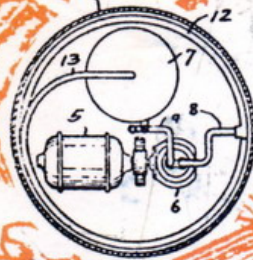
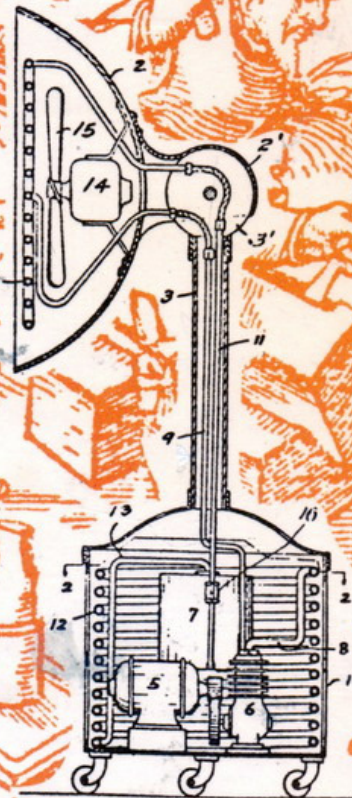


Building Services Engineering

A Review of Its Development

Neville S. Billington
and
Brian M. Roberts



PERGAMON PRESS

International Series on
Building Environmental
Engineering, Volume 1

Building Services Engineering

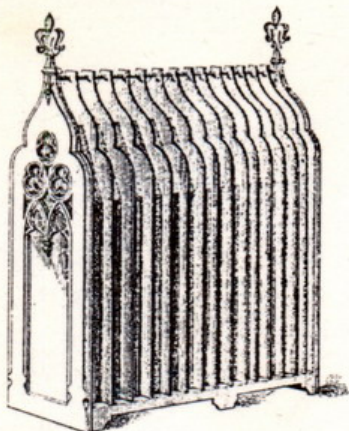
A Review of Its Development

Contents

The Study of Human Requirements and Comfort
Human Physiology and Metabolism
Human Needs and Comfort

Building Engineering Systems and Equipment
Heating
Ventilation
Refrigeration
Air Conditioning
Plumbing and Sanitation
Piping and Pumps
Firefighting
Lighting
Automatic Control
Other Engineering Topics

Heating and Ventilating Design
Index



GOthic HOT WATER OR
STEAM RADIATOR.



0 08 026741 6

PREFACE

In attempting to deal in a single volume with the development of those disciplines which we now call building services engineering, we have been faced with difficult choices. We have felt it desirable to sacrifice minute and exhaustive detail in order to stress the significant technical advances and their social and economic consequences. Pressure of space has prevented us from dealing with applications to transport or to general industrial problems; we have for the same reason reluctantly excluded any discussion of cooking equipment, although it is an important domestic service.

The literature on heating and ventilation is certainly older, and probably more extensive, than that on any other discipline within building services engineering, yet, curiously, the development of heating and ventilating engineering over the past century has not previously been traced, whereas the story of refrigeration and of lighting in the same period has been recorded. We make no apology for having treated the progress of heating and ventilation at relatively great length, for its stages encompass the whole growth of civilisation and the development of modern modes of thought. We see in it the trial and error and the empiricism of the early days, even the re-discovery of older ideas, before the growth of knowledge in the physical, medical and psychological sciences paved the way for numerate design. The effects of sociological change in moving from a feudal (and monastic) system to an industrialised urban existence, and of the broadening of the educational base, freed from the restrictions of monasticism, the birth of an industry and the emergence of the consulting engineer, are generally more easily seen via the advances in heating and ventilating engineering. Technologies of more recent origin (such as refrigeration) have developed in a different and more direct way. They were essentially based on the discoveries of contemporary science, and by availing themselves of these, they were able largely to bypass the empirical stages. They were established in a period of industrial growth, and in consequence gave rise to the modern concept of industrial research and development.

We are indebted to a great many friends and colleagues, both at home and abroad, who have helped us in many ways. In particular, we should mention F. Clain, M. Gartside, Barrie Graham, Professor Inoue, F. Meszaros, G. Rooley and Dr F. M. H. Taylor, for private talks and correspondence, and the staff of the BSRIA Library for unstinted assistance with difficult enquiries.

CONTENTS

List of Illustrations	xi
Introduction	1
<u>Part I The Study of Human Requirements and Comfort</u>	7
Chapter 1 Human Physiology and Metabolism	9
1.1 Metabolism	9
1.2 Extreme Conditions	12
1.3 Hypothermia	13
1.4 Radiation	14
1.5 Vision and Hearing	15
References	16
Chapter 2 Human Needs and Comfort	17
2.1 Tom's a-cold	17
2.2 Summertime Temperatures	20
2.3 Working Conditions	21
2.4 Comfort	22
2.5 Ventilation Requirements	29
2.6 Indices of Warmth and Comfort	42
2.7 Atmospheric Electricity	45
2.8 Acoustics	47
2.9 Lighting	55
2.10 Total Environment	61
2.11 Water Supply	63
2.12 Atmospheric Pollution	64
References	67
<u>Part II Building Engineering Systems and Equipment</u>	71
Chapter 3 Heating	73
3.1 Fires and Chimneys	73
3.2 The Stove	92
3.3 Steam Heating	101
3.4 Hot Water Heating	110

3.5	Accelerated Hot Water Heating	112
3.6	Pressurised Hot Water	115
3.7	District Heating	122
3.8	Boilers	127
3.9	Radiators and Convectors	146
3.10	Radiant Heating	156
3.11	Electric Heating	163
3.12	Gas Heating	171
	References	174
Chapter 4	Ventilation	177
4.1	Natural Ventilation	177
4.2	Warm-air Heating	187
4.3	Assisted Ventilation	200
4.4	Mechanical Ventilation	209
4.5	Bellows, Windmills and Fans	218
	References	237
Chapter 5	Refrigeration	239
5.1	Natural Ice	239
5.2	Freezing Mixtures	243
5.3	Gas Liquefaction	244
5.4	Vapour Compression	246
5.5	Ether Machines	246
5.6	Ammonia Machines	249
5.7	SO ₂ Machines	252
5.8	CO ₂ Machines	253
5.9	Freon Refrigerants	254
5.10	Other Refrigerants	255
5.11	Rotary Compressors	255
5.12	Turbo-compressors	256
5.13	The Screw Compressor	257
5.14	Absorption Cooling	258
5.15	Equipment Development (1850-1900)	263
5.16	Jet Machines	265
5.17	Cold-air Machines	266
5.18	Peltier Cooling	271
5.19	Vortex Tube	271
5.20	Domestic Refrigeration	272
5.21	The Frozen Meat Trade	273
5.22	The Heat Pump	275
5.23	District Cooling	278
5.24	Solar Cooling	279
	References	279
Chapter 6	Air Conditioning	281
6.1	Patterns of Growth	281
6.2	Before Mechanical Refrigeration	284
6.3	Earth Cooling Systems	286
6.4	Water Sprays and Medicants	287
6.5	Ice-block Cooling	289
6.6	The First Chilled Water Systems	289
6.7	Humidification	291
6.8	Dehumidification	295
6.9	Air Cleaning	297
6.10	Odour Removal	300
6.11	Air Distribution	300
6.12	Room Air Conditioning Units	301

6.13 All-air Systems	306
6.14 Air-water Systems	309
6.15 Other Systems	311
6.16 Air Curtains	312
References	313
Chapter 7 Plumbing and Sanitation	315
7.1 Water Supply	315
7.2 Sanitation	329
7.3 Bathing	340
7.4 Closets	346
7.5 Domestic Hot Water Supply	356
References	360
Chapter 8 Piping and Pumps	362
8.1 Materials	362
8.2 Piping and Ducting	363
8.3 Valves	369
8.4 Pumps	370
References	380
Chapter 9 Firefighting	381
9.1 Fire Engines and Brigades	381
9.2 The Development of Fire-fighting Apparatus	387
9.3 The First Sprinklers	388
9.4 Fixed Systems	391
9.5 Detection and Alarm	391
9.6 Fireproof Buildings	392
References	394
Chapter 10 Lighting	395
10.1 Daylighting	395
10.2 Candles and Lamps	402
10.3 Gas Lighting	413
10.4 Electric Lighting	425
References	437
Chapter 11 Automatic Control	438
11.1 Measuring Devices	439
11.2 Temperature Control	441
11.3 Electrical Controls	445
11.4 Pneumatic Control	446
11.5 Valves	450
11.6 Humidity Control	451
11.7 Boiler Controls	453
11.8 Steam Pressure Controllers	454
11.9 Control Theory	456
11.10 Optimum Start Control	457
11.11 Electronic Controls	458
11.12 Building Automation Centres	459
References	460
Chapter 12 Other Engineering Topics	462
12.1 Refuse Handling and Disposal	462
12.2 Lifts and Escalators	464
12.3 Fuels	465
12.4 Legislation	471
12.5 Heat Recovery Equipment	477
12.6 Solar Energy Utilisation	479
References	481

<u>Part III Heating and Ventilating Design</u>	483
Chapter 13 Heating and Ventilating Design	485
13.1 Heat Losses	485
13.2 The Development of Thermal Transmittance	490
13.3 Ventilation and Infiltration Losses	495
13.4 Building Fabric Losses	497
13.5 Basic Design Temperature	498
13.6 Wild Heat	500
13.7 Degree-days	500
13.8 Intermittent Heating Calculations	501
13.9 Heat Emission from Pipes and Radiators	503
13.10 Fluid Flow	510
13.11 Pipe and Duct Sizing	514
13.12 Summer Conditions	520
13.13 Psychrometric data	521
13.14 The Computer Revolution	522
References	525
Name Index	529
Subject Index	533

LIST OF ILLUSTRATIONS

Frontispiece — Hot water supply and cooking apparatus (1867)

Part I

Frontispiece — Thermal comfort studies

1.1 The Atwater human calorimeter (1899)	11
1.2 Water-cooled refrigerating blanket (1879)	14
2.1 ASHVE comfort chart for still air (1943)	19
2.2 Hill's temperature-humidity chart	27
2.3 Discomfort in adults holding a heated handle	29
2.4 Reid's apparatus for ventilation trials (1844)	32
2.5 Effective temperature chart	43
2.6 Comfort zone	45
2.7 Noise-measuring truck, New York (1929)	48
2.8 Reverberation values for concert halls	51
2.9 Equal-loudness contours	53
2.10 View of Wolverhampton (1866)	65

Part II

Frontispiece — Chimneypiece in the Marble Hall, Clandon

3.1 Hypocaust at Saalburg	75
3.2 Central hearth, Penshurst	78
3.3 Algarve chimney	81
3.4 Pennsylvania Fireplace (1745)	83
3.5 Joly's fireplace	85
3.6 Common flue (1857)	90
3.7 Room in a Moscow palace, with masonry stove	93
3.8 Convoluted stove	95
3.9 Musgrave stove (1857)	96
3.10 Two portable stoves	98
3.11 Tudor's patent for steam heating (1885)	105
3.12 Paul vacuum system	107
3.13 Dunham vacuum system	108
3.14 Keisselbach steam storage system	109
3.15 Rouquaud system (1899)	113
3.16 Barker's system for promoting water circulation (1903)	115
3.17 Perkins' system in British Museum (1835)	117
3.18 Holcroft and Hoyle's steam boiler (1854)	130
3.19 Foster's terminal-end saddle boiler (1867)	133

3.20 Annular boiler by Bouillon and Muller	133
3.21 Wright's flame-impact boiler (1870)	134
3.22 Wagstaff's cast-iron sectional boiler (1874)	135
3.23 'Challenge' boiler	135
3.24 Two American hot-water boilers	136
3.25 Corner-tube boiler (1958)	137
3.26 Domestic boiler with integral storage (1937)	139
3.27 Juckes' chain-grate stoker	142
3.28 Screw stoker (1937)	143
3.29 Wollaston's gas producer (<i>ca.</i> 1910)	144
3.30 Return-bend and box-end coils	147
3.31 Coil casing	148
3.32 Gothic hot-water stove (<i>ca.</i> 1867)	149
3.33 Bundy radiator	149
3.34 Koerting radiators	150
3.35 Ceiling heating at Bank of England	158
3.36 Stramax panel	159
3.37 Nor-ray-vac radiant tube	161
3.38 Advertisement for electric radiators	166
3.39 Oil stove (1890)	171
3.40 Gas-fired radiant stove	173
4.1 Galton's ventilating grate	179
4.2 Tredgold's ventilator (<i>ca.</i> 1820)	180
4.3 Ridge ventilators	187
4.4 Bockler's stove	189
4.5 Cockle stove	191
4.6 Early air heaters	192
4.7 Warm-air heating	194
4.8 St. Petersburg City Hospital	195
4.9 Warm-air stove (1842)	197
4.10 Ventilating gas burner, House of Commons (1852)	201
4.11 Adam Walker's scheme for ventilation and warming	202
4.12 Hospital bed (Fleming)	203
4.13 Ventilation of House of Lords (1847)	205
4.14 Pentonville Prison	206
4.15 Automatic air pump for York Hospital	209
4.16 Sanderson's circular hospital ward	213
4.17 Seistan windmills	220
4.18 Mine fans (1555)	222
4.19 Desaguliers' fan	223
4.20 Guibal chimney	224
4.21 Combes' fan	225
4.22 Two fans	226
4.23 Rateau screw fan	227
4.24 Harzé fan	228
4.25 Fabry blower	230
4.26 Archimedes screw fan	231
4.27 Helical fans	232
4.28 Contra-rotating fan	235
4.29 Mortier's cross-flow fan (1892)	236
4.30 Mixed flow fan (1960)	237
5.1 Ice house	240
5.2 Steam driven ice saw (1883)	241
5.3 Loefz' ice-making machine (<i>ca.</i> 1860)	244
5.4 Perkins' ether machine (1834)	247
5.5 Methyl ether compressor (Linde, <i>ca.</i> 1875)	249
5.6 Linde's ammonia compressor (<i>ca.</i> 1876)	250

List of Illustrations

xiii

5.7 Boyle's ammonia machine (1872)	251
5.8 Pictet's SO ₂ machine (ca. 1878)	252
5.9 Turbo-compressor (1932)	258
5.10 Grasso single-screw compressor (1975)	259
5.11 Carré's intermittent household absorption machine (1859)	260
5.12 Carré's continuous absorption machine (1859)	261
5.13 Electrolux absorption cycle	262
5.14 DeLaVergne refrigerating plant with atmospheric condensers (1890)	264
5.15 Kirk's cold air machine (1862)	268
5.16 Lightfoot cold air machine (1886)	270
5.17 Audiffren-Singrün SO ₂ compressor	272
6.1 Wind towers at Yazd, Iran	285
6.2 Dr. Jeffrey's earth coiling system (India, 1858)	287
6.3 Air washer for temporary House of Commons (1838)	288
6.4 Ice-block cooling system at Carnegie Hall, New York (1891)	290
6.5 Hall and Kay humidifier (ca. 1908)	292
6.6 'Vortex Ventilo-head' humidifier (ca. 1908)	294
6.7 Victorian dust collector (1869)	295
6.8 Plaster air diffusers, Chicago Auditorium Theatre (1889)	302
6.9 Portable room cooler	303
6.10 Schutz's room air conditioner (1926)	304
6.11 Babcock's window air conditioner (1931)	305
6.12 Terry and Komroff's self-contained air conditioner (1943)	307
6.13 Crane's air-mixing house ventilator (1868)	308
6.14 Induction system	310
7.1 The Hanging Gardens of Babylon (4000 BC)	316
7.2 Aqueducts outside Rome (ca. 350 AD)	320
7.3 A London water-carrier (1572)	322
7.4 London Bridge waterworks (1635)	323
7.5 Turriano's 'Artificio' at Toledo (1588)	325
7.6 Roberts' rain-water separator	327
7.7 Earth closet (ca. 1923)	339
7.8 Liverpool trough water closet (ca. 1869)	340
7.9 Terracotta bath from Minoan palace, Crete	341
7.10 Cagaloglu Hammam, Istanbul	342
7.11 Stepped bath, Gujarat, India (ca. 1500)	343
7.12 Domestic bath tub of late 18th century	344
7.13 Electric bath installation (1886)	346
7.14 Public toilet at Timgad (ca. 100 AD)	347
7.15 Sir John Harington's water closet (1596)	349
7.16 Cummings's water-seal closet (1775)	350
7.17 Law's pan closet (1796)	352
7.18 Jennings' closet (1892)	353
7.19 Early water heater	356
7.20 Solid fuel water heater and bath (1897)	357
7.21 Combined cooking range and bathwater heater (1897)	357
7.22 Perkins' system used for hot water supply (1884)	359
7.23 Mixed cylinder-tank system (1904)	359
8.1 Machine for making lead pipe (1883)	365
8.2 Egyptian shaduf (1500 BC)	370
8.3 Archimedes spiral screw (ca. 230 BC)	370
8.4 Roman force pump, Silchester	371
8.5 Rotary displacement pump (1588)	372
8.6 Papin's 'Rotatilis Suctor et Pressor Hassiacus' (1689)	374
8.7 Massachusetts pump (1818)	376
8.8 Blake's vertical 'disc' pump (1831)	377

8.9	The three pumps (by Appold, Bessemer and Gwynne) at the 1851 Exhibition	377
8.10	Domestic central heating pump (<i>ca.</i> 1955)	379
9.1	Fire squirt as used at the Great Fire of London (17th century)	382
9.2	Jan van der Heiden's fire pumps (Amsterdam, 1673)	383
9.3	Early fire-fighting apparatus (17th century)	384
9.4	Fire engine by Braithwaite and Ericsson (1830)	387
9.5	First automatic sprinkler by Harrison (1864)	390
9.6	Parmelee's improved sprinkler (1878)	390
9.7	Fused sprinkler (<i>ca.</i> 1880)	390
9.8	Grinnell sprinkler head (<i>ca.</i> 1881)	390
9.9	Lescale's automatic fire escape (1878)	392
9.10	Water-cooled structure for fire protection (80 Cannon St., London; 1976)	394
10.1	Daylighting of Egyptian temples (<i>ca.</i> 2000 BC)	396
10.2	The Pantheon, Rome (AD 126)	397
10.3	Halles Centrales, Paris (1853)	401
10.4	Float lamp (13th century)	404
10.5	Roman lampholders	405
10.6	German stage, with hanging chandeliers (17th century)	408
10.7	A 16th century scholar	409
10.8	Cardan's sketch of his lamp (<i>ca.</i> 1550)	410
10.9	Chandeliers at Brighton Pavilion	417
10.10	Benham's ventilating gas light (<i>ca.</i> 1860)	420
10.11	Sugg's dining-room ventilating light (<i>ca.</i> 1875)	422
10.12	Wenham recuperative inverted gas lamp (<i>ca.</i> 1890)	423
10.13	Carbon arc lighting outside Royal Exchange, London (1881)	428
10.14	Staite's incandescent lamp (1848)	430
10.15	Roberts' incandescent lamp (1852)	430
10.16	Edison's high-resistance platinum lamp (1879)	432
10.17	Edison's platinum in vacuum lamp (1879)	432
11.1	Hair hygrometer (de Saussure, 1780)	440
11.2	Drebbel's thermostat (early 17th century)	441
11.3	Damper regulator for hot water boiler (1870)	443
11.4	Appold's apparatus (1866)	443
11.5	Direct acting bourdon tube thermostat (<i>ca.</i> 1908)	445
11.6	Electro-pneumatic system - the electric thermostat (<i>ca.</i> 1890)	447
11.7	Johnson pneumatic bimetal thermostat (<i>ca.</i> 1912)	448
11.8	Thermoregulator (<i>ca.</i> 1900)	449
11.9	Dewpoint thermostat (1911)	452
11.10	Differential hygrostat (Carrier, 1911)	453
11.11	Primary air controller (Monnot, 1884)	455
11.12	Koerting primary air controller (mercury) for steam boilers (1890)	455
11.13	Koerting primary air controller (1906)	456
11.14	Monitoring panel, Masonic Peace Memorial Building, London (1933)	459
12.1	Section of Horsfall destructor furnace (1923)	463
12.2	Otis elevator, Eiffel tower (1889)	465
12.3	Rolling staircase at Paris World Exhibition (1900)	466
12.4	Drake's oil well (1859)	469
12.5	Koerting oil burner (1911)	470
12.6	Heat pipe	478
12.7	Bailey's solar water heater (1908)	480

Part III*Frontispiece* — ISO radiator test room

13.1	Tredgold's heat loss experiment (1824)	486
13.2	Ground isotherms	498
13.3	Occurrence of cold spells	499
13.4	Influence functions	504
13.5	Preheating time	506
13.6	Cast-iron radiator tests (1931)	509
13.7	Friction chart (1913)	518
13.8	Sol-air temperature	521
13.9	Carrier psychrometric chart (1917)	523

INTRODUCTION

"Those who cannot remember the past are condemned to repeat it" (Santayana).

"In attempts to improve, it is always desirable to know exactly what progress has been made — to be able to measure the distance we have laid behind us in our advances, and also that which remains between us and the object in view. The ground which has been gone over is easily measured, but to estimate that which still lies before us is frequently much more difficult" (Rumford).

"Technology covers as wide a field as history, and has of necessity history's slowness and ambiguities. Technology is explained by history, and in its turn, explains history" (Braudel)⁽¹⁾.

Bronowski has observed that man, almost alone of all the animals, does not accept his (natural) environment, but seeks to change and modify it to suit his own needs and purposes. The present work is an outline of the history of man's efforts to make this change; but in compiling it, the force of Braudel's statement became evident. It clearly became impossible to treat the advance of technology in isolation: the social causes of the advance, and the social consequences of the advance, are so significant that to omit mention of them would have been misleading, if not an actual dereliction.

Architecture and building services engineering together constitute man's attempts at environmental control. Together they seek to provide the most suitable environments in which people can work, play and have their being. They seek to minimise the physiological and psychological stresses imposed by the natural ambience. They free man from at least some of the constraints imposed by climate and geography. They have been essential elements in the advance of every civilisation; they may perhaps have contributed to their fall also.

Architecture is the passive element, engineering the active element of the combination. This is not in any sense derogatory: neither one can succeed without the other. Traditional styles of architecture have been developed to give the best possible protection in any one climate, short of engineering control. The thick-walled buildings of the Sahara are particularly efficacious in maintaining equable temperatures inside. The white exteriors reflect sunlight; the narrow streets give maximum shade; the small windows exclude solar heat. Rather similar characteristics typify the architecture of the European countries which border the Mediterranean. In the more humid tropics, where diurnal temperature changes are slight, native architecture uses light buildings with opportunity for copious ventilation.

Architecture, however, gives only limited protection against the climate. It cannot change the temperature; it cannot give light where none exists; it cannot supply water or remove waste. These are the province of engineering.

The originators of early inventions are rarely known, particularly where these are gradual developments of pre-existing techniques. These inventions were however born of need. We have seen how methods of water supply were gradually improved as a consequence of the increasing demands of a growing and more urbanised population. The same forces, less successfully, were operative in sanitation. Heating and ventilation were hardly necessary in the early civilisations which grew up in the warm sub-tropical regions, as Markham has pointed out. It is perhaps significant that the Romans, the first to attempt to colonise the temperate areas of central and Western Europe, were also the people who were pre-eminent in the development of heating and ventilation.

The decline of the early civilisations led to an abandonment, if not a loss, of Greek and Roman technologies, at least in Western Europe, where there was a reversion to an earlier peasant existence. The monasteries of France and Germany survived and retained a core of knowledge which was later exported to Britain with the Norman Conquest.

Islamic and Eastern cultures were unaffected, but apparently made little progress in environmental control. (In Islam, the need to do so was slight.) When travel between Europe and the Near East became possible in times of peace, Islamic methods were reported (e.g. by Ogilvie) and Father Gramont recorded Eastern technology. These had some influence on the Western culture of the Middle Ages and after.

Between the Conquest and the 15th century the monasteries were the repositories of knowledge: it is small wonder that the arts of civilisation were developed in them. In the latter part of this period, the growth of trade enabled knowledge to spread: technologies developed in one part of Europe were translated and adopted in other parts, though this was often a slow process, dependent on the availability of local resources and needs. The last factor became less and less important as the trading patterns enlarged, but it never entirely disappeared, since to import all the necessary resources would be uneconomic.

In the 15th and 16th centuries, we see a revival of experimental science and philosophy, based on observation, and the application of knowledge to practical problems. Large-scale mining was the source of much technological progress from the 15th century on, especially in Germany. The problems involved in pumping, hauling and ventilation stimulated research in allied fields. It was the beginning of the age when genius could flower (Galileo, da Vinci), but those who could indulge their enquiring bent were necessarily of the educated and rich few. In the two centuries which followed, scientific discoveries were made by dilettantes, seekers after knowledge for its own sake. They had no recognised profession. But in the 18th century, members of universities began to contribute. It is probably no accident that many of them were physicians — a discipline which had at least some observational and experimental basis. It was at this time, too, that the basic sciences of physics and chemistry, and the art of mathematics, were being developed in the universities.

A. G. R. Smith has said⁽³⁾

"A basic need if scientific discoveries are to have a significant practical effect on the conditions of life of the average man, is a close prolonged and large-scale alliance between science and technology. It was not to exist before the later eighteenth century at the earliest."

Tredgold was one of those who attempted to forge this alliance.

The Industrial Revolution was a turning point. Its inception was due to the steam engine which provided a new source of power. Once this was available, power-driven machines displaced manually-operated devices; workshops and factories superseded cottage industry; urbanisation spread rapidly. New skills were required, not only by the workpeople, but by the makers of tools. Inventions were then largely due to the manufacturers, like Boulton, Watt and Murdoch, who were also able to exploit these inventions. This may be said to be the beginning of the heating industry. A number of engineering firms included the installation of heating systems in their business; consultants, like Tredgold, arose.

The experiences of the Industrial Revolution awakened the social conscience, and people became ever less willing to accept the squalid and unhealthy conditions of the 18th and early 19th centuries.

The 19th century was the period of the great social reformers. In the context of this history, Duchâtelet and Villermé in France contributed greatly during the first decade to the ideas on public health; in the middle of the century Arnott, Kay and Southwood Smith, Galton and Chadwick urged the necessity for improved water supplies, drainage, sanitation and ventilation of dwellings in Britain; and Pettenkofer established the Munich School of Hygiene in 1865. Other reforms included the prohibition of chimney boys, and there was the introduction both of factory legislation and of important attempts by private individuals (cf. Chadwick's report) to ameliorate the conditions of factory and other workers. Neither was heating neglected. The 1857 Board of Health Commissioners made significant steps in setting down, probably for the first time, the requirements for satisfactory warming — a statement which, apart from the temperature level, has been accepted ever since.

One notices the involvement of eminent scientists in this work — Lavoisier, Gay-Lussac, Leblanc; Wheatstone, Campbell-Stokes and Roscoe. This was a significant step towards the development of a science of Building Services engineering. Previously, almost without exception, work in this field had been the result of efforts by individual savants and dilettante inventors. In the 20th century, there were (and are) many who have devoted their whole life to such matters (Bedford, the ASHRAE teams, Hopkinson, Sabine, Morse, Parkin, Rietschel, Carpenter and others).

An important factor in the development of techniques for heating and ventilation was the increasing number of public buildings in the early and middle years of the 19th century, erected to cater for an urban population. The new municipal authorities then being set up not only required their schools, their town halls and administrative offices, but they were anxious to build prestige buildings as places of public assembly. Asa Briggs mentions Bradford Town Hall as one; St George's Hall, Liverpool, is perhaps another. To these "patrons", cost was of less significance, and they were prepared to experiment (or rather, to allow experiment) in their buildings. The Government itself was no mean sponsor, as witness the many schemes used at various times in the Houses of Parliament. It must be admitted that the desire for improvement, or the desire to take advantage of the most modern knowledge, lay at the back of every attempt, whether occasioned by simple dissatisfaction, or by disaster (e.g. the fire of 1834, or bombing in World War II).

Possibly "lobbying" of members of committees was partly responsible for this attitude, for obviously an inventor (as many after Sutton) would endeavour to secure a trial at public expense. A few, like Winsor, arranged their own public demonstrations; but he was probably alone in setting up a public utility company, the Chartered Gas Light and Coke Company.

From this point on, development and invention were the result of interplay between scientific studies, new materials and methods of manufacture and economic or social needs. No one of these can be said to have been fundamental: need led to study,

study to new techniques; but new techniques also led to study and to new needs.

Some of the original discoveries were accidental, and were useless until a need for them existed. In other cases, and gas is a prime example, from an accidental observation, followed by a number of unrelated *ad hoc* experiments, the need was created by percipient entrepreneurs.

Amongst the academics, the British scientists seem to have been "purer" than the French and German counterparts. Meissner in Vienna, Lavoisier, Péclet and Pettenkofer, applied their scientific results to practical problems (or was it that the practical problems inspired their scientific inquiries?).

By 1900, the newest technological devices were for the most part not of British origin, and what was of even greater importance, they were being more energetically developed in countries which did not have vast capital locked up in well-tried methods of production. Electric power and the internal combustion engine, for instance, were making rapid progress elsewhere, while Britain with her superb equipment based on steam power, was slowly learning that the good is the enemy of the best.⁽²⁾

Auer von Welsbach, Edison and Swan combined inventive genius with commercial acumen. So too did Linde in Germany and Hellyer in Britain. They perhaps mark the beginning of modern industrial research, geared to identifying needs and finding the means of satisfying them on a commercial basis. The Carrier Company in USA was a prime mover in this direction, followed by DSIR in Britain. (Pettenkofer's School of Hygiene in Munich was not an industrial research laboratory. And although Rietschel at Charlottenburg had an organised research school, this too was divorced from commerce.)

Modern R & D is divided between universities and similar academic bodies, autonomous research organisations and the R & D departments of large companies. There is little scope for the private individual. Discoveries and inventions are largely the result of purposeful, directed effort by teams of investigators, though nothing can replace the inspiration or intuition of the individual, whether leader or member of the team — this last is an essential element in any successful invention.

The explosion of research in the last 50 years has had surprisingly little impact on the technologies of building services. Most of the basic principles were laid down during the previous century, and few significant changes have taken place, save in detail or refinement, and of these, energy economy and automatic control have been the most important. Of greater significance has been the application of the available techniques to a wider range of industries and to the development of the tropical and arctic areas of the globe.

The increasing importance of environmental engineering led to the founding of specialist professional institutions. ASHVE in America and IHVE in Britain were founded in the closing years of the 19th century; the illuminating engineering societies at the beginning of the 20th. The report of the first meeting of the IHVE is amusing:

After the Presidential Address at 5 pm, and some discussion, the meeting was adjourned and dinner was served. The menu was (according to the Report) "most elaborate, and the dinner very satisfactory."

"After dinner was served, the toast master, President Jones, called the members to order, and the following programme was gone through, and evidently much enjoyed by all present:

Pianoforte solo, Mr S. Levey

Toast "The Institution of Heating and Ventilating Engineers" proposed by the President and responded to by Vice-Presidents Nesbit and Russell.

Songs "The Longshoreman" (Mr Crispin)

"Whisper and I shall hear" (Mr Miller)

"The Diver" (Mr Taylor)

"Village Blacksmith" (Mr Brown)

A few yarns by Mr Taylor

Songs "Topical song" (Mr Levey)

"Queen of the earth" (Mr Crispin)

"The World went very well then" (Mr Taylor)

"Mona" (Mr J. Taylor)

"Three beggars" (Mr Miller)

"To my watch" (Mr Brown)

"The powder monkey" (Mr Crispin)

Votes of thanks to President, Secretary and Master of Ceremonies."

How very different from the present day — either at a technical meeting or a formal dinner!

What was probably the first technical journal in the field was the *Rohrleger* — now *Gesundheits-Ingenieur* — established in 1878. In its first years, it drew largely on foreign contributions; but gradually these gave way to original German work. The historian now finds the extremely voluminous journals and proceedings of the professional institutions rich sources of information on progress during the last 50 to 70 years.

REFERENCES

1. Braudel, F. (1973) *Capitalism and Material Life 1400-1800*, Weidenfeld.
2. Derry, T. K. and Williams, T. I. (1960) *A Short History of Technology*, OUP.
3. Smith, A. G. R. (1972) *Science and Society in the 16th and 17th centuries*, Thames and Hudson.