



**INTRODUCTION OF THERMAL ENERGY STORAGE AIR  
CONDITIONING SYSTEM FOR RESORT ISLANDS IN  
MALDIVES.**

P. Induru Dasun

188746E

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

Departments of Mechanical, Electrical and Civil Engineering

University of Moratuwa

Sri Lanka

July 2024

**Declaration**

“I declare that this is my own work and this dissertation does not incorporate without acknowledgement 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 acknowledgement is made in the text.

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

Signature: ..... Date: 02/03/2024

Name of the Student: Pananwelage Induru Dasun

The above candidate has carried out research for the Masters Dissertation under my supervision.

Signature: ... Date: 02/03/2024

Name of the supervisor: Prof. Sanjeewa Witharana.

**Abstract**

Energy conservation came into the discussion more than decades ago. All the institutionalized structures in related industries embodied of highly developed capital western countries have been developing charters, standards, regulations and even constitutions to declare the foremost importance of conservation of energy. The involvement to the subject matter evolves throughout the recent persistent human civilisation into highly commercialized modern high-tech level. Single molecule of energy form is misused can keenly be tracked by the right implementation of forestated approaches of energy conservation.

Building services field, without a doubt, should be accounted for considerable amount energy consuming form of man-made industry. International Energy Agency stated that buildings in the globe that operational consume nearly 30% of world energy demand. Without getting into second thought, as building services engineers, undoubtedly can say that the contribution of the Air Conditioning Systems in building shall fall at higher range of that portion. Yes, as stated again in the introductions, more than 20% of building's total energy is consumed by the applications to keep the occupants in thermally comfortable environment as per the International Energy Agency.

However, meantime in the region (specially in Sri Lanka and Maldives), by experience of nearly 8 years in the industry can identify that the honest contribution to the energy conservation or sustentation is found rarely from specially in commercial applications of air conditioning. This exercise might hopefully address the idea by formation of tactical energy restoration method from its form of state for the hotel industry.

**Acknowledgement**

I would like to give my sincere gratitude to Prof. Sanjeewa Witharana for his undoubted help throughout the work of this dissertation. Even in the vacations of his practice he valued my work and trusted me on the task while contacting me from the overseas also. My undergraduate and postgraduate teachers help me through the journey of engineering and my thank will be granted to them.

Specially need to mention the AutoCAD modeler Chanaka Bombuwala of our company YONSAN ENGINEERING for his support to make the final CAD design for this dissertation even in his tight schedule and I am verry thankful for his support.

## Contents

Chapter 1 .....	1
1.1 Introduction.....	1
1.2 Context.....	2
1.3 Project Title.....	2
1.4 Research Supervisor.....	2
1.5 Research Gap .....	3
1.6 Aim and Objectives.....	3
1.7 Methodology .....	4
1.8 Work Flow Chart.....	5
Chapter 2 .....	6
2. Literature Review .....	6
2.1 Heat Exchangers .....	6
2.1.1 Heat Exchanger Types .....	7
A. Fin and Tube Heat Exchangers.....	7
B. Plate Heat Exchangers.....	8
C. Shell and Tube Heat Exchanger.....	9
2.1.2 Heat Transfer in Heat Exchangers.....	9
2.1.3 Manufacturing Process of Heat Exchangers.....	11
2.1.4 Modelling of Heat Exchangers.....	13
A. Theory.....	13
B. Effectiveness of A Heat Exchanger.....	20
2.1.5 Heat Exchanger Selection.....	23
A. Heat Transfer Rate: .....	23
B. Fouling Factor:.....	24
C. Lmtd Correction.....	25
D. Dimensionless Analysis.....	27
E. Economy .....	28
2.2 Chiller .....	28

2.2.1	Compressors .....	29
A.	Positive Displacement Compressors.....	30
A)	Reciprocating Compressors.....	30
B)	Scroll Compressor .....	30
C)	Screw Compressors. ....	31
B.	Dynamic Compressors. ....	32
D)	Centrifugal Compressor.....	32
2.2.2	Refrigeration Cycle.....	34
A.	York YCIV Air Cooled Chiller Refrigeration Cycle.....	35
B.	York YVAA Air Cooled Chiller Refrigeration Cycle.....	35
C.	Trane CVHF Centrifugal Chiller Refrigeration Cycle.....	36
D.	Trane CVHE Centrifugal Chiller Refrigeration Cycle.....	38
2.2.3	Overview.....	39
2.3	Thermal Storage Air Conditioning.....	43
2.3.1	Main System Components .....	44
A.	Heat Transfer Fluid. ....	44
B.	Ice Storage Tank.....	49
C.	Ice Making Chiller. ....	51
2.3.2	Thermal Storage Operation.....	52
A.	Closed System.....	52
B.	Open System .....	54
Chapter 3	.....	55
3.	Applications of Thermal Storage Air-Conditioning Systems.....	55
3.1	Thermal Storage Air Conditioning Practices.....	57
A.	Thermal Chicago District Cooling System. ....	57
B.	Thermal Storage Air Conditioning Systems in Japan.....	60
3.2	Thermal Storage Air Conditioning Experimental Analysis.....	61
Chapter 4	.....	67

4. Feasibility Study on Thermal Storage Air Conditioning System Installation in Maldives.....	67
4.1 Introduction of The Project.....	68
4.2 Power Supply.....	70
4.3 Technology Options.....	70
4.3.1 Production.....	71
4.3.2 Distribution.....	71
4.3.3 Energy Transfer Station.....	73
4.4 System Architecture.....	75
4.4.1 The Model.....	75
4.4.2 Energy Balance.....	77
Chapter 5.....	80
5 Thermal Energy Storage Plant Design.....	80
5.1 Thermal Energy Storage.....	82
5.2 Central Energy Transfer Station.....	84
Chapter 6.....	92
6 Implementation Method.....	92
6.1 Operating Modes of The Plant.....	93
Conclusion.....	94

## List of Figures

Figure 2. 1 Fin and Tube Heat Exchangers .....	7
Figure 2. 2 Plate Heat Exchangers .....	8
Figure 2. 3 Shell and Tube Heat Exchanger .....	9
Figure 2. 4 Shell and tube heat exchanger flow patterns .....	10
Figure 2. 5 Fin and tube heat exchanger flow patterns .....	11
Figure 2. 6 In and Out temperatures of counterflow heat exchanger.....	13
Figure 2. 7 Cylindrical boundary conditions of flowing fluids .....	17
Figure 2. 8 LMTD Correction factors. [Image courtesy; IIT] .....	26
Figure 2. 9 Main components of centrifugal chiller. [Image courtesy; York].....	29
Figure 2. 10 Pre-Rotation Vanes or Guide Vanes of a compressor inlet [Image courtesy- Formax Engineering] .....	33
Figure 2. 11 Refrigeration cycle and pressure enthalpy diagram.....	34
Figure 2. 12 York YCIV & YCAA chiller refrigeration cycle .....	36
Figure 2. 13 Trane CVHF/CVHE centrifugal chiller [Image courtesy-Trane] .....	38
Figure 2. 14 Design guide for cool thermal storage. [Image courtesy ASHRAE].....	43
Figure 2. 15 Ice storage system main components. [Image courtesy Residential energy library].....	44
Figure 2. 16 Water glycol freezing points and other solutions [Image curtesy <a href="https://www.engineeringtoolbox.com/">https://www.engineeringtoolbox.com/</a> ].....	46
Figure 2. 17 Ice storage tank/ Static tank. [Image courtesy; Trane. Polyethylene, polypropylene or steel constructed ice storage tanks are available in different sizes and configurations from several global manufacturers.] .....	51
Figure 2. 18 Closed system with plate heat exchanger. [Image courtesy Residential energy library].....	53
Figure 2. 19 Open glycol ice storage system. [Image courtesy Residential energy library] .....	54
Figure 3. 1 Chicago District Cooling System Plant at Franklin and Van Buren St. [Image courtesy: Chicago district cooling system] .....	58
Figure 3. 2 Chicago Downtown District Cooling System Components. [Image courtesy: Chicago district cooling system].....	59
Figure 3. 3 Number of Thermal Storage Air Conditioning Systems Installed in Japan. [Image Courtesy Heat Pump and Thermal Storage Technology Centre of Japan.] .....	61
Figure 3. 4 Variations in Cold Storage Fluid Temperature During Charging Process. [Data Courtesy Department of Renewable Energy, HCMC University of Technology and Education] .....	63

Figure 3. 5 Variations in Heat Transfer Fluid Temperature During Discharging Process. [Data Courtesy Department of Renewable Energy, HCMC University of Technology and Education.] .....	64
Figure 3. 6 Variations in Cold Storage Material Temperature During Discharging Process. [Data Courtesy Department of Renewable Energy, HCMC University of Technology and Education.].....	66
Figure 3. 7 Variations in Temperature of Air Leaving the FCU During Discharging Process. [Data Courtesy Department of Renewable Energy, HCMC University of Technology and Education.] .....	66
Figure 4. 1 SONEVA SECRET Resort Satellite View .....	69
Figure 4. 2 Pre-Insulated Pipe Installation.....	72
Figure 4. 3 Direct Energy Transfer Station for a Single Bedroom Villa Via a Manifold. ....	74
Figure 4. 4 Indirect Energy Transfer Station Via PHE for a Typical Station. ....	74
Figure 4. 5 Tourist Arrivals Throughout the Years in Maldives. Data Courtesy Maldives Monetary Authority. ....	76
Figure 4. 6 District Distribution System for the Resort Island .....	77
Figure 4. 7 District Cooling Load Profile of the Resort .....	77
Figure 4. 8 Load Shifting from the Ice Thermal Storage. ....	79
Figure 5. 1 Ice Building Duration vs Glycol Supply Temperature. [Image Curtesy BAC] .....	83
Figure 6. 1 Load Shaving Strategy Option for Selected Load Profile. ....	95
<b>List of Tables</b>	
Table 2. 1 Fouling Factors: [Data Courtesy H & C Heat transfer solutions Ontario Canada] .....	25
Table 2. 2 Glycol solution properties comparison at 40 degrees Celsius. [Data courtesy- Trane] .....	47
[Table 2. 3 Glycol solution impact on cooling coil performance comparison. Data courtesy- Trane] .....	48
Table 4. 1 Total Energy Supply in Maldives by Sources. Data Courtesy: [International Renewable Energy Agency.] .....	67

Table 4. 2 Total Energy Supply Growth in Maldives by Sources. [Data Courtesy: International Renewable Energy Agency]. .....	67
Table 4. 3 Total Energy Demand and Production Divisions for the Resort. ....	78
Table 5. 1 Energy demand per day for conventional and TESAC system application for the facility. ....	89
Table 5. 2 Supply and Installation Cost and Maintenance Cost of Major equipment of TESAC System and Conventional System.....	90