An Introduction to District Heating and Cooling

Low carbon energy for buildings

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To Kim, Owen and Jenny

Contents

Part II The Engineering of DH and DC systems

Preface

I began working in the field of District Heating (DH) in 1983, 40 years ago. I was very fortunate to join Orchard Partners and work with William Orchard and John Macadam. At that time there were hopes that there would be a national programme of investment in DH as part of an energy conservation strategy. Since then, there have been a number of false dawns for the industry but in 2013 the Government published its first national heat strategy which identified heat networks as part of the long-term solution to achieve net zero emissions by 2050. Ten years later the Government's energy strategy described heat networks as 'vital to making net zero a reality'. A number of studies have estimated the economic potential for heat networks to be between 18% and 43% of the total heat demand. Whichever figure proves to be correct this still represents a huge increase in capacity from the current market share of around 3%. To deliver this capacity will require many more skilled people to enter the industry, whether that is engineers, technicians, project managers, lawyers, financiers, commercial advisers or marketing specialists. The primary purpose of this book is to help new entrants, and especially engineers, gain some essential knowledge quickly so that they can contribute to realising the national potential for DH.

Structure of the book

The book is in three parts:

Part I provides a general introduction to district heating and cooling (DH/C) with chapter 1 providing some historical context and chapter 2 describing the physical components that make up a typical DH/C scheme. It is intended that this will be of interest to a non-technical readership as well as providing a useful background for engineers.

Part II discusses the engineering of DH/C beginning in chapter 3 with heating and cooling systems within buildings and how existing systems may need to be modified to suit DH/C. This is followed by chapter 4 which shows how the interface between the DH/C networks and the building should be designed to deliver an efficient system. Chapter 5 discusses the piped networks themselves, the technologies used and the main design aspects including: pumping and pressures, heat losses, optimal pipe sizing, stress analysis and quality control. Chapter 6 reviews the wide range of heat sources that are now available for heat networks, starting with gas-fired CHP which has been the commonest heat source for some time, followed by heat pumps, heat recovery and renewable energy sources. Chapter 7 focuses on the strategic design decision of the selection of operating temperatures and puts forward proposed temperatures that would be suitable for a heat pump based system supplying existing buildings. This part of the book concludes with chapter 8 which discusses some operational aspects including water treatment and heat metering both of which are critical to a successful scheme. In Part II I have sought to explain how fundamental engineering concepts can be applied to the challenges of DH/C to form a bridge between theoretical knowledge and the practical problems faced by engineers delivering projects. I have included 11 fundamental equations that an engineer will need to be familiar with, however, these have been kept to a minimum. This part of the book may be useful in supporting taught courses in DH/C or more generally in mechanical engineering degree courses.

Part III has a broader scope than the engineering of DH/C. Chapter 9 sets out how to make a case for DH/C beginning with the well-known energy trilemma of environment, cost and security of supply. Some other potential advantages of DH/C to potential customers are also explored. Chapter 10 looks at a wide range of new opportunities that DH/C could profit from in the future. The role that DH/C could have in helping to manage the challenge of increasing amounts of variable renewable electricity generation is assessed using a simplified model of future generation and demand patterns. This shows that there is a case for increased amounts of thermal energy storage and that gas-fired CHP may still have a valid role into the 2030s. The chapter also considers other long-term options that the Government has identified in the 2023 energy strategy 'Powering up Britain' including: hydrogen, small modular reactors and carbon capture usage and storage and how DH/C could be linked to these initiatives. With climate change leading to increasing temperatures, a section examines the ways in which DH can be linked with DC to improve efficiency, including the use of ambient temperature networks. The new Government policy on zoning of cities to promote rapid growth of DH is discussed. The chapter concludes with some ideas on how the costs of DH can be reduced so that customers will be better served and market share can be increased.

Chapter 11 contains a summary of some of the themes of the book and why I think the case for DH/C remains as strong as ever.

District cooling

Although the title of the book is *District Heating and Cooling*, inevitably there is more of an emphasis on heating than cooling. This is partly because much of the technology is either suitable for both heating and cooling or similar to both. However, I am aware that there is much more detail on DC that could have been included and I would refer the reader to two valuable sources of further information on DC:

ASHRAE District Cooling Guide (2nd edn) and Owner's Guide for Buildings Served by District Cooling, ASHRAE, 2019

Sustainable District Cooling Guidelines, IEA, 2020 https://www.iea-dhc.org/the-research/annexes/annex-xii/annex-xii-project-05.

Website links

Where possible I have provided hyperlinks to references in the Bibliography, especially for Government reports which can be accessed easily. I have included the link to the main site rather than the actual document referenced as often the site contains other useful guidance and references.

In some parts of the book, especially chapter 6, I have included some hyperlinks in the text. These are links to websites about projects, organisations or companies of interest rather than to specific documents. I have selected sites that provide the most useful information about a particular project—not necessarily the website of the owner of the scheme.

Devolved governments

I am aware that in dealing with Government policy this has been based on policies applicable to England. There are differences in the ways in which DH/C is being supported and developed by the devolved governments. My lack of knowledge of these differences and the limited reference to these does not imply that they are not important. In fact, in many areas the devolved Governments are leading the way for the UK. The information is as up to date as possible at the time of writing but this aspect of the book will obviously become out of date as policies develop.

Further reading

I have made many references to the CIBSE/ADE Code of Practice CP1.2 which lists requirements to be followed and compliance with CP1.2 is often a condition of a grant award or a planning application. It is hoped that this book will provide additional background so that the reasoning behind the requirements of CP1.2 can be better understood (see bibliography for chapter 3 reference [9]).

The very comprehensive textbook *District Heating and Cooling* by Svend Frederiksen and Sven Werner has been particularly valuable to me in writing this book and it is highly recommended for further reading, especially as it provides a Scandinavian perspective (see bibliography for chapter 1 reference [6]).

In addition to the sources in the Bibliographies, which are provided at the end of each chapter, the following websites are very useful for general guidance and information on the industry and many have extensive resources available to download.

Useful websites

The Association for Decentralised Energy https://www.theade.co.uk/

Euro Heat and Power https://www.euroheat.org

Heat Networks Delivery Unit https://www.gov.uk/guidance/heat-networks-delivery-unit

Heat Network Support Unit Scotland https://www.heatnetworksupport.scot/

International Energy Agency, District Heating and Cooling https://www.iea-dhc.org/home

UK District Energy Association: https://ukdea.org.uk/.

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I am very grateful to the Institute of Physics for the opportunity to write this book and the encouragement of the Series Editor David Elliott. Thank you to Caroline Mitchell and Isabelle Defillion for all their help and advice which made the whole process easier than I had envisaged.

I have only been able to write this book because of the knowledge I have gained through working with excellent colleagues over the last 40 years. These include: at Orchard Partners, William Orchard and John Macadam, at Steensen Varming Mulcahy, Dusan Markovic, Michael Carver and Bryan Franklin, at Parsons Brinckerhoff, Dominic Bowers and Ian Burdon, at AECOM, Richard John and Ant Wilson, at Islington Council, Lucy Padfield, at Engie, David Culver and Ben Watts, and at Sustainable Energy, Gabriel Gallagher, Lee Evans and Chrissy Woodman. I would also like to pay tribute to the late Jens Overgaard of Ramboll from whom I learnt much. It has been a pleasure working with many other colleagues in the industry, whether as co-workers, in client organisations or with contractors and suppliers, too numerous to mention individually, although the dedication of Michael King and Phil Jones have been inspirational.

I am very grateful to all who kindly reviewed draft chapters of the book and provided valuable comments. The book is greatly improved as a result of your work and I enjoyed catching up with old friends in the process. So, my special thanks to: Ian Allan, Professor Mark Barrett, David Burke, Peter Concannon, Martin Crane, Annabel Harford, Rufus Ford, Dr Gabriel Gallagher, Bruce Geldard, Gareth Jones, Charlotte Large, John Macadam, Dr Anthony Riddle, Oliver Riley, Andy Simms, Phillippe Terrine, Stephen Ward, Mark Whettall, David Whitfield, Dr Robin Wiltshire and Owen Woods. Of course, the responsibility for the final text lies entirely with myself.

I would like to thank my children, Owen and Jenny and my wider family for their encouragement. Finally, thank you to my wife Kim for her expert advice (as the author of three books herself) and kind support for this book as for everything else in my life; I could not have completed this without you.

Legal disclaimer

Author biography

Paul Woods

Paul Woods graduated in Engineering from Cambridge University and, after initial training in the nuclear power industry, started working in District Heating (DH) for Orchard Partners in 1983. He took a part-time MSc at Cranfield University in energy and the environment. He continued to work in DH, District Cooling (DC) and the broader field of energy and buildings, taking lead roles in the design of the building services of the New British Library (with Steensen Varming Mulcahy) and the DH/C systems for Heathrow Terminal 5 (with Parsons Brinckerhoff). He was technical advisor to the UK Government for the implementation of the Energy Performance of Buildings Directive (with AECOM). He led two international research projects for the IEA District Heating and Cooling programme and was Chief Technology Officer for two research projects in DH for the Energy Technologies Institute. In 2009, he co-authored the report on the Potential and Costs of DH (known as the Poyry report) which informed the Government's heat strategy. He was seconded to Islington Council to develop the Bunhill DH project. International experience has included working on DH projects in Turkey, the Republic of Ireland, Australia, South Korea, Romania, Russia and DC projects in Malaysia and India. Paul represented the UK on the European CEN standards committee for DH pipe systems and chaired the BSI committee RHE9/3. He was editor of CIBSE's Application Manual for CHP (AM12) and author of the first edition of the CIBSE/ADE Code of Practice for Heat Networks CP1 and co-author of the second edition. At Engie, Paul was appointed Concessions Director and was responsible for the strategic development of their six UK district heating and cooling schemes, including at the Queen Elizabeth Olympic Park (QEOP), later taking on an operational role at QEOP. Since 2017, after moving to Brecon, Paul has been working as an independent consultant on a number of DH and DC projects including in Cardiff, Bristol, South Dublin, Solihull and Bridgend and is an Associate with Sustainable Energy Ltd.

Symbols

A	cross-sectional area of pipe (m^2)
A	area of heat exchanger (m^2)
c	specific heat capacity (kJ kg^{-1} K)
d_i	pipe internal diameter (mm)
d_o	pipe external diameter (mm)
e_e	electricity emissions factor
e_g	gas emissions factor
e_{grid}	grid emission factor
E	Young's modulus (kN mm^{-2})
E_w	work efficiency
E	electricity output
F	friction on pipe in ground (N m^{-1})
F_{chp}	fuel input
g	gravitational acceleration (m s^{-2})
H	heat output
h	height (m)
k	thermal conductivity (W $m^{-1}K^{-1}$)
k	roughness coefficient (m)
$\dot{m}$	mass flow rate (kg s^{-1})
P	power (kW)
p	pressure (N m^{-2})
Δp	pressure difference (N m^{-2})
Q	heat energy flow rate (kW)
T	temperature (K)
ΔT	temperature difference (°C)
t_w	pipe wall thickness (mm)
U	heat transfer coefficient (W m^{-2}K)
v	velocity (m s^{-1})
V	volume flow rate (m^3 s^{-1})
z	z-factor for steam turbine extraction
α	temperature coefficient of linear expansion (K^{-1})
η_b	boiler efficiency (%)
η_{grid}	grid efficiency (%)
η_e	CHP electrical efficiency (%)
η_h	CHP heat efficiency (%)
λ	friction factor
μ	dynamic viscosity (Ns m^{-2})
ρ	density (kg m^{-3})
σ	stress (N mm^{-2})

Glossary of acronyms

ADE	The Association for Decentralised Energy
AGR	advanced gas-cooled ractor
AHU	air-handling unit
ATES	Aquifer Thermal Energy Storage
ASHP	air source heat pump
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
BEIS	Department for Business, Energy and Industrial Strategy
BEMS	building energy management system
BESA	Building Engineering Services Association
CCGT	combined cycle gas turbine
CCUS	carbon capture usage and storage
CEN	European Committee for Standardisation
CHP	combined heat and power
CIBSE	Chartered Institution of Building Services Engineers
CoP	coefficient of performance
DC	district cooling
DECC	Department of Energy and Climate Change
Defra	Department of Environment, Food and Rural Affairs
DESNZ	Department of Energy Security and Net Zero
DH	district heating
DH/C	district heating and cooling
DHW	domestic hot water
DPCV	differential pressure control valve
DUKES	Digest of UK Energy Statistics
ETI	Energy Technologies Institute
GB	Great Britain, i.e. the UK excluding Northern Ireland
GHNF	Green Heat Networks Fund
GSHP	ground source heat pump
GWP	global warming potential
HNDU	Heat Networks Delivery Unit
HIU	Heat Interface Unit
HNIP	Heat Networks Investment Project
HV	high voltage 11 kV
IRR	Internal Rate of Return
LA	local authority
LMTD	log mean temperature difference
LNG	liquefied natural gas
LV	low voltage 400 V
mtoe	million tonnes of oil equivalent
NPC	Net Present Cost
NRSWA	New Road and Street Works Act
PICV	pressure independent control valve
OCGT	open cycle gas turbine
OPEC	Organisation of Petroleum Exporting Countries
SIGE	spark-ignition gas-engine

SMR	small modular reactors
UNFCCC	United Nations Framework Convention on Climate Change
WRAS	Water Regulations Approval Scheme
WSHP	water source heat pump