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

LIST OF FIGURES

LIST OF TABLES

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
$\varepsilon_{sys.xt}$	Energy efficiency of the TES system
ΔH_{pc}	Enthalpy of phase change
$\lvert\Delta H^0_{n\rightarrow m}\rvert$	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
$C_{p.mat}$	Specific heat of the media/material
$C_{p.mat.l}$	Specific heat of the media/material in liquid phase
$C_{p.mat.s}$	Specific heat of the media/material in solid phase
$C_{p.comp}$	Specific heat of the component
ESC_{sys}	Energy storage capacity of the system
$ESC_{sys.sens}$	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
$ReTi_{sys.chatge}$	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