Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

DEVELOPMENT OF AN ENERGY MONITORING AND TARGETING METHODOLOGY FOR THE MOST EFFICIENT OPERATION OF CHILLED WATER SYSTEMS

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Engineering
in
Energy Management

at Massey University, Palmerston North, New Zealand

Federica Vaino
2008

ABSTRACT

The increasing price of oil and the destabilisation of the world's climate are urging governments, businesses and individuals to constantly investigate energy-efficient technologies and methodologies and pursue the adoption of energy efficiency programmes in a global effort to reduce energy consumption, greenhouse gas emissions and ultimately energy costs.

In New Zealand, one of the biggest industrial energy efficiency projects was started in 2002 by a multinational dairy company, the Fonterra Co-operative Group, in partnership with the energy service company Demand Response Ltd; the project currently aims at reducing by 15% the energy costs at all Fonterra's major production sites throughout the country. This thesis, undertaken as part of the above project, examines the development and implementation of a structured and integrated energy monitoring and targeting methodology (M&T) for the most efficient operation of all Fonterra's chilled water systems, with an initial focus on the ones installed at Clandeboye, one of the Fonterra's sites involved in the energy saving project.

A data collection system (*Insite*) was already in place at Clandeboye to enable storage and analysis of some of the site's utility metering data. After identification of key chilled water system components and definition of data requirements for M&T purposes, an analysis of past energy consumption trends (based on multiple regression calculations) was carried out to develop an historical benchmark of the energy used, compare it with current energy performance and thus identify opportunities for future improvements. The creation of an M&T reporting system for presenting findings to operators and management was the last essential part of the thesis development.

The study has highlighted that the robustness of the proposed regression model was badly affected by the unreliability of the existing data collection system and the uncertainty associated with poorly documented changes to operating conditions/plant configuration that had occurred over time. The conclusion is that, while the developed M&T methodology is theoretically valid and readily applicable, further developments are necessary (and recommended) to make it suitable for other similar systems.

ACKNOWLEDGEMENTS

I wish to thank my thesis supervisors, Prof. Don Cleland, Dr Richard Love and Dr Wyatt Page, for providing me with much needed support and encouragement throughout the development of this project. Their guidance has been invaluable.

I am also pleased to acknowledge the assistance of all Demand Response engineers, who gave me their time and resources to help me understand their work with Fonterra and build my knowledge of their database.

My thanks also go to Christine Lang, the Fonterra Process Technologist at Clandeboye who was my main point of contact on site and an essential source of system information and data.

My sincere gratitude goes to Allan Davidson, my managing director, who not only accommodated flexible working arrangements but also gave me his unconditional support, which translated into the necessary concentration and tranquility to keep working on this project even at times of high workload.

Finally, my hearty thanks go to my husband Dominic, who patiently and understandingly shared his wife with this demanding project and to my parents in Italy, whose constant love and encouragement has given me the strength to persevere and eventually complete this thesis.

TABLE OF CONTENTS

CHAPTER 1 – INTRODUCTION 1

1.1 Project Background 1

1.2 Project Objectives 3

CHAPTER 2 – CHILLED WATER SYSTEMS 4

2.1 Introduction 4

2.2 Chilled water 4

2.3 The Mechanical Vapor-Compression Refrigeration Cycle 5

2.3.1 Performance of a Refrigeration Cycle 10

2.4 Refrigeration System Components 12

2.4.1 Compressors 12

2.4.2 Condensers 18

2.4.3 Expansion Devices 21

2.4.4 Evaporators 23

2.5 Clandeboye's Chilled Water Systems 25

2.5.1 Powder Chilled Water Plant 26

CHAPTER 3 – MONITORING AND TARGETING 32

3.1 Introduction 32

3.2 M&T Key Elements 33

3.2.1 Data Collection 34

3.2.2 Data Analysis 35

3.2.3 Reporting of Findings 40

3.3 Conclusions 41

CHAPTER 4 – DATA COLLECTION 42

4.1 *Insite* – The Existing Database 42

4.2 Additional Data Sources 44

4.3 Data Identification and Collection 47

4.3.1 Process Heat Exchangers 48

4.3.2 Chilled Water Flows 50

4.3.3 Supply and Return Chilled Water Temperatures 51

4.3.4 Electricity to Chillers and Ancillary 53

4.3.5 Chillers' Data 54

4.3.6 Outside Temperature/Humidity Data 54

4.4 Data Collection Issues 55

4.4.1 Milk and Product Flows Uncertainty 55

4.4.2 Incorrectness of Chilled Water Flow Data 56

4.4.3 Purging of Electricity Data 56

CHAPTER 5 – CREATING BENCHMARKS 58

5.1 Introduction 58

5.2 Identification of variables 59

5.3 Data Set 61

5.3.1 Data Aggregation 62

5.3.2 Multicollinearity 62

5.3.3 Outliers 65

5.4 Regression Analyses 67

5.5 Benchmarking equation 70

5.6 Initial model test 71

CHAPTER 6 – THE REPORTING SYSTEM 73

6.1 Introduction 73

6.2 The STATUS Report 74

6.3 Report Structure 82

6.3.1 The Data Worksheet 82

6.3.2 The Analysis Worksheet 84

6.3.3 The Run-Macro Worksheet 85

6.3.4 The Daily Worksheet 85

6.3.5 The Targets Worksheet 88

6.4 Report Development 88

CHAPTER 7 – CONCLUSIONS 90

APPENDIX A 92

APPENDIX B 100

REFERENCES 101

LIST OF FIGURES

Figure 2.1: Schematic of a vapour-compression refrigeration system 6

Figure 2.2: Example of a Mollier diagram (source: Pizzetti, 1980).....7

Figure 2.3: Ideal refrigeration cycle on a pressure-enthalpy chart 8

Figure 2.4: Schematic of an economised refrigeration system 11

Figure 2.5: Theoretical economised cycle.....12

Figure 2.6: Basic reciprocating piston (source: ASHRAE Handbook, 2008).....13

Figure 2.7: Reciprocating compressor cycle on a pressure-volume diagram (adapted from Pizzetti, 1980).....14

Figure 2.8: Sequence of compression process in single-screw compressor (source: ASHRAE Handbook, 2008).....15

Figure 2.9: Twin-screw compression process (source: ASHRAE Handbook, 2008) 16

Figure 2.10: Cross section of a centrifugal compressor (source: ASHRAE Handbook, 2008) 17

Figure 2.11: Impeller exit velocity diagram (source: ASHRAE Handbook, 2008).....17

Figure 2.12: Shell and tube heat exchanger, U-tube design (source: www.wikipedia.org).....19

Figure 2.13: Schematic representation of an evaporative condenser (source: Manske et al., 2001) 21

Figure 2.14: Thermostatic expansion valve (source: Pizzetti, 1980).....22

Figure 2.15: High pressure float valve (source: The 3EStrategy, Guide Book4).....22

Figure 2.16: Schematic of direct expansion evaporator (source: Pizzetti, 1980) 23

Figure 2.17: Welded plate heat exchanger showing separate flow paths (source: ASHRAE Handbook, 2008).....24

Figure 2.18: Schematic of flooded evaporator (source: Pizzetti, 1980).....25

Figure 2.19: Powder plant system layout: chillers.....27

Figure 2.20: Powder plant system layout: end users 30

Figure 2.21: Clandeboye process schematic.....31

Figure 4.1: Screenshot of *Insite*.....43

Figure 4.2: Powder plant process schematic (milk treatment and lactose) (source: Demand Response, 2005).....45

Figure 4.3: Powder plant process schematic (powder 1 & 2) (source: Demand Response, 2005).....46

Figure 4.4: Screen dump of powder chilled water reticulation system (source: Clandeboye SCADA system) 47
Figure 4.5: Chilled water reticulation schematic showing the flow meters and probable end users (heat exchangers) 52
Figure 4.6: Screenshot of *Insite* showing the powder plant electrical meters 53
Figure 5.1: Daily electricity to powder plant during the observation period 61
Figure 5.2: Excel output for regression D5 (4 variables, daily data, no outliers) 70
Figure 5.3: Electricity use versus target 72
Figure 6.1: Two of the initial report drafts 76
Figure 6.2: The first two-page report draft 80
Figure 6.3: The final STATUS report 81
Figure 6.4: Compressor chart inclusive of transient operation 84
Figure 6.5: Compressor chart after the Macro activation 85

LIST OF TABLES

Table 2.1: Powder plant chillers: technical specifications 28
Table 4.1: Pumps fed by chillers' transformers but unrelated to chilled water 54
Table 5.1: Regression variables 60
Table 5.2: Correlation matrix for half hour data (15 variables) 63
Table 5.3: Correlation matrix for 24-hour data (15 variables) 64
Table 5.4: Suspected outliers in milk flow readings on INSITE database (total nominal flow rate is 392 m3/h) 66
Table 5.5: Summary of regression results 69
Table 6.1: Dataset in the data worksheet 83
Table 6.2: Screenshot of a *Daily* worksheet. 87