the highest hydrate
P	Shaft Power of Compressor
$P_{nom.sys}$	Nominal power at discharge
$P_{nom.sys.charge}$	Nominal power at charge
Q	Energy Transferred
Q_c	Heat Rejection Rate of Condenser
Q_0	Cooling Capacity
$Q_{sys.charge}$	Heat absorbed from the heat Sources during charging
$Q_{sys.discharge}$	Heat delivered to the heat sinks during discharging
$ReTi_{sys}$	Response time - discharge
$ReTi_{sys.charge}$	Response time – charge
T_f	Final Temperature of PCM
T_i	Initial PCM Temperature of PCM
w	Mass fraction of additives or matrixes

Subscripts	Description
c	Condenser
$comp$	Component
e	Evaporator
l	Liquid
lat	Latent
mat	material/ media
p	Pump
pc	phase change
s	Solid
$sens$	Sensible
sys	System