BEST COPY AVAILABLE

Variable print quality

A STUDY OF ENERGY IN A COMPLEX INDUSTRIAL ENVIRONMENT

VOLUME II:- APPENDICES

A thesis in two volumes submitted to the University of Aston in Birmingham for consideration for the award of Doctor of Philosophy

Michael Francis Gray, BSc
March 1980

A STUDY OF ENERGY IN A COMPLEX INDUSTRIAL ENVIRONMENT

VOLUME II: APPENDICES

CONTENTS Page

* * *

Diagrams and Tables

Diagrams and tables are located near to the point in the text to which they relate. Each is numbered in such a fashion that the first digits refer to the chapter in which it occurs, the second the section it is in, and the third the sequence within that section.

LIST OF PLATES - APPENDICES

(Note: See figure C14 for positions of thermograms for Tyre 5)

(Note: The legend to the above abreviations is given in table 9.3.3 Chapter IX)

APPENDIX A

DATA AND GRAPHICAL RESULTS OF STATISTICAL ANALYSIS USING BIVARIATE MULTIPLE REGRESSION

A1 Summary of Tables and Figures Included

Table A1a

DATA A - FORT DUNLOP: 1969 - 1976

T Ambient Temperature	D Degree Days	W Product Output	F Total Fuel	E Electricity	Z Total Energy	A Town Water	B Borewell Water	S Steam	C Comp. Air & Hydrau.	G Direct M. Hrs.	H Total M. Hrs.	J T. Energy Prod. Out.	K Steam Prod. Out
^oC		10^6kg	10^6MJ	10^6MJ	10^6MJ	10^3m^3	10^3m^3	10^6kg	10^6MJ	10^3Hr.	10^3Hr.	MJ/kg	kg/kg
5.3	318	6.1	304.5	39.7	344.2	194.2	73.4	75.7	6.9			56.4	12.4
0.1	423	7.1	364.2	41.4	405.6	216.5	76.2	86.2	7.4			57.1	12.1
2.7	384	9.2	463.9	51.5	515.4	257.5	83.9	95.0	9.1			56.0	10.3
7.0	249	6.5	300.3	36.5	336.8	211.4	55.7	63.9	6.7			51.8	9.8
10.9	143	7.6	300.8	40.3	341.1	189.0	72.6	60.0	7.1			44.9	7.9
13.7	93	8.5	321.8	47.7	369.5	271.7	142.1	61.6	8.9			43.5	7.2
16.9	40	6.4	214.5	37.9	252.4	247.0	115.8	41.5	6.9			39.4	6.5
16.1	34	3.2	113.2	23.4	136.6	140.0	43.0	25.2	4.1			42.7	7.9
13.3	90	6.3	222.2	39.6	261.8	188.9	69.1	52.3	8.1			41.6	8.3
12.5	115	6.2	245.1	38.8	283.9	223.5	85.2	55.5	7.7			45.8	9.0
4.9	312	5.8	271.7	38.0	309.7	237.9	79.0	65.8	7.3			53.4	11.3
3.1	387	7.3	406.8	50.0	456.8	259.7	72.7	85.2	9.8			62.6	11.7
3.3	375	5.3	290.7	33.0	323.7	213.5	72.6	74.6	5.8			61.1	14.1
2.5	358	6.3	338.9	39.5	378.4	218.2	79.4	87.1	7.2			60.1	13.8
}5.0	648	14.6	574.9	86.0	660.9	459.4	170.6	162.5	14.9			45.3	11.1
12.9	102	1.6	85.6	9.0	94.6	111.5	27.4	21.9	1.4			59.1	13.7
16.5	51	2.5	92.2	19.1	111.3	167.1	38.4	29.1	3.7			44.5	11.6
15.3	46	6.8	173.5	39.5	213.0	233.6	119.1	52.5	8.4			31.3	7.7
15.9	53	3.5	88.3	29.1	117.4	137.1	76.7	28.0	5.2			33.5	8.0
14.3	72	6.4	166.0	38.9	204.9	213.9	131.0	48.6	7.6			32.0	7.6
10.6	170	7.3	206.3	39.4	245.7	220.6	130.5	48.6	7.8	418.2	452.8	33.7	6.7
7.3	237	7.1	229.3	39.5	268.8	222.7	127.8	69.9	7.3	415.2	449.5	37.9	9.8
4.0	363	9.1	324.0	46.9	370.9	300.0	159.2	95.8	8.8	545.4	586.8	40.8	10.5

Table A1b

Ambient Temperature ^oC	Degree Days	Product Output 10^6kg	Total Fuel 10^6MJ	Electricity 10^6MJ	Total Energy 10^6MJ	Town Water 10^3M^3	Borewell Water 10^3M^3	Steam 10^6kg	Comp. Air & Hydrau. 10^6MJ	Direct M. Hr. 10^3 Hr.	Total M. Hr. 10^3 Hr.	T. Energy Prod. Out. MJ/kg	Steam Prod. Out kg/kg
4.2	356	5.6	219.5	32.1	251.6	190.9	106.3	60.4	6.0	324.1	346.8	44.9	10.8
4.4	319	7.0	230.1	39.4	269.5	228.6	129.0	69.4	6.6	409.1	437.0	38.5	9.9
5.1	325	7.7	283.9	45.4	329.3	280.1	156.1	84.7	8.6	454.4	487.4	42.8	11.0
7.5	249	5.9	200.6	33.2	233.8	195.9	115.2	59.6	6.2	344.3	369.1	39.6	10.1
11.4	155	6.7	238.3	35.9	274.2	210.2	121.6	55.6	6.9	388.6	415.1	40.9	8.3
12.0	111	7.8	224.8	42.0	266.8	251.5	152.0	62.6	8.3	457.8	484.5	34.2	8.0
17.1	40	6.1	177.6	33.9	211.5	226.8	123.9	48.6	6.6	363.5	390.1	34.7	8.0
15.4	43	3.0	77.6	21.2	98.8	185.2	45.5	22.6	3.9	185.3	199.7	32.9	7.5
14.2	93	5.7	166.5	35.4	201.9	201.6	134.8	39.3	7.0	345.8	373.3	35.4	6.9
11.2	161	5.6	174.9	33.6	208.5	168.1	89.8	47.4	6.5	339.7	367.1	37.2	8.5
5.5	294	5.7	191.7	32.9	224.6	169.0	90.7	55.8	6.2	323.2	349.5	39.4	9.8
6.1	285	6.5	260.0	41.5	301.5	236.6	113.4	89.5	8.0	372.2	403.3	46.4	13.8
3.4	372	5.5	215.6	33.3	248.9	158.2	88.1	65.5	5.6	325.3	353.7	45.3	11.9
3.8	336	3.7	214.6	23.6	238.2	135.4	74.2	70.8	4.8	238.4	260.9	64.4	19.1
6.3	285	6.4	257.3	34.6	291.9	178.6	106.7	82.4	7.0	411.3	445.9	45.6	12.9
8.1	213	5.1	191.2	29.6	220.8	138.3	82.4	60.7	6.2	309.9	335.4	43.3	11.9
10.6	167	5.6	198.6	32.2	230.8	150.8	91.2	58.8	6.8	342.4	370.8	41.2	10.5
11.9	123	7.0	223.6	39.6	263.2	176.7	107.8	60.6	8.1	437.2	474.7	37.6	8.7
15.1	59	4.4	133.0	24.1	157.1	108.0	63.7	36.2	5.0	265.4	288.4	35.7	8.2
15.1	53	4.0	112.2	26.1	138.3	127.7	77.7	38.6	5.3	269.2	292.9	34.6	9.7
11.5	138	5.4	179.4	34.2	213.6	178.1	97.4	46.0	7.0	353.8	384.4	39.6	8.5
10.1	180	5.7	191.5	33.6	225.1	156.6	89.0	57.6	6.9	363.1	395.3	39.5	10.1
6.2	276	6.1	202.4	34.3	236.7	210.4	90.6	63.1	7.1	368.5	399.6	38.8	10.3
4.9	322	5.4	268.3	35.0	303.3	160.2	98.9	73.1	7.1	327.6	353.2	56.2	13.5
4.2	347	5.6	215.1	34.6	249.7	150.9	67.2	65.5	7.5	360.5	389.9	44.6	11.7
4.4	316	5.7	230.3	34.1	264.4	170.7	75.4	70.8	7.2	361.4	392.3	46.4	12.4
6.4	310	6.3	259.1	40.6	299.7	168.6	137.6	82.4	9.4	424.1	460.4	47.6	13.1
6.8	258	4.7	199.3	28.9	228.2	136.8	97.2	60.7	6.8	309.4	335.2	48.5	12.9
11.3	143	4.6	223.8	29.8	253.6	146.2	121.9	58.8	7.6	329.3	357.4	55.1	12.8

Table A1c

Ambient Temperature °C	Degree Days	Product Output 10^6kg	Total Fuel 10^6MJ	Electricity 10^6MJ	Total Energy 10^6MJ	Town Water 10^3M^3	Borewell Water 10^3M^3	Steam 10^6kg	Comp. Air & Hydrau. 10^6MJ	Direct M. Hrs 10^3 Hr.	Total M. Hrs. 10^3 Hr.	T. Energy Prod. Out. MJ/kg	Steam Prod. Out. kg/kg
15.0	69	6.3	195.7	39.5	235.2	158.1	158.3	60.6	10.8	427.1	465.0	37.3	9.6
15.8	46	3.9	168.7	24.0	192.7	121.3	106.8	36.2	6.7	260.5	283.8	49.4	9.3
16.4	43	3.6	125.0	26.6	151.6	133.7	149.1	38.6	7.0	262.8	287.0	42.1	10.7
14.2	78	4.7	152.2	32.9	185.1	153.7	110.0	46.0	8.1	339.7	370.4	39.4	9.8
9.0	214	5.7	180.3	32.9	213.2	146.5	113.5	57.6	8.1	362.8	395.3	37.4	10.1
5.5	291	5.4	212.2	33.2	245.4	156.8	118.0	63.1	7.0	364.2	397.4	45.4	11.7
4.4	335	5.2	255.5	36.2	291.7	202.4	83.6	73.1	6.7	365.5	398.9	56.1	14.1
5.4	316	2.8	175.2	16.6	191.8	87.0	49.7	49.0	2.8	182.2	199.1	68.5	17.5
5.4	288	3.3	168.0	19.4	187.4	108.9	58.0	48.4	3.4	222.0	240.4	56.8	14.7
5.4	322	5.6	233.2	32.4	265.6	156.9	98.5	69.3	7.9	377.3	408.5	47.4	12.4
7.4	243	4.7	176.4	27.0	203.4	123.5	50.3	55.7	4.2	294.9	319.5	43.3	11.9
10.9	158	4.8	184.1	28.2	212.3	136.8	41.7	54.6	5.0	311.8	337.7	44.2	11.4
13.4	87	5.2	171.1	30.9	202.0	155.8	48.1	51.0	6.2	330.3	359.8	38.8	9.8
14.3	46	3.9	120.6	21.2	141.8	99.8	42.3	34.7	3.5	243.9	266.8	36.4	8.9
15.0	68	4.0	109.1	24.9	134.0	121.2	80.9	36.8	4.0	244.5	267.0	33.5	9.2
11.8	123	5.3	143.7	30.7	174.4	142.6	57.4	48.9	5.8	310.0	338.7	32.9	9.2
7.7	248	6.0	182.5	31.6	214.1	141.3	53.0	54.4	6.0	332.9	363.0	35.7	9.1
6.0	282	5.3	190.1	29.5	219.6	142.9	52.0	56.5	6.0	314.7	342.7	41.4	10.7
7.5	239	6.3	275.9	34.7	310.6	181.0	67.0	71.9	6.8	386.0	420.7	49.3	11.4
6.1	287	4.5	171.4	28.4	199.8	126.0	49.3	48.2	6.1	262.7	286.1	44.4	10.7
4.0	328	4.7	204.3	28.4	232.7	149.7	58.3	55.3	5.1	287.9	314.3	49.5	11.8
4.4	348	5.9	243.1	34.3	277.4	179.4	66.5	69.8	6.4	354.1	387.6	47.0	11.8
8.3	227	4.1	170.8	24.0	194.8	120.8	46.7	48.1	4.4	248.2	272.9	47.5	11.7
9.5	194	4.6	173.0	26.8	199.8	120.9	51.9	48.8	5.3	291.2	320.2	43.4	10.6
14.5	91	4.4	132.3	27.3	159.6	126.4	53.5	41.3	5.0	295.3	323.7	36.2	9.4
17.3	30	3.3	93.9	19.2	113.3	88.7	39.5	27.3	4.0	220.6	242.2	34.3	8.4
19.2	31	2.9	94.8	20.6	115.4	103.9	44.3	28.4	3.9	216.9	238.1	39.8	9.7
13.3	96	4.2	135.8	26.7	162.5	130.5	52.0	37.6	5.5	276.5	303.3	38.7	9.0
10.2	182	4.5	162.3	27.1	189.4	128.8	69.4	45.5	5.2	284.2	311.5	42.1	10.1
6.2	298	4.5	187.8	27.4	215.2	122.3	61.4	55.5	5.3	290.8	317.4	47.8	12.3
10.7	331	4.6	221.7	31.4	253.1	151.9	57.9	65.8	5.6	291.7	318.7	55.0	14.3

Table A1d

Ambient Temperature ^{o}C	Degree Days	Product Output 10^6kg	Total Fuel 10^6MJ	Electricity 10^6MJ	Total Energy 10^6MJ	Town Water 10^3M^3	Borewell Water 10^3M^3	Steam 10^6kg	Comp. Air & Hydrau. 10^6MJ	Direct M. Hrs. 10^3 Hr.	Total M. Hrs. 10^3 Hr.	T. Energy Prod. Out. MJ/kg	Steam Prod. Out. kg/kg
6.1	302	3.4	144.6	20.6	165.2	97.7	57.4	44.5	4.2	216.9	236.6	48.6	13.1
4.2	332	4.6	195.5	28.3	223.8	125.9	75.4	65.6	5.2	289.8	316.0	48.7	14.3
4.6	343	5.7	238.2	35.4	273.6	162.7	88.7	76.4	6.3	364.1	396.3	48.0	13.4
7.7	237	4.1	162.6	25.2	187.8	123.9	67.6	50.9	4.7	264.2	288.2	45.8	12.4
11.8	127	4.5	159.0	27.7	186.7	125.8	65.3	50.0	5.5	290.0	316.5	41.5	11.1
16.6	54	4.5	129.9	25.2	155.2	135.4	64.8	39.3	5.5	296.5	324.0	34.5	8.7
18.4	30	4.2	116.4	27.4	143.8	126.7	78.9	34.3	5.9	302.6	330.8	34.2	8.2
16.7	47	2.1	56.9	15.8	72.7	92.7	41.0	20.1	2.9	145.7	161.4	34.6	9.6
12.8	100	4.5	134.1	29.5	163.6	135.6	76.8	36.9	6.4	298.1	329.0	36.4	8.2
10.1	175	4.6	144.7	29.7	174.4	105.5	97.8	43.7	6.0	304.6	334.2	37.9	9.5
5.7	302	4.5	161.0	30.0	191.0	99.2	113.0	49.5	5.9	303.4	332.8	42.7	11.0
1.5	437	5.5	269.0	38.5	307.5	168.2	185.7	81.3	7.7	389.0	425.9	55.9	14.8

Table A2 DATA B. FORT DUNLOP: 1976

Degree Days	Total Fuel 10^6 MJ	Specific Fuel MJ/kg	Total Steam 10^6 kg	Specific Steam kg/kg
302	145	42.6	44.5	13.1
332	196	42.6	65.6	14.3
343	238	41.8	76.4	13.4
237	163	39.8	50.9	12.4
127	159	35.3	50.0	11.1
54	130	28.9	39.3	8.7
30	116	27.6	34.3	8.2
47	57	27.1	20.1	9.6
100	134	29.8	36.9	8.2
175	145	31.5	43.7	9.5
302	161	35.8	49.5	11.0
437	269	48.9	81.3	14.8

MEAN VALUES

207	159	36.0	49.4	11.2

SYMBOLS

D	F	J	S	K

Table A3 DATA C. FORT DUNLOP ANNUAL CONSUMPTIONS 1966-76

Town Water $10^3 m^3$	Borewell Water $10^3 m^3$	Total Water $10^3 m^3$	Total Fuel 10^6 MJ	Total Energy 10^6 MJ
2568	1909	4477	3369	3823
2909	2028	4937	3332	3788
3346	1673	5019	3545	4021
3159	1164	4323	3528	4013
2996	1359	4355	2775	3194
3037	1655	4692	2424	2851
2382	1282	3664	2386	2766
2205	1555	3760	2336	2724
1918	836	2754	2126	2452
1859	782	2641	2000	2322
1800	1214	3014	1895	2237
MEAN VALUES				
2562	1405	3967	2701	3108
SYMBOLS				
A	B	A+B	F	Z

Table A4 DATA D. DUNLOP UK INDIVIDUAL DIVISIONS: 1975

Divisions	No	Town Water $10^3 m^3$ (A+B)	Total Fuel 10^6 MJ (F)	Total Energy (Z)
Industrial Group				
Fluid Seal	1	140	96	150
Belting	2	232	153	162
Hydaulic Hose	3	128	96	137
Industrial Hose	4	52	97	118
Oil & Marine	5	49	81	93
G.R.G.	6	693	476	550
Polymer Eng.	7	278	197	231
Precision Rubber	8	17	30	44
Rubber Plastics	9	24	45	57
Total (excluding Fire Armour)		1613	1271	1542
UK Tyre Division				
Fort Dunlop	10	1977	2004	2326
Speke	11	766	780	989
Inchinnan	12	400	491	567
Washington	13	49	92	130
Regent	14	67	219	243
Total (excluding United Reclaim and N.T.S.)		3259	3586	4255
Engineering Group				
Aviation	15	69	139	178
Plant & Equipment	16	8	61	65
Wheel	17	560	365	434
Suspensions	18	66	18	44
Redditch Moulding	19	1	17	24
Total		704	600	745
Grand Total (excluding Fire Armour, United Reclaim, N.T.S., Consumer Group)		5576	5457	6542
MEAN VALUES		293	287	344

Table A5

DATA E U.K. TYRE DIVISION FACTORIES : 1973-75

1. PORT DUNLOP Product Output 10^6kg (W)	Steam 10^6kg (S)	Total Fuel 10^6MJ (F)	Elect. 10^6MJ (E)	Amb.Temp. °C (T)	2. SPEKE Product Output 10^6kg (W)	Steam 10^6kg (S)	Total Fuel 10^6MJ (F)	Elect. 10^6MJ (E)	3. INCHINNAN Product Output 10^6kg (W)	Steam 10^6kg (S)	Total Fuel 10^6MJ (F)	Elect. 10^6MJ (E)	4. WASHINGTON Product Output 10^6kg (W)	Steam 10^6kg (S)	Total Fuel 10^6MJ (F)	Elect. 10^6MJ (E)
5.6	65.5	215.1	34.6	4.2	1.8	26.3	105.0	12.8	1.3	14.6	42.1	7.1	-	-	-	-
5.7	70.8	230.3	34.1	4.4	2.7	26.8	116.5	11.9	1.5	16.9	48.5	8.2	-	-	-	-
6.3	82.4	259.1	40.6	6.4	3.2	31.4	154.8	15.0	1.8	21.3	45.5	9.9	0.7	-	13.1	2.9
4.7	60.7	199.3	28.9	6.8	2.5	23.0	106.7	16.6	0.8	11.3	37.6	5.2	0.5	-	10.0	2.6
4.6	58.8	223.8	29.8	11.3	2.7	25.6	104.0	11.6	1.5	15.4	50.2	7.7	0.5	-	9.3	2.9
6.3	60.6	195.7	39.5	15.0	2.7	17.4	73.7	12.5	1.7	18.6	60.1	9.5	0.7	-	9.4	2.9
3.9	36.2	168.7	24.0	15.8	2.0	13.8	57.7	8.4	0.7	7.6	22.0	4.0	0.6	-	7.4	3.1
3.6	38.6	125.0	26.6	16.4	1.8	10.6	44.6	9.8	1.0	11.4	33.8	5.7	0.2	-	3.8	2.0
4.7	46.0	152.2	32.9	14.2	0.5	6.3	19.1	3.3	0.4	4.7	14.3	3.1	0.7	2.6	8.7	2.7
5.7	57.6	180.3	32.9	9.0	2.6	25.6	106.2	11.6	1.6	16.7	50.6	7.7	0.6	2.8	8.8	3.4
5.4	63.1	212.2	33.2	5.5	2.5	26.0	67.6	11.8	1.7	17.1	52.3	8.1	0.5	2.9	9.2	2.9
5.2	73.1	255.5	36.2	4.4	2.4	30.0	72.9	11.5	1.8	20.7	63.5	8.8	0.6	4.3	12.8	2.6
2.8	49.0	175.2	16.6	5.4	1.1	21.8	75.3	12.0	0.8	7.3	23.5	4.6	0.2	2.5	7.4	1.6
3.3	48.4	168.0	19.4	5.4	2.6	26.8	103.4	8.9	1.0	10.3	30.7	3.6	0.3	2.4	6.9	1.8
5.6	69.3	233.2	32.4	5.4	3.0	35.6	124.3	12.3	1.7	17.9	53.2	7.8	0.6	3.6	10.6	2.6
4.7	55.7	176.4	27.0	7.4	2.1	23.7	80.2	9.5	1.3	12.7	39.1	6.4	0.5	3.0	8.7	2.8
4.8	54.6	184.1	28.2	10.9	2.2	22.0	70.8	9.4	1.6	15.4	46.1	6.5	0.6	2.4	8.4	3.2
5.2	51.0	171.1	30.9	13.4	2.0	18.5	55.6	9.6	2.0	17.5	57.7	8.5	0.7	2.6	8.4	2.7
3.9	34.7	120.6	21.2	14.8	1.6	14.3	43.0	7.3	0.7	7.0	20.6	3.8	0.4	1.7	5.6	2.7
4.0	36.8	109.1	24.9	15.0	1.5	13.2	41.8	8.5	1.1	10.7	32.2	5.1	0.3	1.1	3.8	2.2
5.3	48.9	143.7	30.7	11.8	2.0	14.4	59.0	11.7	1.8	17.3	48.4	8.2	0.8	2.9	8.9	3.2
6.0	54.4	182.5	31.6	7.7	1.6	23.2	55.8	9.5	0.8	10.8	32.7	4.5	0.7	3.5	10.4	3.5
5.3	56.5	190.1	29.5	6.0	1.4	20.6	99.6	9.7	0.9	12.1	36.2	4.9	0.7	3.9	11.7	3.5
6.3	71.9	275.9	34.7	7.5	1.4	27.4	95.4	11.4	1.6	21.2	50.3	8.5	0.7	3.8	12.3	2.6
4.5	48.2	171.4	28.4	6.1	1.2	20.7	73.4	11.6	1.1	12.4	37.5	4.7	0.7	2.9	8.4	2.7
4.7	55.3	204.3	28.4	4.0	1.7	26.1	87.4	16.6	1.2	15.9	48.1	6.3	0.7	2.9	8.8	2.6
5.9	69.8	243.1	34.3	4.4	2.3	31.8	100.8	20.6	1.2	18.9	57.2	7.4	0.9	3.4	10.3	3.3
4.1	48.1	170.8	24.0	8.3	2.0	18.4	69.8	15.2	1.2	11.9	38.7	4.7	0.9	2.6	7.3	2.8
4.6	48.8	173.0	26.8	9.5	1.7	19.7	62.5	15.7	1.3	13.2	42.1	5.8	0.9	2.2	7.1	2.9
4.4	41.3	132.3	27.3	14.5	1.8	13.9	44.1	16.5	1.5	14.7	46.9	6.8	1.0	2.4	7.7	3.4
3.3	27.3	93.9	19.2	17.3	1.8	13.5	41.8	15.0	0.7	7.8	25.3	3.4	0.6	1.7	5.6	2.3
2.9	28.4	94.8	20.6	19.2	6.3	48.3	19.4	7.1	0.5	6.7	22.4	3.1	0.3	0.9	3.1	1.1
4.2	37.6	135.8	26.7	13.3	2.0	14.9	52.4	17.6	1.5	15.2	52.1	7.1	0.9	2.3	7.7	3.3
4.5	45.5	162.3	27.1	10.2	1.7	16.7	60.1	15.0	1.0	11.6	37.5	5.6	0.8	2.3	7.2	2.9
4.5	55.5	187.8	27.4	6.2	1.8	23.1	73.9	15.1	1.1	13.2	43.5	5.8	0.8	2.7	8.7	2.9
4.6	65.8	221.7	31.4	10.7	1.9	26.4	95.3	18.3	1.2	15.9	51.4	6.5	0.9	3.6	10.7	3.5
MEAN VALUES																
4.8	53.2	180.7	25.7	9.7	2.0	20.9	75.4	12.2	1.2	13.3	41.5	6.1	0.6	2.7	8.3	2.8

Figure A6 **Fuel vs. Production Output**

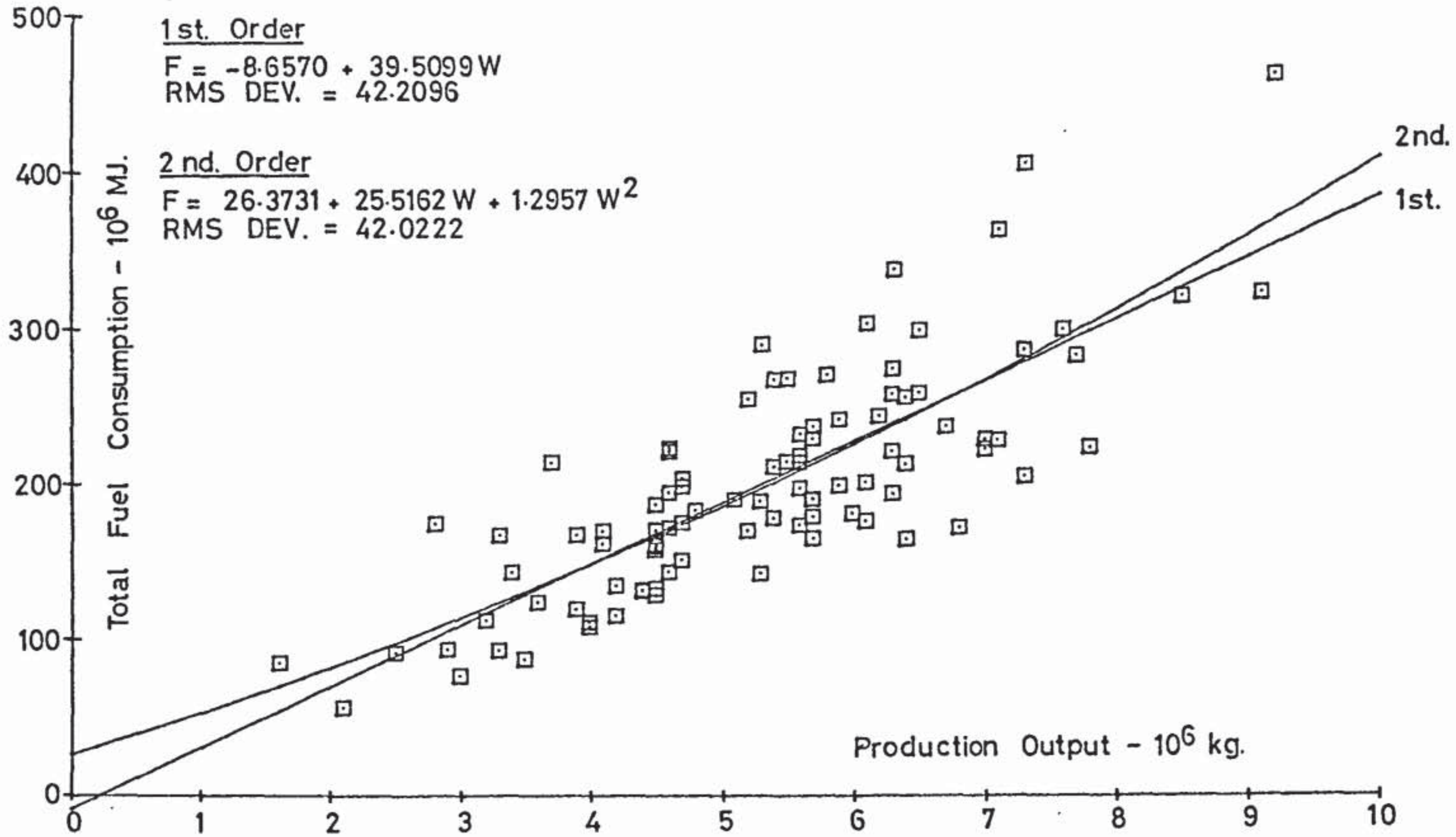


Figure A7 Electricity vs. Production Output

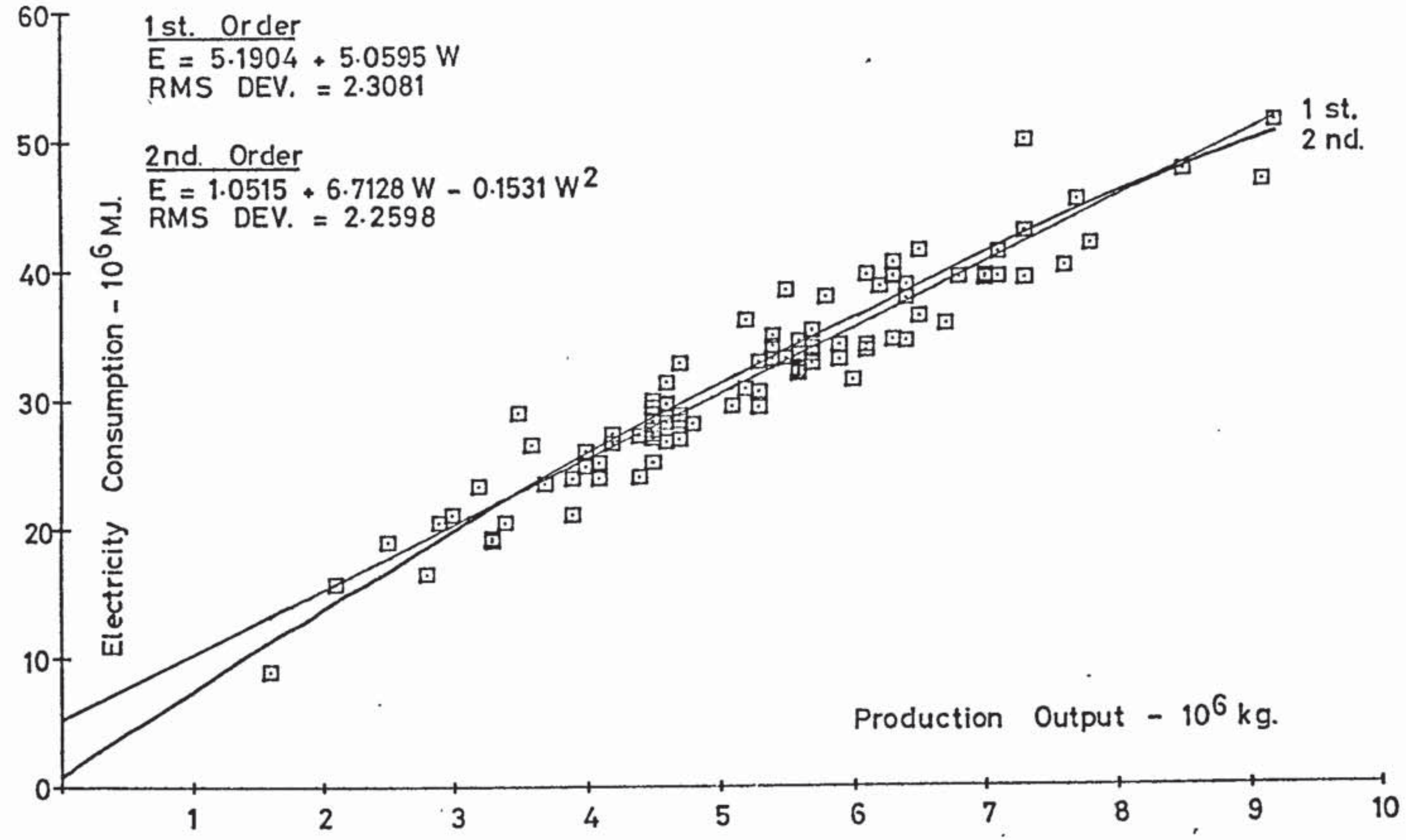


Figure A8 **Total Energy vs. Production Output**

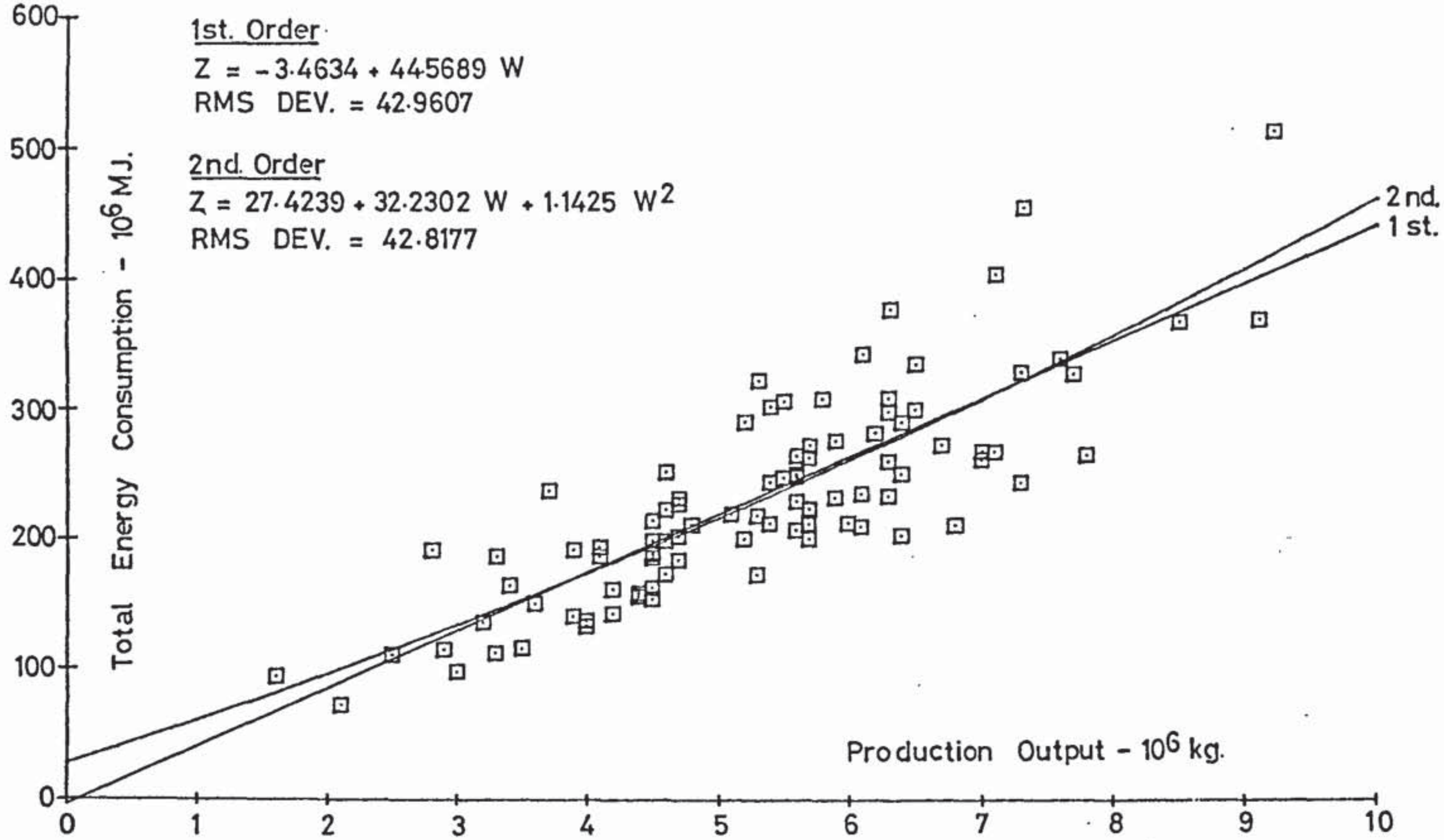


Figure A9 **Town Water vs. Production Output**

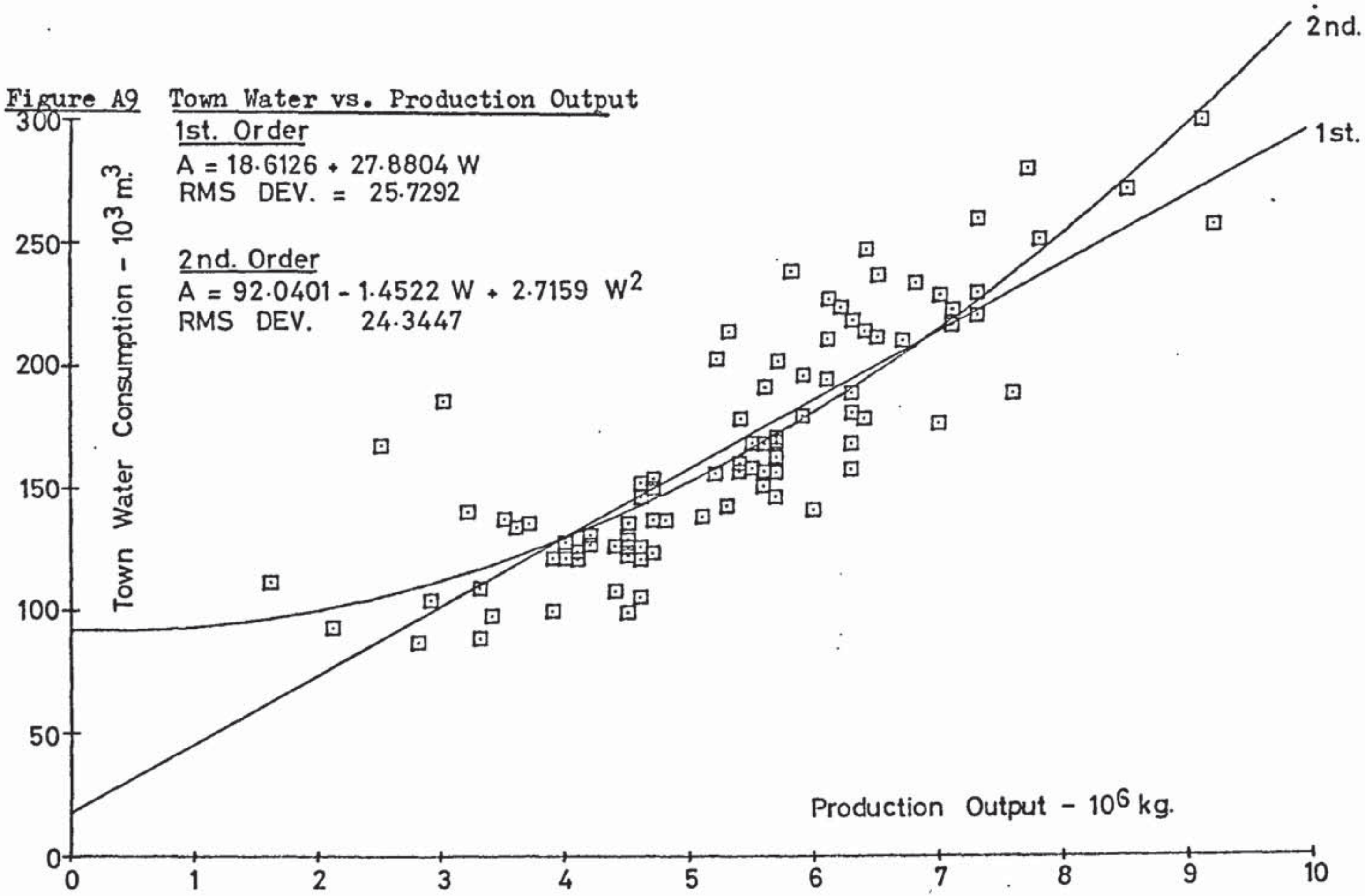


Figure A10 Borewell Water vs. Production Output

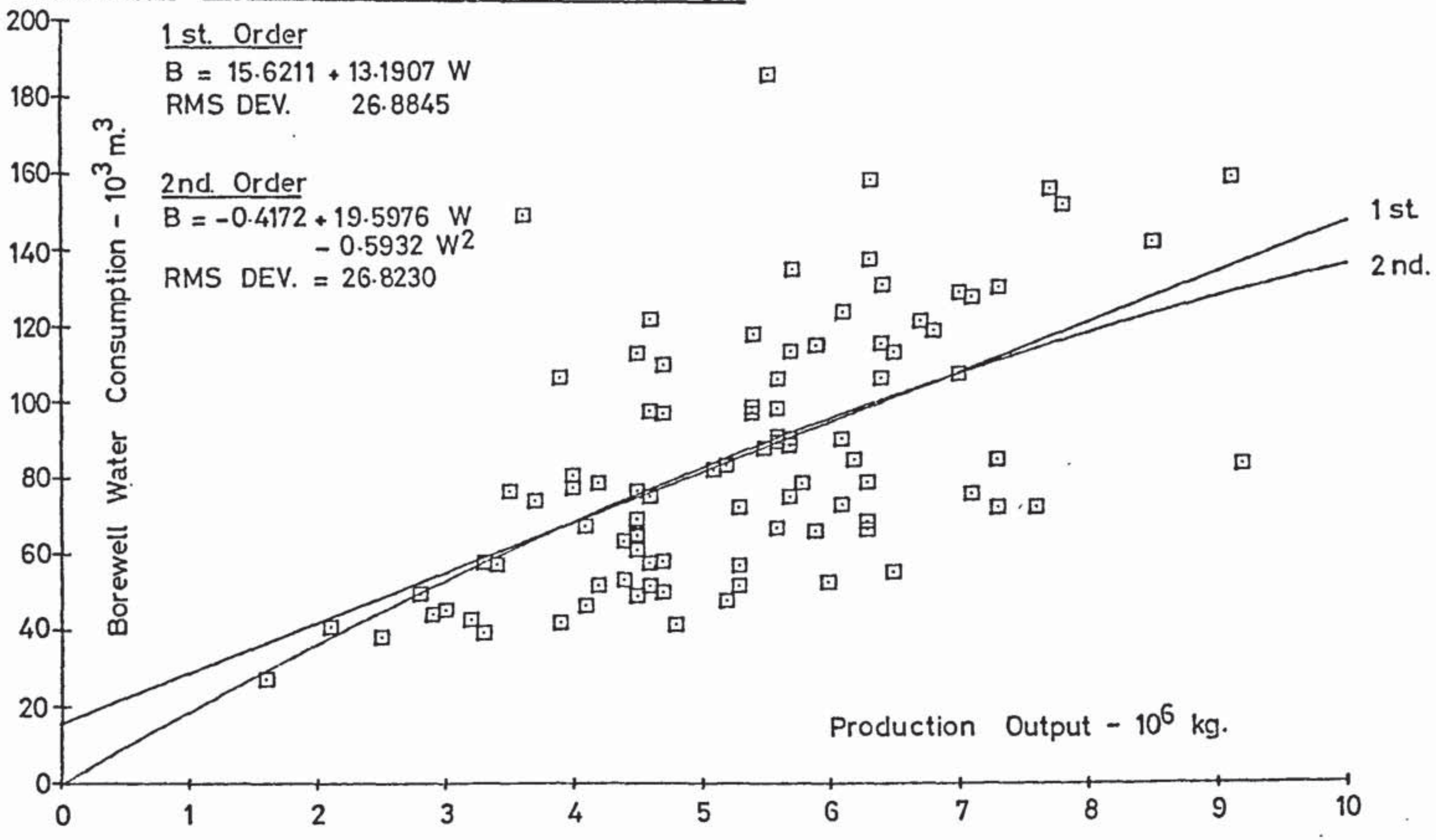


Figure A11 Steam vs. Production Output

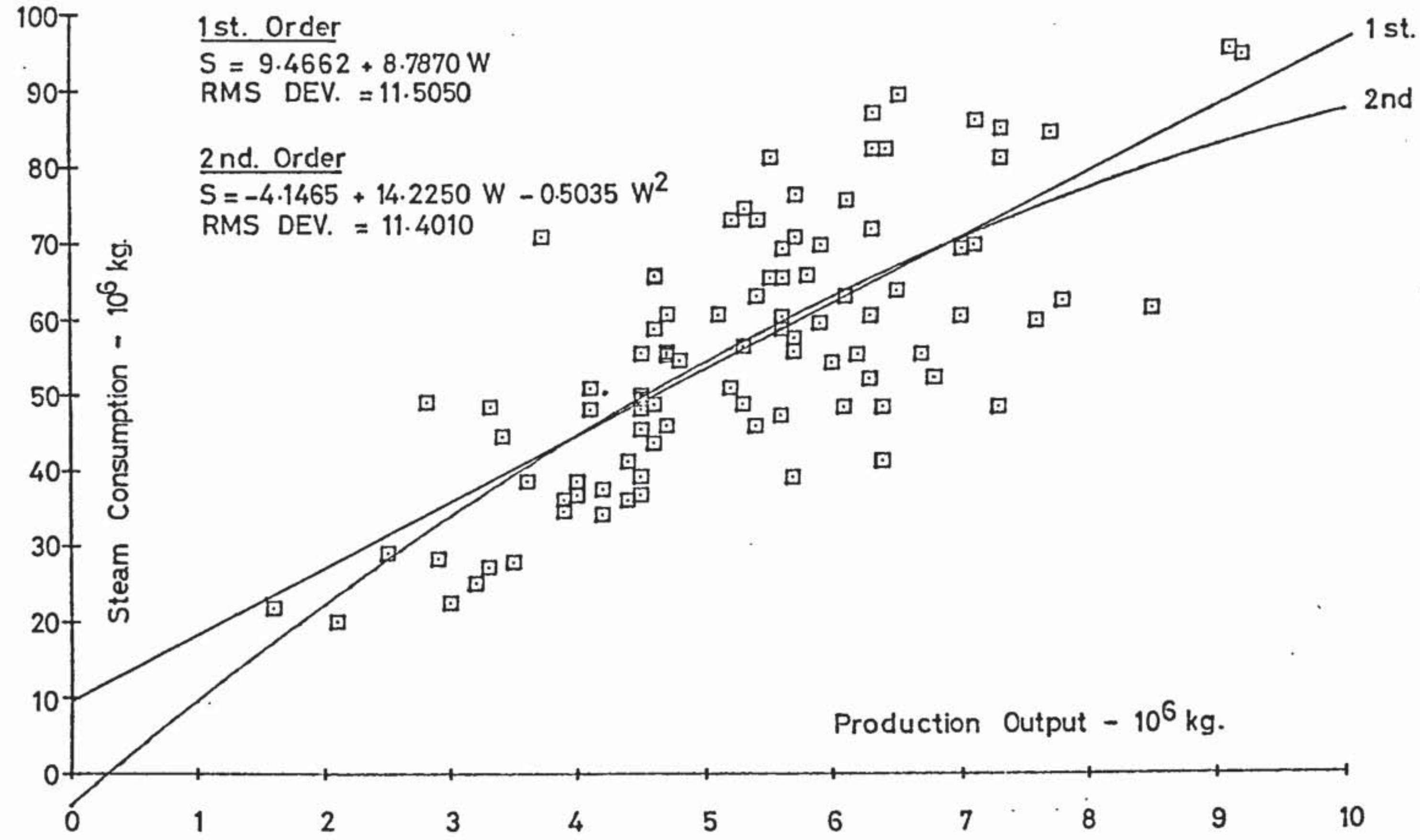


Figure A12 Total Fuel vs. Temperature

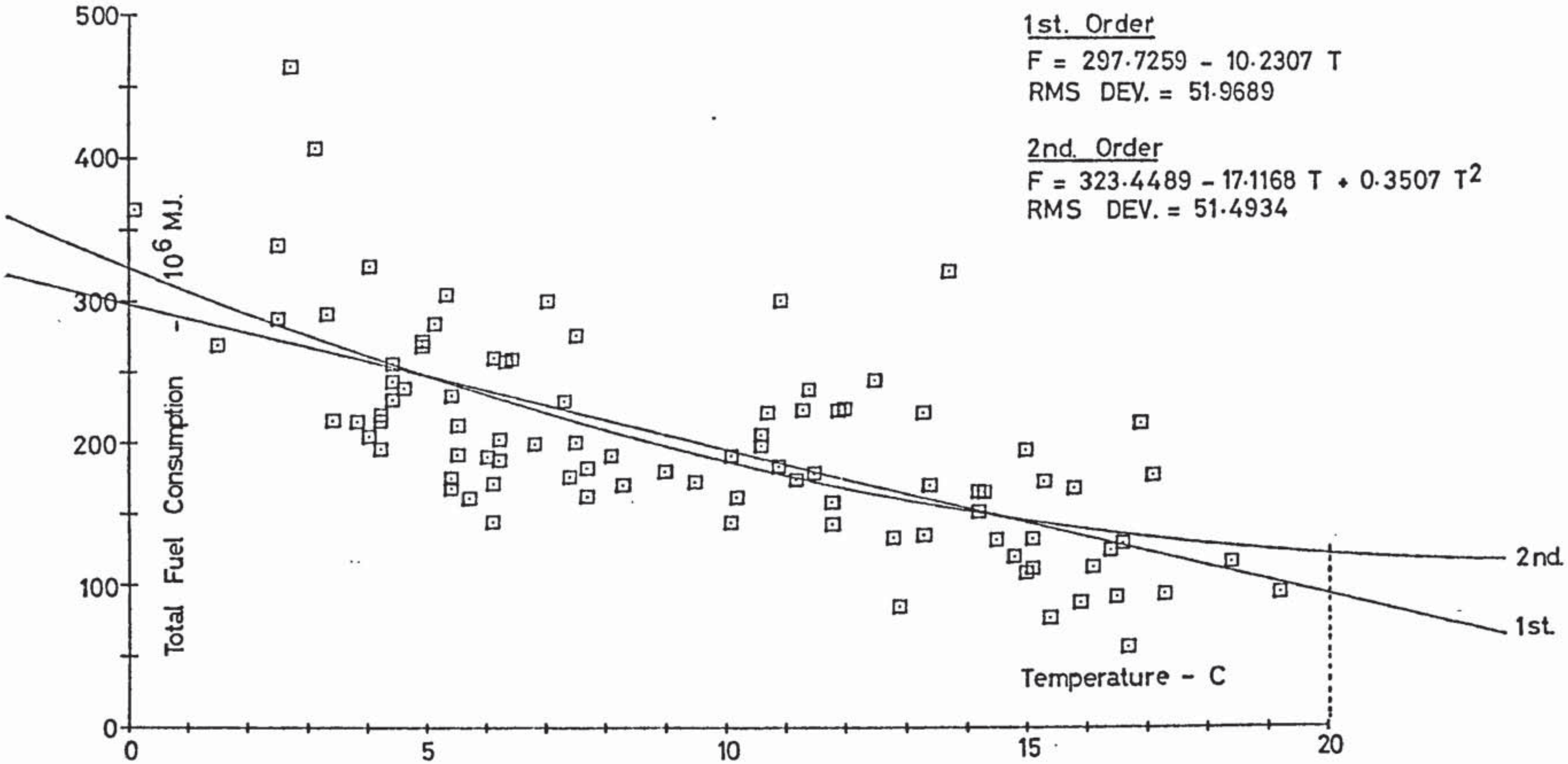


Figure A13 Total Energy vs. Temperature

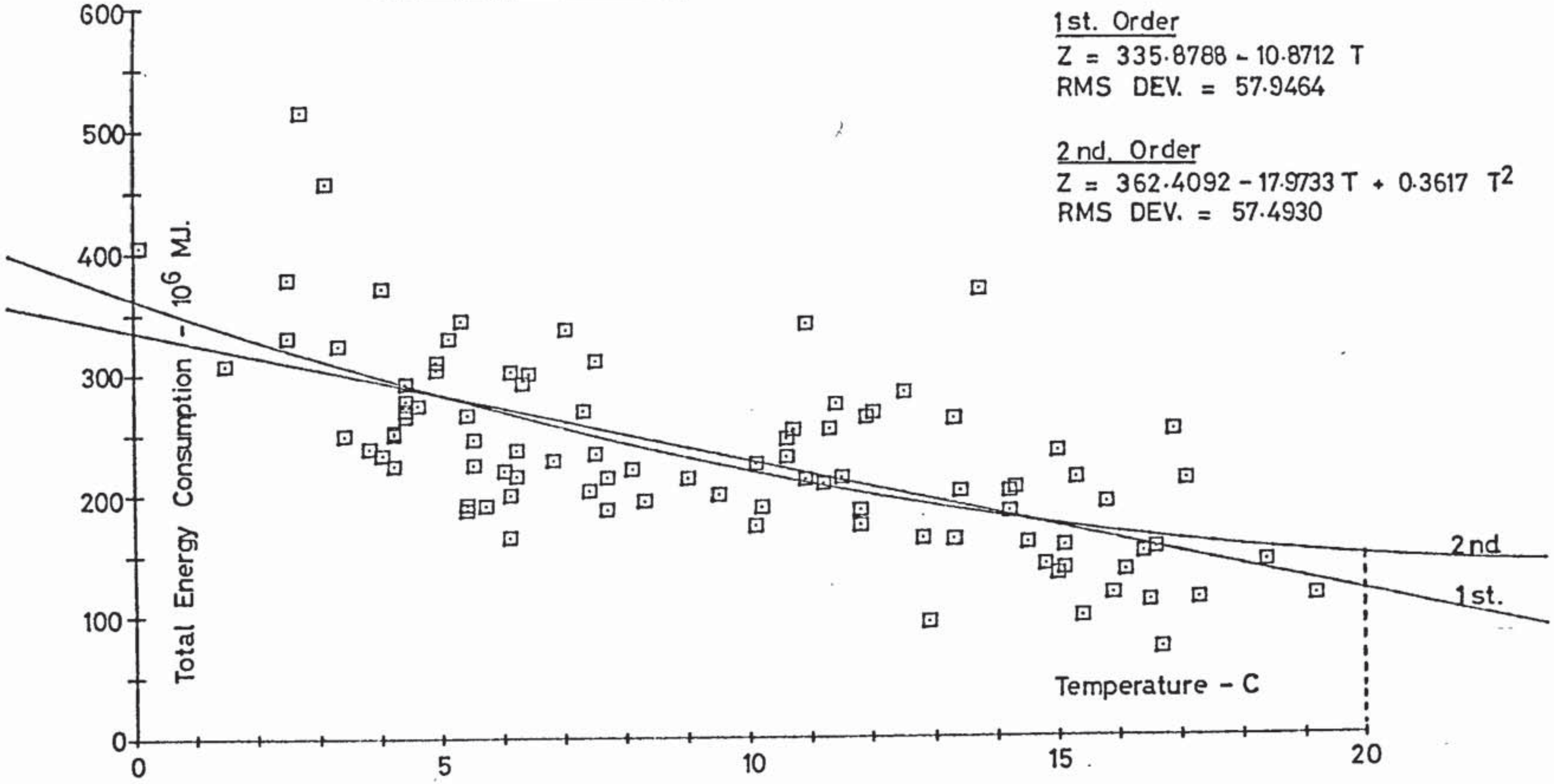


Figure A14 Steam vs. Temperature

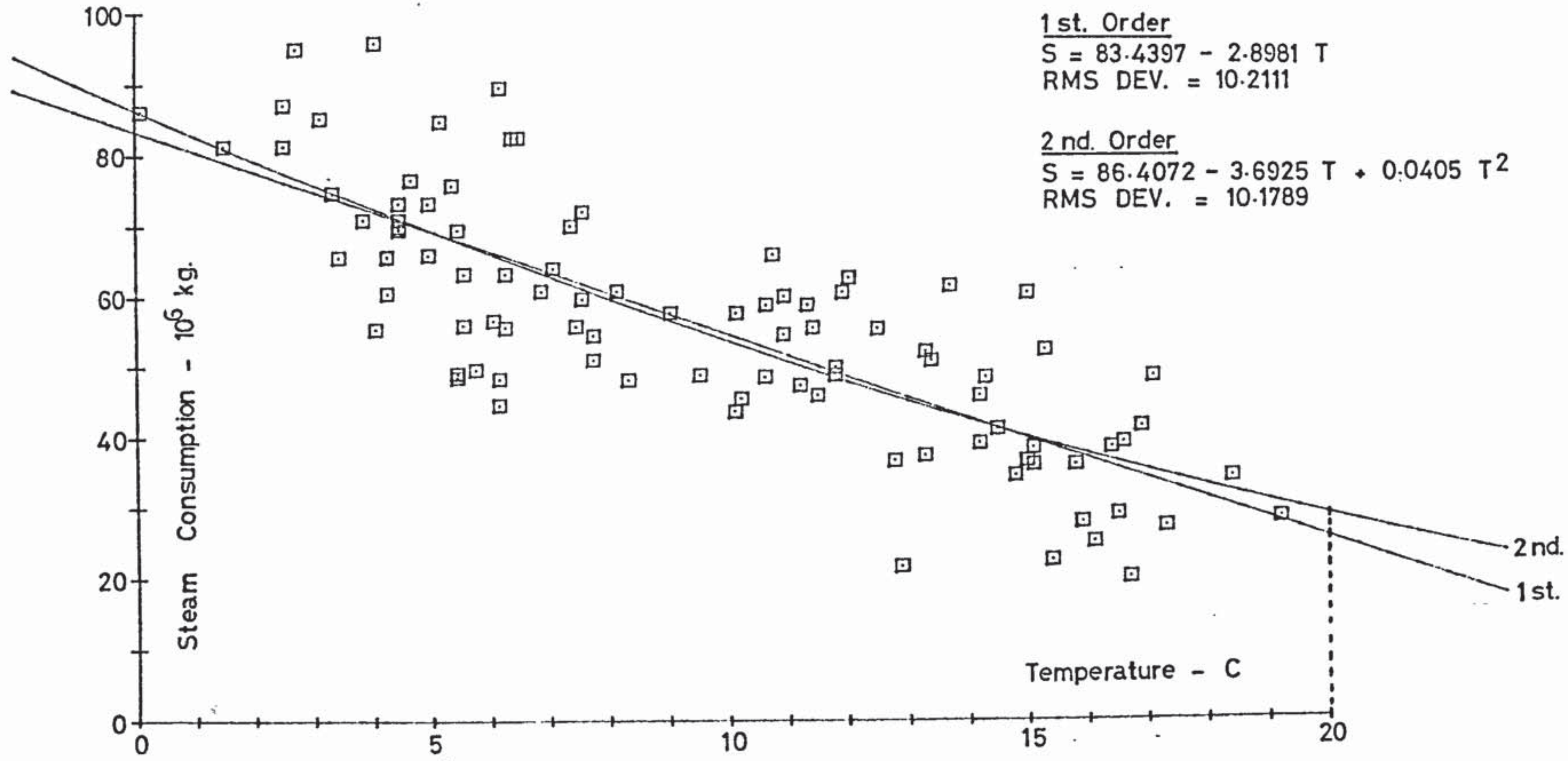


Figure A15 Specific Fuel vs. Temperature

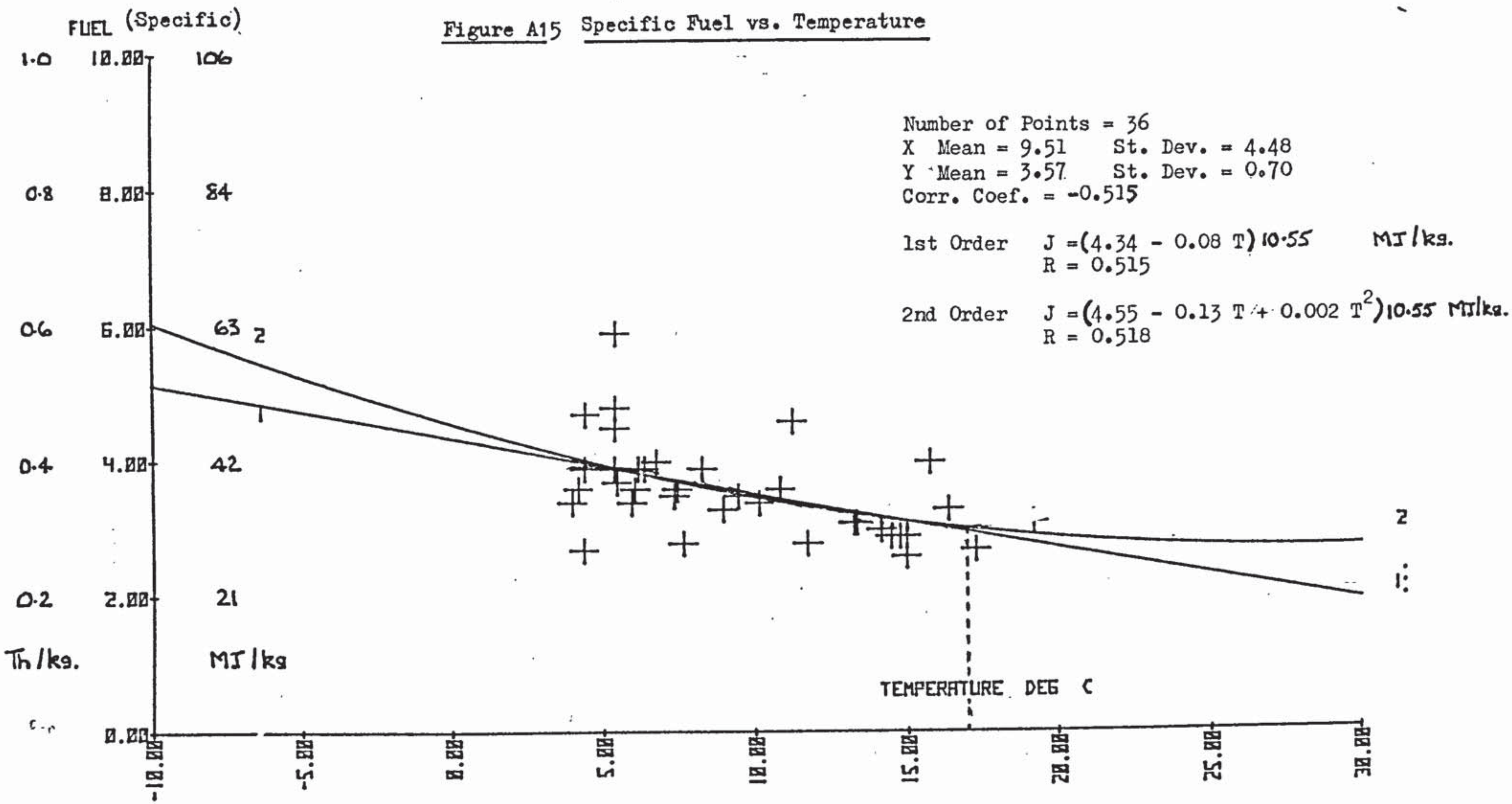


Figure A16 Specific Steam vs. Temperature

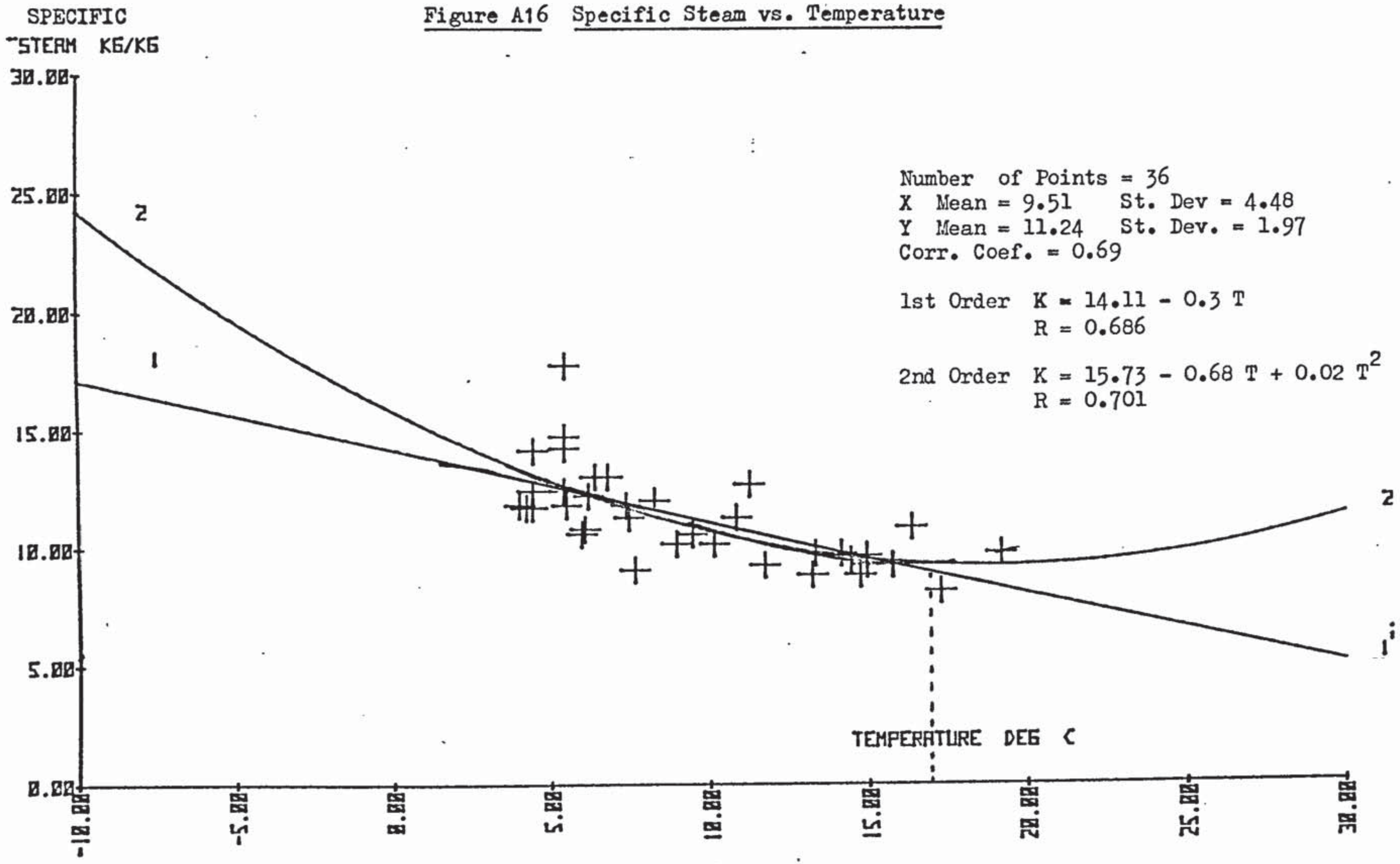


Figure A17 Direct Manhours vs. Production Output

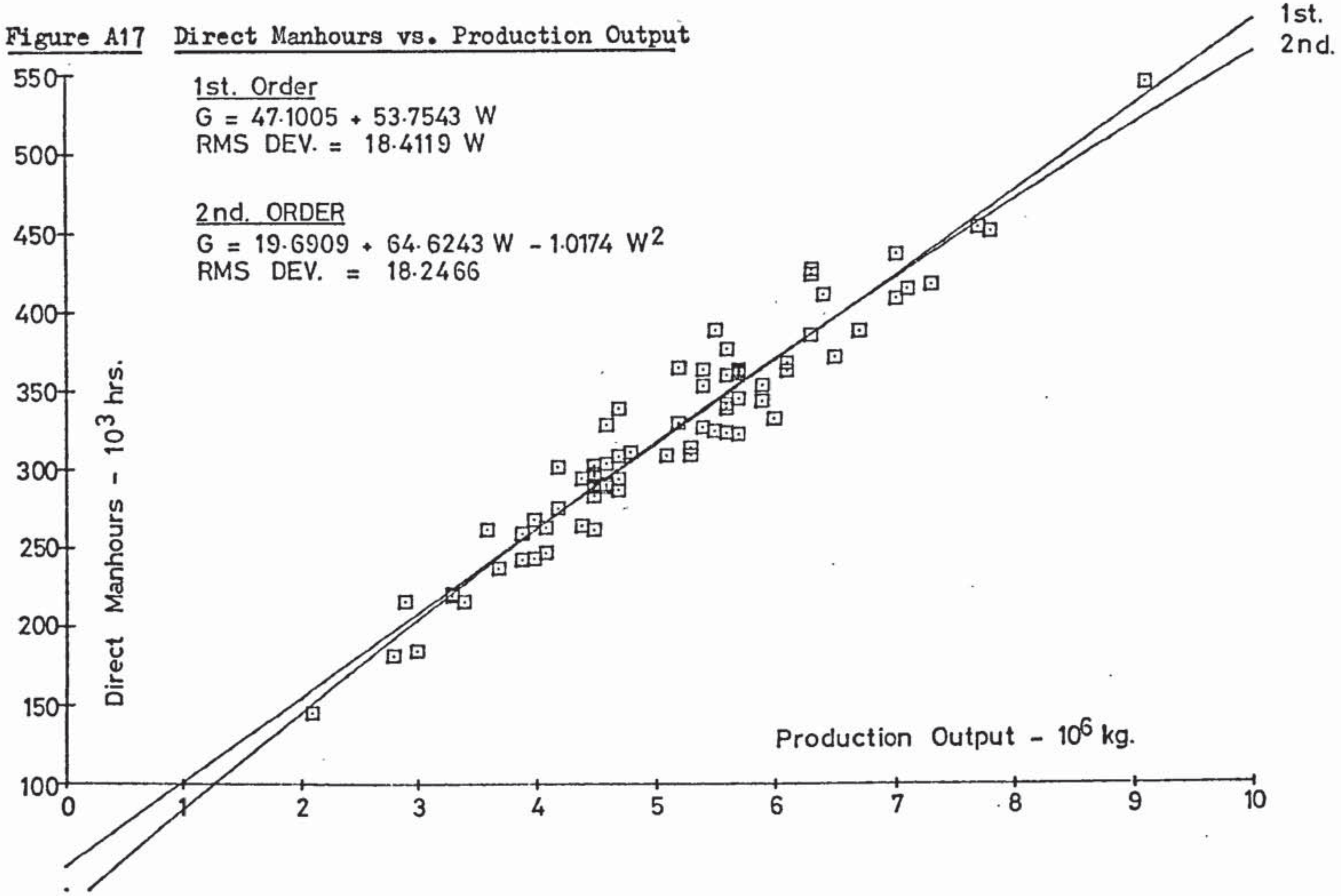


Figure A18 Total Manhours vs. Production Output

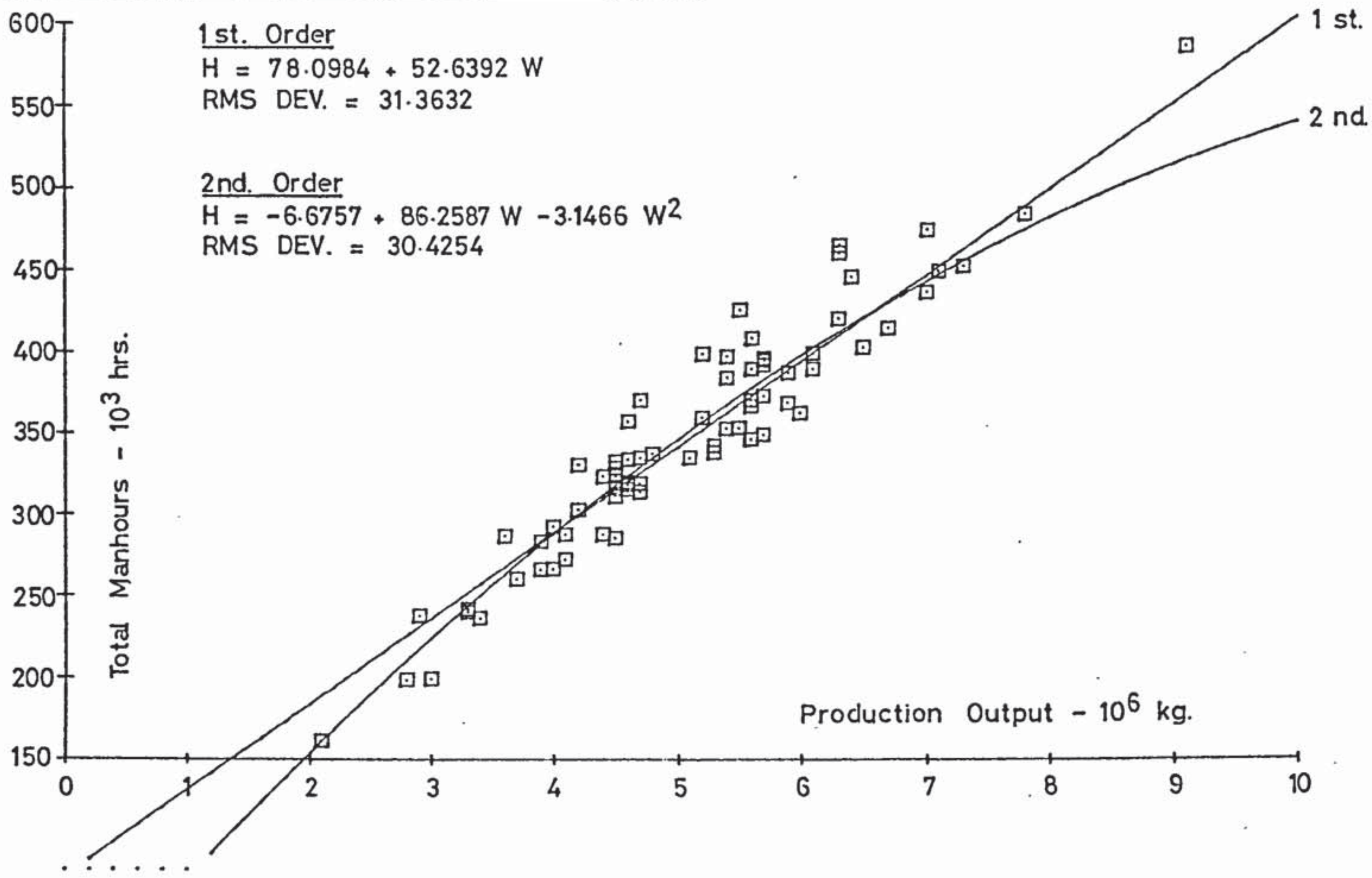


Figure A19

Total Energy vs. Total Manhours

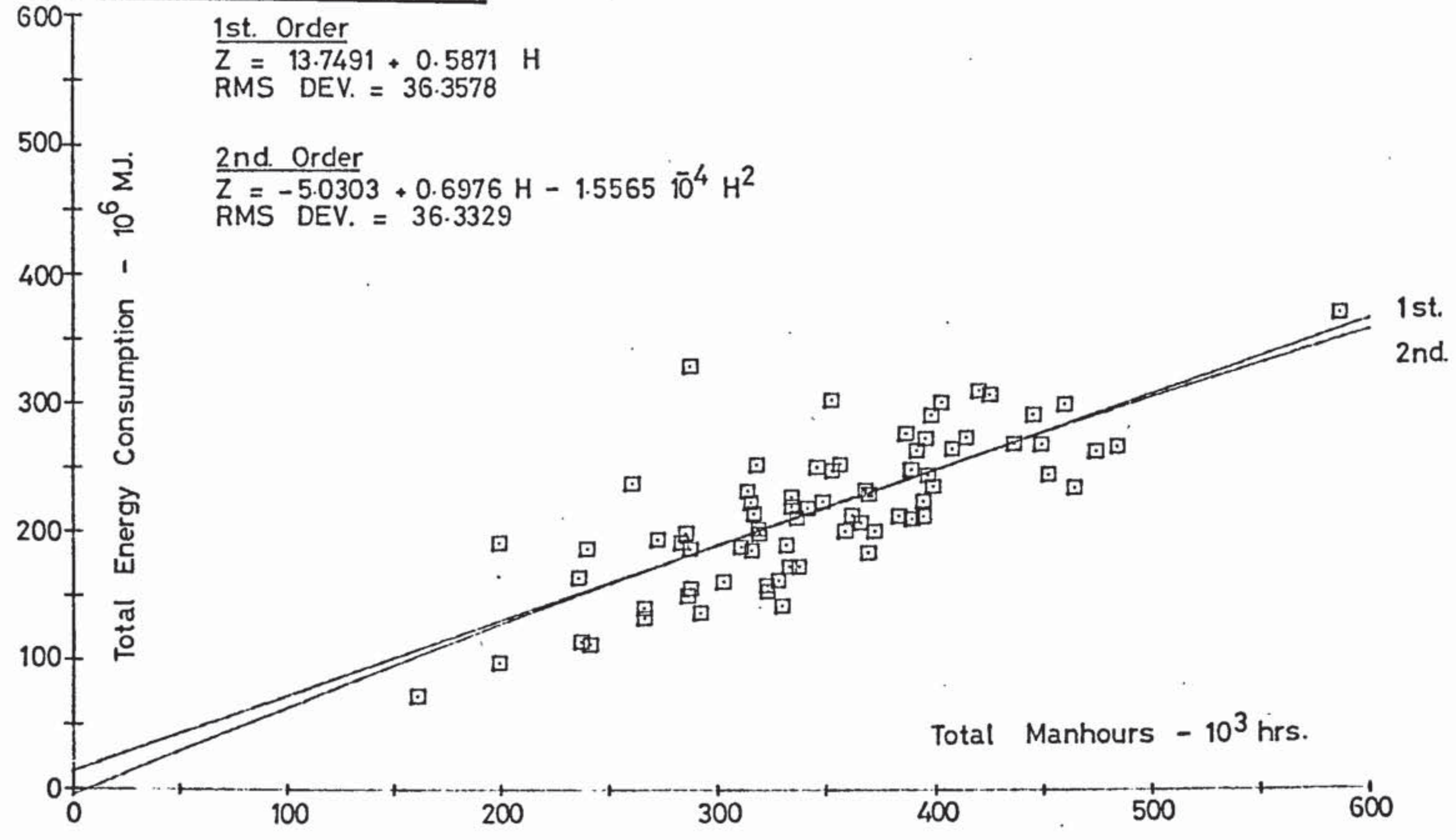


Figure A20 Steam vs. Total Manhours

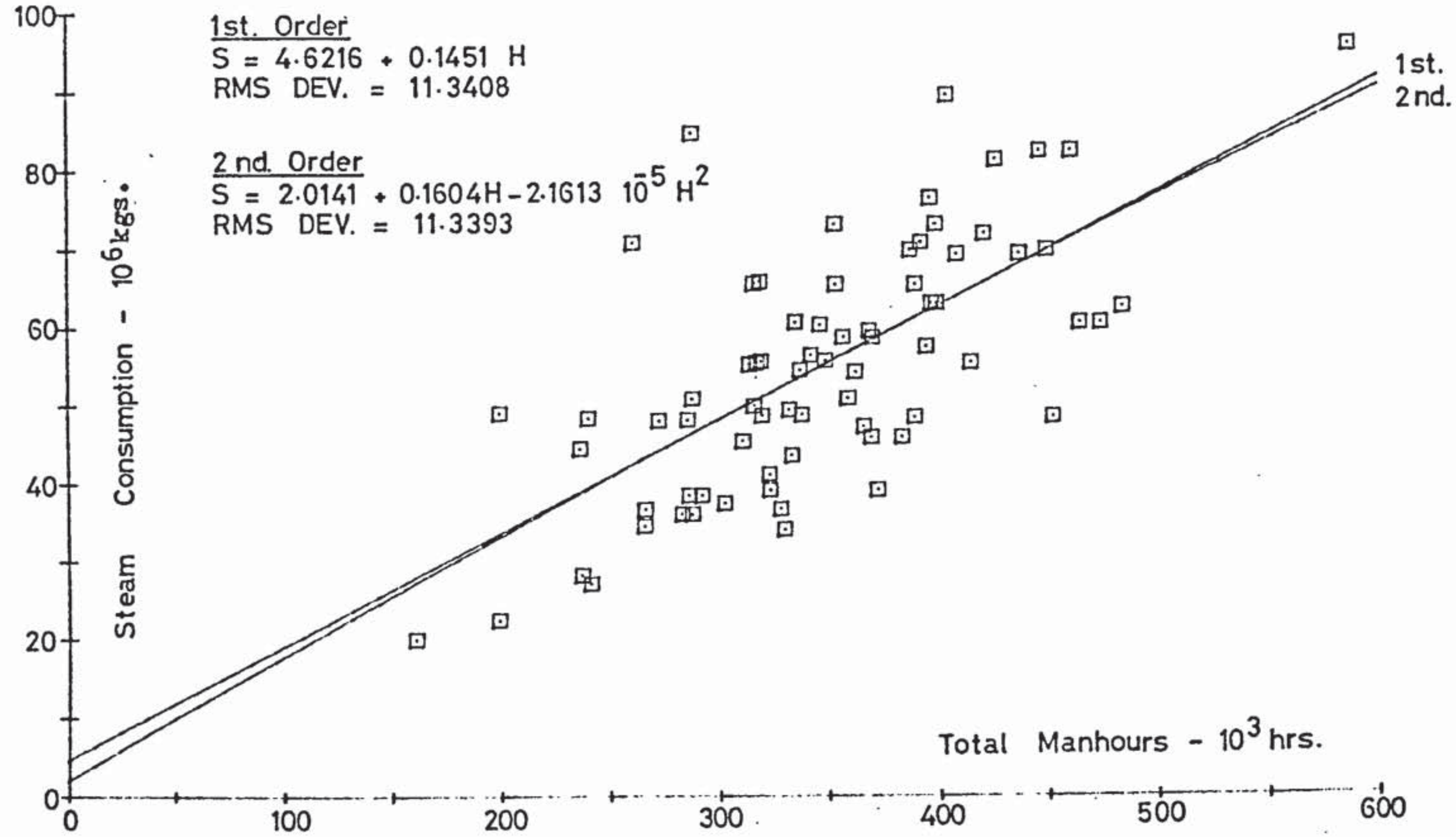
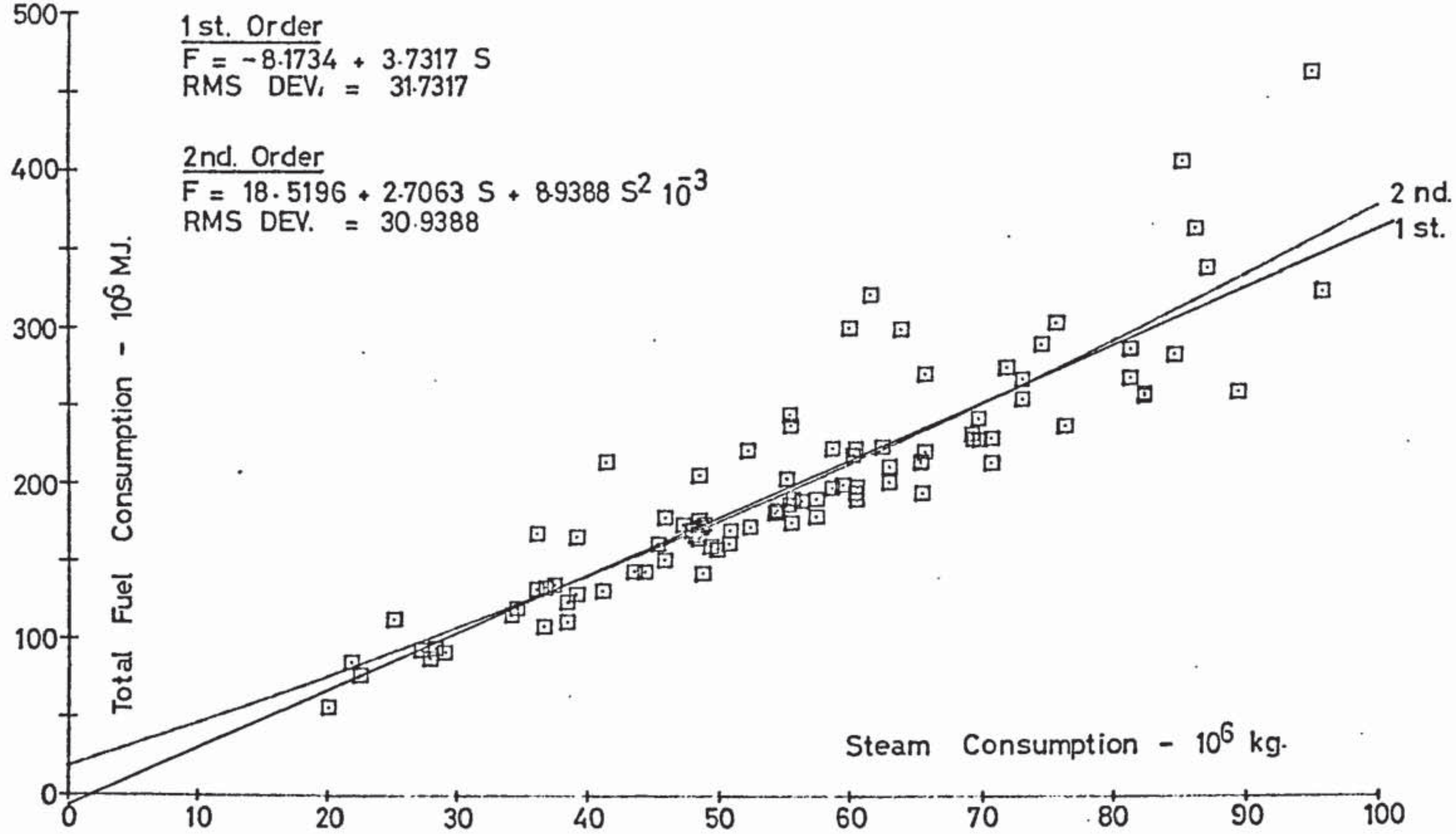


Figure A21 Total Fuel vs. Steam



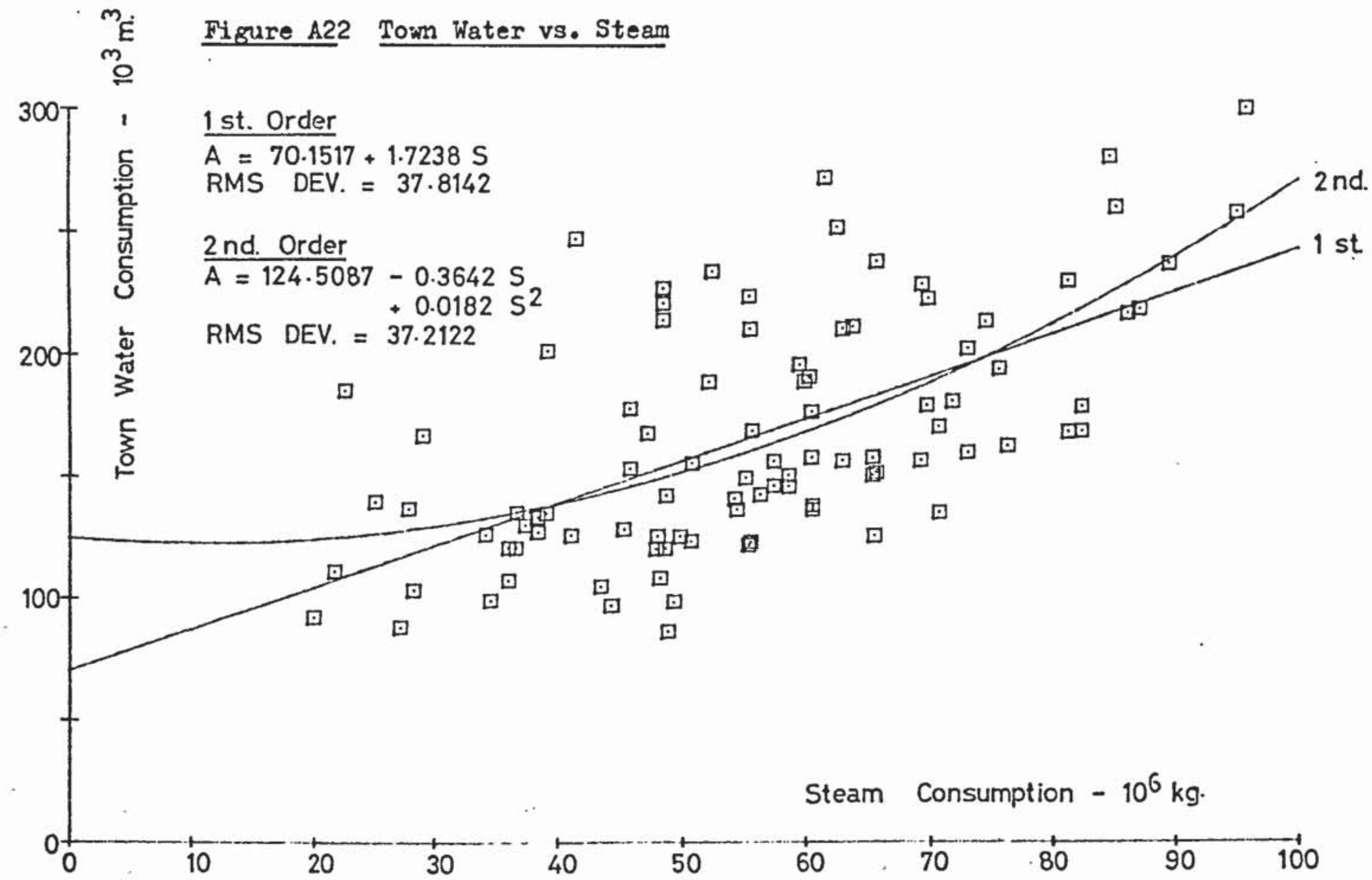


Figure A22 Town Water vs. Steam

A2 1 Results of Polynomial Regression

The following results have been obtained from the Hewlett Packard H.P. 9830 programmable calculator, using a Polynomial Regression Pack developed by D.C. Hickson. This programme however, did not provide a correlation coefficient for each equation, consequently feasibility of the 'fit' has been assessed on the RMS deviation; the average percentage fluctuation equalling the RMS value divided by the upper limit of the y scale.

It must be noted that for specific consumption analyses, the results obtained were based on only 36 sets of data.

A2.1 Independent Variable = Production Output (W)

A Total Fuel Consumption (F)

- It is impossible to produce tyres without consuming some energy. This enforces the adoption of the 2nd order equation. The feasibility of this choice might well be reinforced by the probability that at low and high production levels, effective fuel usage is poor; whilst throughout the average montjly output range (3,000 to 8,000 tonnes), dependence is more linear.

- The degree of scatter is large, representing an average fluctuation of 8.4%. This shows a poor correlation although still marginally significant when related to the number of points considered.

- The degree of scatter tends to increase with higher output. This could be due to: poor data: poor control of fuel; improvements in utilisation of fuel during the period; and variation in ambient temperature. Output tends to be higher in the winter than during the summer months, so temperature variation is likely to have more effect at this end of the scale.

- The fuel overhead of 26.4 TJ/month is small when related to the average monthly consumption (14%). This could, however, be low since no account has been made for variable overhead.

- The gradient of the line, an indication of efficiency, is mainly dependent on the linear term for smaller outputs. Assuming linearity, improved efficiency would reduce the gradient, which if there was no consequent alteration to fixed overhead, the y intercept might well become positive with the tilting of the line. Ignoring overheads, fuel consumption therefore varies between 2.5 and 39.5 TJ for every 1,000 tonnes of output.

- With evidence of no-linearity at the extreme limits, plus the increasing proportion of the overhead in total consumption as output drops, it is clear that specific consumption is not a suitable measure of efficiency. Assuming the 1st order equation, specific consumption varies as:

$$f = \frac{F}{W} = 39.5 - \frac{8.7}{W}$$

which is non-linear. Similarly with the 2nd order, specific consumption varies as:

$$f = \frac{F}{W} = + 25.5 + 1.3W + \frac{26.4}{W}$$

- Assuming the 2nd order equation to be feasible, the optimum production output for maximum effective usage can be obtained from:

$$\frac{df}{dw} = 1.3 - \frac{26.4}{W^2} = 0$$

hence $W = 4.5$

Assuming the 1st order, maximum efficiency occurs at infinite W, or in real terms, at the maximum output possible for the factory. In practice, linearity will not follow at levels of activity outside the design limits for a factory. It can therefore be deduced that Fort Dunlop operating at excessive output levels is not conducive to fuel efficiency.

B <u>Electricity Consumption (E)</u>

- Choice of equation in this case must lie with the 1st order since, based on theory, it is unlikely that electricity consumption could ever reach a maximum point of inflection; as is the case with the 2nd order equation. Observing the plot, it is difficult to predict any non-linearity at either end of the limits.

- Controllability of electrical use is evident with linearity and a low degree or variation of scatter (average flutuation = 3.9% in the range). This makes for a high degree of significance for this relationship, electrical consumption being almost entirely dependent on production.

- From this two points emerge. Firstly, improvements in efficiency from 1969 to 1976 have obviously been minimal. This could be due to more effective usage at the onset relative to other services such as fuel, thus making further improvement more difficult. Secondly, there is little evidence of other variables, such as hours of daylight, influencing consumption. Lighting etc., must therefore contribute to the fixed overhead.

- The level of fixed overhead of 5.3 TJ/month is higher than that for fuel, amounting to 17% at average activity levels. This could be due to a constant lighting load. Obviously no account can be made for variable overhead such as mechanical/electrical power ratio on machines etc.

- In the case of electricity, variation in specific consumption with output is solely due to the effect of overhead. With this being fairly large, once again there is evidence that specific consumption is not an effective measure of efficiency. Assuming the 1st order equation:

$$e = \frac{E}{W} = \frac{5.2}{W} + 5.1 \quad \text{(which is non-linear)}$$

  Ignoring overhead, approximately 5.1 TJ of electricity are consumed for every 1,000 tonnes of tyres produced.

- Maximum output will provide the optimum level for effective utilisation, assuming linearity holds true at these higher levels.

C Total Energy Consumption (Z)

- As in the case of fuel, it is impossible to have a negative intercept and so the 2nd order equation must be chosen. It is interesting to note, however, that the effect of including electricity in the total has been to reduce this to - 3.5.

- Taking the 2nd order, the most noticeable difference between fuel and total energy is the increased gradient. Once again, however, the correlation approaches linearity over the normal working output range (3,000 to 8,000 tonnes). The mode of the relationship between energy and output, however, demonstrates in physical terms the dominance of the thermal input.

- As for fuel, the degree of scatter at 7.1% fluctuation is large, thus showing poor correlation but relative significance. The amplitude of scatter tends to be greater at higher output levels probably for the same reasons.

- The total energy overhead per month of 27.4 TJ is smaller than expected amounting to 13% of an average monthly consumption. Once again no account has been made for variable overhead.

- If the 1st order is assumed, a slight improvement in efficiency of energy use could tend to tilt the line to give a positive intercept. As in the case of fuel, therefore, linearity should be considered over the normal operation range. Ignoring overheads, energy consumption can be said to range between 32.2 and 44.6 TJ for every 1,000 tonnes of output.

- Since non-linearity and overheads do exist, however, it is again selfevident that specific consumption is not a suitable measure of efficiency. With the 2nd order equation, this varies as:

$$z = \frac{Z}{W} = \frac{27.4}{W} + 32.2 + 1.1\,W$$

- The optimum production output, therefore, occurs when:

$$\frac{dz}{dw} = 1.1 - \frac{27.4}{W^2} + 0$$

hence $W = 50$

D Town Water Consumption (A)

- In this case, choice of order is more difficult. With the high degree of scatter the assumption is that the 1st order should be selected. The feasibility of the choice might be questioned in the light of poor control being a major contributor to overhead; consequently the 2nd order might be realistic. On the other hand, low production tends to occur in the summer, and with little call for steam-heating (a large water consumer), plus the declining use of manpower domestic requirements at this time, the lower value may be acceptable. Physical measurements taken during past shut-downs have estimated, with no production during a summer month, water usage can be between 40,000 and 65,000 lit/day (equivalent to a maximum of 48,000 m^3 a month). This is in accordance with the lower value.

- The extent of scatter is large, amounting to an average fluctuation of 8.5%. Whilst correlation is poor, the relationship is marginally acceptable.

- Unlike that for fuel, the degree of scatter does not increase with output but is random. Whilst water conservation has improved usage in the period, this is more likely to be from the effect of poor control.

- The water overhead of 18,600 m^3/month accounts for as little as 12% at average production levels. It is plausible, however, that there is a large variable overhead associated with the number of employees on the site at any one time; i.e. washing and toilet facilities, heating etc. This, however, tends to be related to production activity. It should be explained that water consumption will tend to increase with heating requirements, since only a small proportion of condensate is returned to the boilers.

- The gradient of the 1st order equation is such that, assuming no overhead, 27,900 m^3 are required for every 1,000 tones of tyres produced.

- Specific consumption, particularly at low output, is not, however, a suitable basis for effective use evaluation.

$$a = \frac{A}{W} = \frac{18.6}{W} + 27.9$$

With this in mind, the maximum level of production for highest effective use would be the optimum.

E Borewell Water Consumption (B)

- For obvious reasons of a negative intercept for the 2nd Order plot, the linear equation must be chosen. This complies with assumptions based on the degree of scatter. It is also unlikely that the equation should have a maximum point of inflection.

- The degree of scatter in this case is extremely large, the average fluctuation being over 13%, peaking to 50% of the scale limit. Correlation is poor and somewhat insignificant which suggests that borewell water is only partially related to production activity.

- Clarification of an alternative variable is uncertain which suggests that, although there is a slight trend for scatter to increase with production output, the main cause is lack of control on usage.

- In contrast to town water, however, overhead per month is relatively small (15,600m^3), but at average consumptions accounts for over 19% of water pumped. This is thought to be due to lack of control of cooling circuit water, large quantities being unnecessarily lost to drain.

- The shallower gradient of the line in relation to fixed overhead shows less sensitivity to production changes than for town water. Similarly, there is likely to be little variable overhead associated with consumption,since the number of borewells pumping relates to the level and temperature of the pump-room pond and not to any plant being cooled.

- It is difficult to ignore overhead in giving a value of 13,191 m^3 of consumption for each 1,000 tonnes of tyres produced. It is clear that in the case of borewell water, and consequently circulating water, specific usage cannot be a measure of efficiency.

$$b = \frac{B}{W} = \frac{15.6}{W} + 13.2$$

- It can, therefore, be concluded that the most effective usage will occur at maximum output.

F <u>Steam Consumption (S)</u>

- For reasons of a 2nd order, negative intercept and a maximum point of inflection, in contrast to fuel and total energy consumptions, the 1st order equation must be chosen for steam.

- The affects of ambient temperature, inaccuracy of data, poor control, and changes in efficiency in the period account for the degree of scatter, which tends to funnel outwards with increased production. The level of average fluctuation is large at 11.5%. This indicates poor correlation and significance, the major reason being the independent ambient influence. Clearly further investigation is required.

- The fixed steam overhead is also large (95,000 tonnes/month), accounting for some 18% of usage at average consumption levels.

This endorses the relative poor control, particularly effects of temperature. No account can be made for variable overhead.

- Ignoring overhead, the average steam consumption at Fort Dunlop from 1969 to 1976 is 8.8 kg/kg. However, with such a large fixed overhead, specific consumption cannot be used as a measure of performance since:

$$s = \frac{S}{W} = \frac{9.5}{W} + 8.8$$

- As with all linearity, the most effective use of steam should come at higher output levels, due to the thermal mass of equipment such as presses. As in most cases, however, over-production will depart from linearity and decrease efficiency.

- Bases on a heat take up of 2.57 MJ per kg of steam produced and comparing the results with those for fuel, a boiler house efficiency of over 88% is obtained. This is impossibly high, obviating some improbability in the analysis to date.

- There is clear evidence that both fuel and steam use relate to more than one independent variable. Multiple regression must therefore be used before assessment of non-production consumptions can be made. Before this, however, it is useful to consider consumption - temperature dependence.

G <u>Production Output vs Compressed Air and Hydraulics</u>

It was questionable whether compressed air and hydraulics would collectively reflect any meaning when compared with product output. Consequently, analysis failed to proceed beyond the manual computation. Based on the data given earlier and derived from the average electrical consumption for each service, the results of the exercise were:

- Figure A23(a) shows moderate scatter, maximum fluctuation of 45% at any level of output. Whilst this is unacceptable, the average variance is much lower, thus providing some significance.

- Assuming a straight line plot, the fixed overhead 0.9 TJ/month represents 18.5% of the total consumption at average output levels. This is likely to be due to:

    a. excessive air leakage
    b. non-optimisation of start up and shutdown
    c. continuous 'no-load' running of pumps and compressors

- With such high overhead, the most efficient use of air and hydraulics occurs at higher production outputs. This reflects the observed operation characteristics.

- Since both services are produced from electrical energy input, control should be effective. Scatter must, therefore, result from loss effects.

Figure A23 (a)

Compressed Air & Hydraulics vs. Production Output

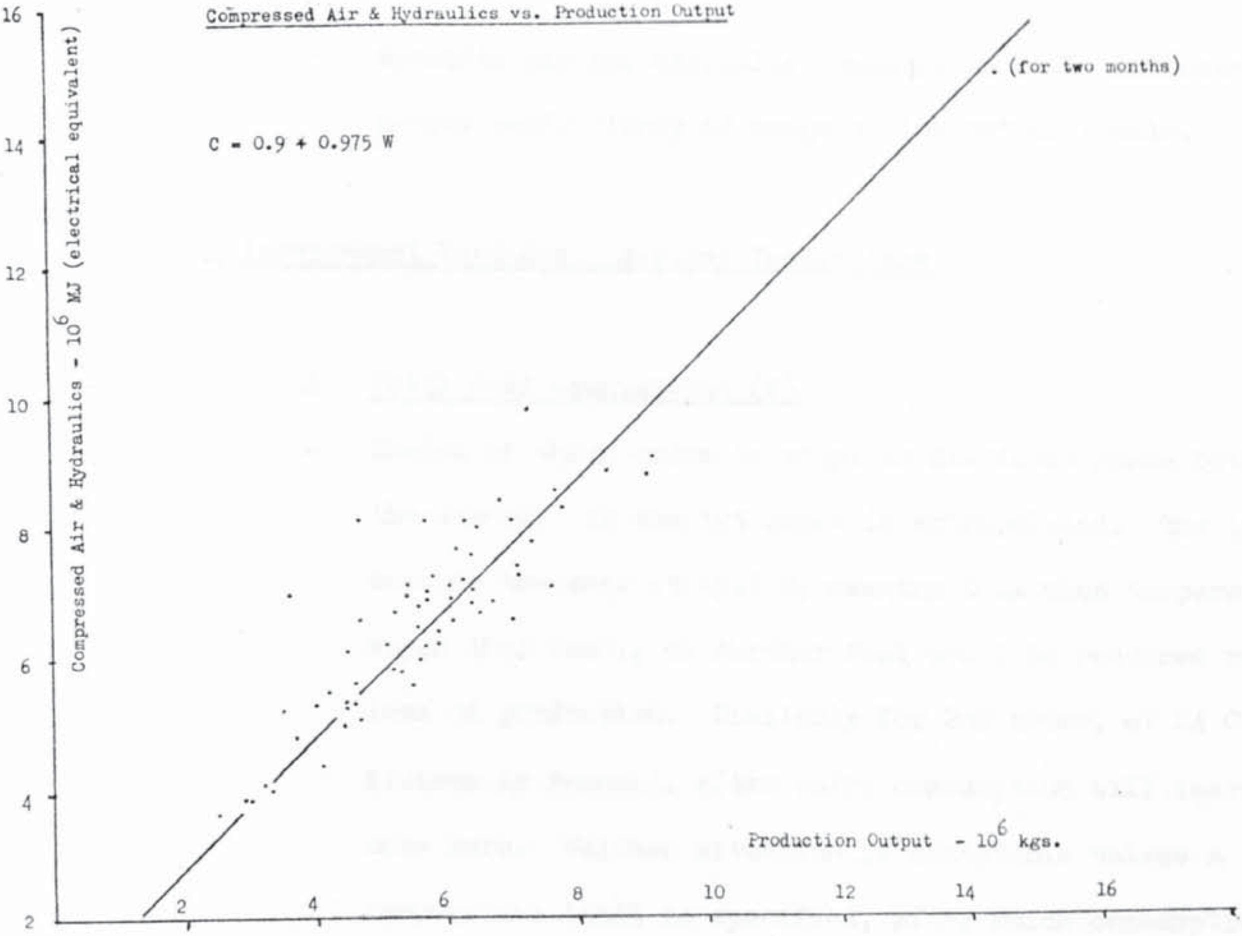
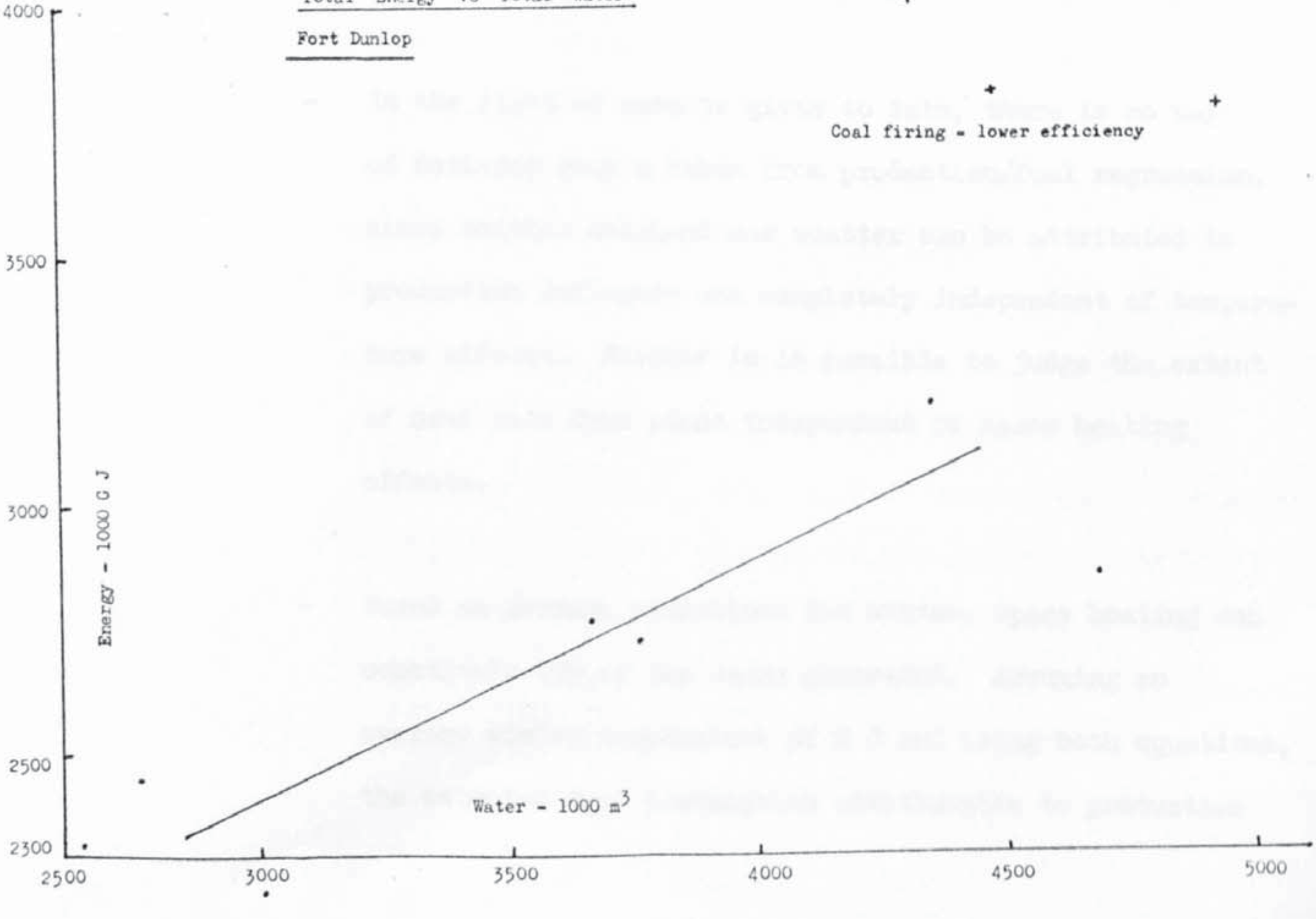


Figure A23 (b)

Total Energy vs Total Water



- Specific air and hydraulic consumption would indicate severe inefficiency of usage at low output levels.

A2.2 Independent Variable = Ambient Temperature

A Total Fuel Consumption (F)

- Choice of which order to adopt is difficult since both fit the theory. If the 1st order is extrapolated. The line crosses the axis at 19.1 C, meaning that when temperatures reach this level, no further fuel would be required regardless of production. Similarly for 2nd order, at 24 C a minimum is reached, after which consumption will increase once more. Neither situation is acceptable unless a temperature limit is specified, after which consumption can only be attributed to production and its inherent heat loss overheads.

- In the light of results given to date, there is no way of deriving such a value from production/fuel regression, since neither overhead nor scatter can be attributed to production influence and completely independent of temperature effects. Neither is it possible to judge the extent of heat loss from plant independent of space heating effects.

- Based on average conditions for winter, space heating can constitute 45% of the steam generated. Assuming an average winter temperature of 4 C and using both equations, the estmated fuel consumption attributable to production only is 144 TJ/month, which when extrapolated as an overhead, intersects each curve at a temperature between 15 and 16 C. With some heating left on in the summer (15%), however, plus additional loss from plant, calculation for an average summer (16 C) produces an intersection between 18 and 21 C. For ease of analysis, therefore, 20 C is assumed the point at which the space heating is isolated and the overhead is attributable to production. This temperature has been taken as the space heating cut-off point for each of the dependent variables in figures A12 to A16.

- Over the range selected, there is still little to choose between the two orders. The degree of scatter advocates the use of the 1st order, but theory suggests that since the cooling of plant is included, the 2nd order should be adopted. In either case both gradients are similar, the only major differences being the value of fuel attributable to production at 20°C and the increasing gradient of the 2nd order equation at lower temperatures. For the most part linearity exists over the working range.

- With interference from production effects, the degree of scatter is large, the average fluctuation being 10.4%, peaking to 40% of the scale limit. Correlation is therefore poor, casting doubts on significance and suggesting that consumption is only partially related to temperature. Production output is obviously a second independent variable, the effect of which will need to be examined through multiple regression.

- From these results, fixed overhead, on the consumption attributable to production is put between 93 and 121 TJ/month. It should be noted that heat loss from plant occurs at higher ambient temperatures than 20°C. Whilst allied to output, this loss will vary with temperature and should not be classed as an overhead. Since the quality of energy actually required to make a tyre is small compared with that actually consumed (16), the remaining energy is lost as heat. This loss, however, is attributable to both production and space heating, but in this instance it must be assumed that the two are separate: space heating shown as the marginal consumption, and fixed output identified with production. Based on these assumptions, at 0°C space heating plus additional heat losses account for over two thirds of the total consumption. With average measurements and estimates of 50% of the total fuel use being for space heating, up to 20% of the heat could be lost through poor insulation. It should be noted, however, that a portion of this heat loss from unlagged pipes is re-radiated for space heating, and should insulation standards improve, the situation might arise where additonal fuel will be needed to maintain comfortable temperatures.

- The main objective of this exercise is to provide a means of temperature correction for fuel consumption, since ambient conditions are independent of production activity and cannot be controlled. Outside multiple regression analysis, this cannot be accurately assessed since, based on polynomial regressions, it is impossible to isolate the effects of production from the ambient influences. Ignoring the fixed overhead, it can be said that for every degree drop in average temperature, an additional 10 to 17 TJ of fuel is required per month, but this relationship is unlikely to be totally linear.

- The only way in which a rough temperature correction can be obtained, when assessing production performance, is by deducting the marginal consumption from the actual fuel usage for the month and comparing this with the fixed overhead given by the equations. This brings consumption to a common base at 20°C.

B <u>Total Energy Consumption (Z)</u>

- Once again the degree of scatter is large but less than that for fuel, the average fluctuation being 9.7%. Consequently, choice of order is difficult. For the 2nd order linearity is evident over the range 0 to 20°C. A second independent variable (production activity) must be introduced before adequate selection can be made.

- Fixed overhead, entirely a function of output, is put between 118 and 147 TJ/month. Based on this result, at 0°C space heating plus additional losses account for less than two thirds of the overall consumption due to the effects of electricity.

- Ignoring the fixed overhead, for every one degree drop in average temperature, an additional 11 to 18 TJ of energy is required each month, with the relationship likely to be linear.

- Production performance is once again difficult to evaluate. Approximate temperature correction can be obtained using the method outlined for fuel use.

C <u>Steam Consumption S</u>

- The conclusions drawn from fuel use vs temperature are likely to apply to steam. In this case, however, choice of order of equation might include a cubic relationship. However, to maintain simplicity, only the first and second order will be considered.

- For the range of temperature considered, the 2nd order equation is almost linear with only small overhead variation at the 0 and 20°C limits when compared with the 1st order. The 1st order can therefore be adopted.

- The degree of scatter is large (10.2% fluctuation) due to effects of the production variable. However the scatter appears more uniform with fewer peak variations.

- Fixed overhead, attributed to production, is between 25 and 29 million kg per month. Consequently at 0°C, space heating and other losses constitute over two thirds the steam damand.

- Ignoring the fixed overhead, each degree drop in average temperature is accompanied by an additional 3 to 4 million kg of steam consumed per month, the relationship being close to linear.

- As in the previous cases, however, consumption cannot be accurately corrected for temperature variation due to the degree of scatter and low correlation significance. The method used for fuel will give an approximate correction to the 20°C base.

D Specific Fuel Consumption (J)

Comparison of the effective use of fuel in production may be produced by relating specific consumptions to temperature variation. This would eleminate the need for multiple regression techniques. The following results for fuel and steam have been based on a small number of points taken for each month during 1973 to 1975.

- Based on the assumptions made for fuel consumption in A2.2 A, 20°C is the temperature at which space heating is turned off. In the case of steam, however, specific consumption (given in the following section E) for the 2nd order equation has a minimum point of inflection at 17°C. Increases thereafter are not credible, which infers a lowering of the cut-off point to 17°C, with the lower limit still at 0°C.

- With these new constraints, there is little to choose between the two equations, differences in fixed overhead and gradient being small. The 1st order equation might, therefore, be adopted in view of the degree of scatter.

- The significance of the relationship between specific consumption and temperature is minimal, with a correlation coefficient of 0.5. There is evidence that specific consumption will itself vary with output. In comparison with ambient conditions, this is assumed to be constant, which could amongst other reasons (data accuracy) account for the scatter.

- The proportion of overhead attributable to production output is put at 31 MJ/kg. Consequently at $0^{\circ}C$, only a third of the fuel consumed is attributable to heat loss and space heating. This contrasts with the two-thirds calculated using total consumptions, which is thought to be a more accurate estimate.

- Discounting overhead, for each degree of temperature drop below $20^{\circ}C$, an additional 0.84 MJ/kg is required, the relationship being linear.

- Having deduced a more accurate estimate for temperature effects, improved correction for ambient variation can be obtained for production performance.

$$P = J - 0.84\,(20-T) \text{ MJ/kg}$$

where P = the temperature corrected specific fuel consumption

J = the measured specific full consumption (MJ/kg)

T = the average monthly temperature ($^{\circ}C$).

E Specific Steam Consumption (K)

- Based on similar assumptions in E above, the linear equation is assumed to be the best fit for the temperature range considered.

- The degree of scatter, however, is not as large with a correlation coefficient approaching 0.7 which is thought to be significant. The scatter is a result of variation in specific consumption with production, accuracy of data and improvements in performance throughout the period. The main reason for the improved correlation is the increased efficiency of steam raising in 1969 and 1979, brought about by substitution to gas firing.

- The production fixed overhead, assuming this does not alter with changing activity, is 9.0 kg/kg. At $0^{o}C$ therefore, only a third of the steam load is attributable to space heating. This contrasts with analyses of total consumptions but agrees with that of the previous section.

- For each degree of temperature drop below $20^{o}C$, an additional 0.3 kg of steam per kg of product is required; the correlation approximating linearity. The measure of production performance, corrected for temperature, is given by:

$$Q = K - 0.3 \ (20-T) \quad kg/kg$$

where K = the measured specific steam consumption (kg/kg)

- These results assume that space heating is proportional to temperature and that the heat used in the process is

- uneffected by changes in temperature. Such losses, however, are likely to vary with temperature drop, hence adoption of the second order equation. In addition, specific consumption also varies with production output. Multiple regression was, therefore, required for production of a more feasible model.

- Taking both equations for specific fuel and steam use and assuming there are 2.57 MJ taken up in every kg of steam produced, the overall boiler efficiency can be calculated to be 67%. This is not far from a realistic performance for these boilers, if the additional fuel required for non-steam-raising operations is subtracted it can be concluded, therefore, that the regression coefficients have some degree of credibility. A multiple regression analysis will help to endorse these findings.

A2.3 . Independent Variable = Total Manhours

On the evidence of two polynomial regression exercises, it is reasonable to conclude with relative conclude with relative certainty that since there is a high degree of correlation between production output and the number of manhours (a measure of activity), energy consumption will depend as much activity levels as tonnes of tyres produced.Figures A 17 and A 18 depict the close relationship between direct manhours, total manhours and production output. The degree of scatter for the total manhours (5.23% average fluctuation) is greater than that for direct manhours (3.35%). This will be a result of the non-dependence of production on indirect labour activity. Both cases are highly significant. Analysis of energy consumption with activity was, therefore, thought to be justified, the main object being to show how energy usage was 'people' dependent. To this aim total energy and steam have been correlated to total manhours.

A Total Energy Consumption (Z)

- The most likely equation is that of the 1st order, since it is unlikely that there would be a record of activity without any energy consumption. In addition to the normal energy overheads such as transformer losses, heat dissipation etc., which accrue even when activity is zero, the total number of manhours do not include a record for staff. Staff employees use substantial quantities of energy in lighting, heating and hot washing water. This confirms the choice of the first order and the linear relationship.

- The degree of scatter is moderate, average fluctuation being 6.1%. Significance is, therefore, marginal although correlation appears to be better than that for production output. The reason for this could be due to the anticipated hypothesis that the employees, and not just the product, influence the usage of energy. Of course, scatter in this instance will be caused by the same interferences such as ambient conditions, improving efficiency etc. The deduction is, that activity could be a better measure of performance than output.

- The fixed monthly overhead is relatively small at 13.7 TJ. However, $H = G + 31$ and consequently $Z = 31.9 + 0.5871\ G$.

The inference is that the indirect manhours (= 31,000 hrs) tends to halve the overhead normally attributed to production, thus making total manhours a useful base for specific measurement. At average levels, overhead accounts for 6% of the consumption, compared with 10 to 20% for a production output datum.

- The gradient of the line is constant giving 0.6 TJ of energy for every thousand manhours worked. With low overheads, this gradient is a direct measure of the effective use of energy, since the 1st order term is the dominant component.

$$\frac{Z}{H} = \frac{13.75}{H} + 0.59 = \text{constant for large}$$
$$H < 500{,}000\text{hrs/month}$$

Optimum operation based on manhours will, therefore, occur at most operating activity levels.

B <u>Steam Consumption (S)</u>

- Based on the increase in scatter, the 1st order is again chosen as the best fit, particularly since for the 2nd order the results are close to linearity for this range; end effects being minimal.

- Comparitively, the degree of scatter is large (11.3% average fluctuation) making for poor correlation and relative insignificance. The scatter could be due to effects of ambient temperature etc.

- Fixed overhead (4,600 tonnes/month) is small (9%) with respect to average consumptions. This is due to the effects of indirect activity. As in the previous analysis, total manhours become a useful basis for specific measurement.

- The gradient of the line of 0-15 million kg for every 1,000 hours worked gives a relatively linear relationship and a direct measure of performance. Temperature corrected this should be reasonably accurate.

  $$\frac{S}{H} = \frac{4.62}{H} + 0.15 = \text{constant for large } H < 500{,}000 \text{ hours/month}$$

  Optimum operation would still tend to occur at higher levels.

- Possible reasons for manhours being an improved basis for performance judgement are:

  a. Manhours will tend to relate to the energy used for space heating as well production purposes. Any overhead will occur from the necessity to leave certain items of plant switched on, plus the effects of non-production orientated operations. Production will not itself relate to heating, lighting or anything outside the sphere of producing the product.

  b. Manhours can be more readily measured.

A2.4 Independent Variable = Steam

It is useful to relate primary consumptions, such as fuel and water, to the secondary energy sources they produce (i.e. steam), thus ascertaining efficiency of conversion.

A Total Fuel Consumption (Z)

- The effects of poor conversion efficiency in 1969 and 1970 (prior to gas substitution) may account for the negative overhead given with the 1st order plot. According to theory, variation of steam output with fuel input should be linear over the designed working range. However it is not possible to provide steam without fuel. In view of the 2nd order being practically linear, this has been chosen as the best fit.

- The degree of scatter is moderate (6.3% average fluctuation), giving reasonable correlation and marginal significance. The amplitude of scatter tends to increase with steam output, probably due to the 1969/70 coal firing differences. Without these, the 1st order plot might easily be tilted to a positive overhead as shown in the trial investigations.

- The fixed overhead each month is 18.5 TJ, some 11% average consumption. This overhead is made up of two components. Firstly a small quantity of fuel (c 2.5 TJ/month) is used directly in the process, for space heating or domestic purposes. This is independent of the steam being produced and therefore constitutes an overhead. Secondly, some of the energy lost in steam raising can be taken as constant (i.e. losses from radiation, continuous blowdown, warm up etc) and is independent of the steam generated.

- The amount of fuel required to raise steam will also depend on a number of other factors which include:

- The temperature of the feedwater (relates to percentage condensate returned).
- The quantity of steam produced.
- The degree of manual blowdown.
- The combustion efficiency (unburnt fuel in flue gases).
- The heat transfer efficiency (temperature of flue gases).
- The degree of excess air.

These constitute the marginal consumption of fuel, and are dependent on the quantity of steam produced. Ignoring the fixed loss, the gradient of the line will give the effective conversion of fuel energy to steam. Poor combustion, heat transfer, control, low feedwater temperature or high blowdown will increase the gradient. The converse is also true; an efficient boiler will have a lower gradient. The degree of gradient is therefore a measure of marginal or variable overhead and consequently efficiency. Radiation losses and other fixed overheads relate to one boiler. The degree of total loss in a boiler house will vary with the number of boilers on range and hence the steam output. It can be deduced, therefore, that these too are partly marginal.

- The gradient of the line based on the linear 1st order equation, is 3.73, with 2.57 MJ of energy being absorbed by every kg of steam produced discounting the overhead.

$$F \text{ (in MJ)} = \frac{3.73}{2.57} S \text{ (in MJ)}$$

This efficiency of boiler house operation is given by

$$\frac{S \quad \text{(in MJ)}}{F \quad \text{(in MJ)}} = 69\%$$

With the inclusion of fixed overhead losses, the actual average efficiency over the period will be lower than this. However, the level of efficiency is realistic and endorses the use of the correlation as a basis for performance measurement, the average specific fuel consumption being 3.7 MJ/kg.

- At low outputs, there is evidence of non-linearity, resulting from the effects of fixed overhead loss. Similarly at high outputs, the 2nd order term tends to increase consumption. This is in accordance with the theory that the boilers should be run in the designed range. At low load factors and above the designed maximum continuous rating, efficiency of conversion falls. Optimum steam output appears to be between 30,000 and 80,000 tonnes/month.

B <u>Town Water Consumption (A)</u>

- With the high degree of scatter and a minimum point of inflection with the 2nd order equation, choice of correlation must lie with the 1st order.

- The average fluctuation of scatter is 12.6%. This makes for poor correlation and low significance. The conclusion is that whilst water consumption tends to increase with higher steam output, the physical value of specific consumption is uncertain.

- In theory, the fixed overhead should relate to the water consumed outside the boiler house (70,000 m^3/Month). Similarly, the gradient of the line will indicate the quantity of condensate returned. Based on 1195 kg/m^3 for feed water

$$A \text{ (in } 10^3 m^3) = \frac{1.72}{1.20} S \text{ (in } 10^3 m^3 \text{ equivalent)}$$

The percentage condensate returned is then given.

This is a reasonably accurate value when compared with measured returns. However, it is fluctuation of the condensate return which could be one reason for scatter.

- Reviewing more recent data, total consumption of town water on the site averages 150,000 m^3. At this usage, approximately 120,000 m^3 is consumed outside the boiler house and can be classed as overhead. These proportions agree closely with the 2nd order equation,intiminating non linearity at the lower steam levels.

A2.5 Manual Investigations - U.K.T.D.

In addition to the aforementioned exercises, this manual analysis was extended to other factories in the U.K.T.D. It was not intended that the ensuing results be a rigorous analysis of energy performance in the other factories, but rather a tentative comparison with Fort Dunlop consumption patterns. Perhaps at some later date or with a directive from each factory, more accurate results might be obtained. Having plotted in the previous sections the dependent variables against a number of critical factors, the following general conclusions were drawn from the data given in Table A 5.

A Speke

- Poor correlation of steam to production results due to: a number of activities on the site not directly attributable to tyre production; dubious data; poor control; and variation of efficiency with low output or losses.

- For similar reasons, fuel vs production gave poor correlation.

- Unlike Fort Dunlop, electricity did not produce a high correlation, probably due to similar reasons.

- In the context of constant interference with production, varying energy loss and uncertain allocation of consumptions to tyre activities only, no acceptable relationship between these variables could be found.

- When fuel was compared with steam produced the resultant correlation was moderate, the straight line plot rendering an overall efficiency of 77% and an overhead of 10.6 TJ.

- When compared with Fort Dunlop, relationships were poor.

B Inchinnan

- When related to production output, steam usage produced a linear fit with low scatter. For the factories tested, this result had the highest correlation.

$S = 9.9W + 1.1$

Overhead appeared small at 8.3% of average consumption.

- As for steam, the correlation proved significant, with overhead equivalent to 8.4% of average consumption.

  $F = 30.3W + 3.5$

- Electricity vs output revealed yet another significant relationship in accordance with Fort Dunlop, overhead representing 15% of average consumption.

  $E = 4.84W + 0.94$

- Of the factories studied in the manual analyses, Inchinnan showed the closest relationships between energy and production, fixed overheads being suprisingly low.

- When steam and fuel use were compared, the customary good correlation resulted. Overhead was small,

  $F = 2.98S + 1.58$

  reflecting a higher conversion efficiency than expected. Due to generation at two pressures, the actual efficiency could not be calculated.

C <u>Washington</u>

- There was no apparent relationship between fuel or steam and output which was surprising since this is a modern well insulated factory.

- For electricity the answers were similar. One possible reason for this is the higher use of artificial lighting.

- Possible reasons include the steady improvement of specific consumption over the period due to increased output and conservation.

- A plot of steam vs fuel showed remarkable correlation, overhead representing 13% of average consumption.

  $$F = 2.72S + 1.06$$

  The effect of efficient control of new plant is demonstrated.

Binding conclusions drawn from these findings are dangerous, since the analysis has not been rigorous. In addition it is folly to make assumption of equipment or factory operations without in-depth knowledge of each plant.

A2.6 Energy vs Water

Water consumption is often affiliated to the use of energy, because it is a heat sink and because it is used a a media for energy transmission as steam, hot water etc. It is reasonable to assume, therefore, that consumption of these two resources should bear some relationship.

A Fort Dunlop

Based on the data given (annual consumptions 1966-76), the plot shown in Figure A24 compares fuel and energy to town water consumptions for Fort Dunlop. Whilst it was impractical to postulate a suitable equation, bearing in mind the large time span, the following conclusions have been drawn:

Figure A24 Fuel vs Town Water - Fort Dunlop

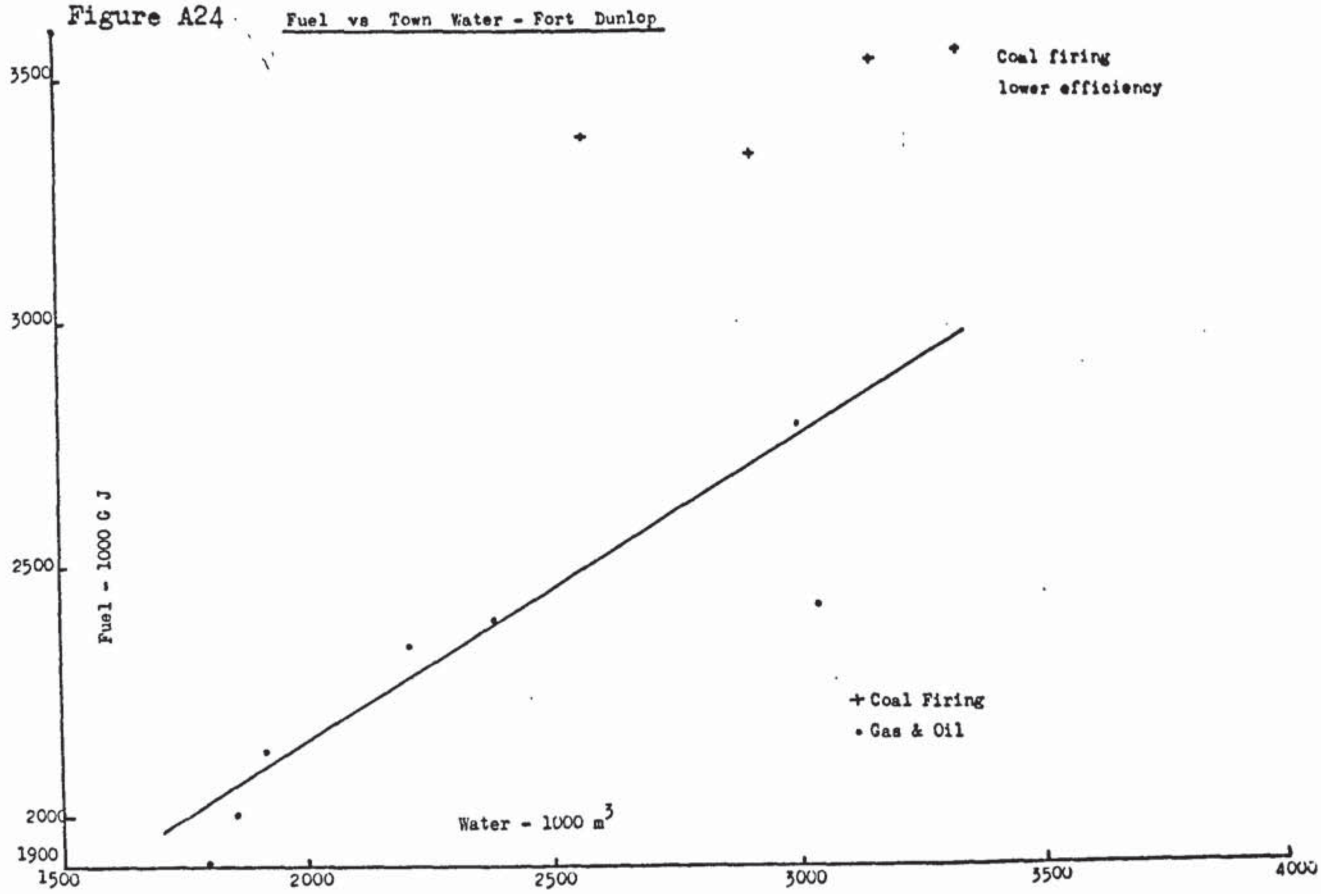
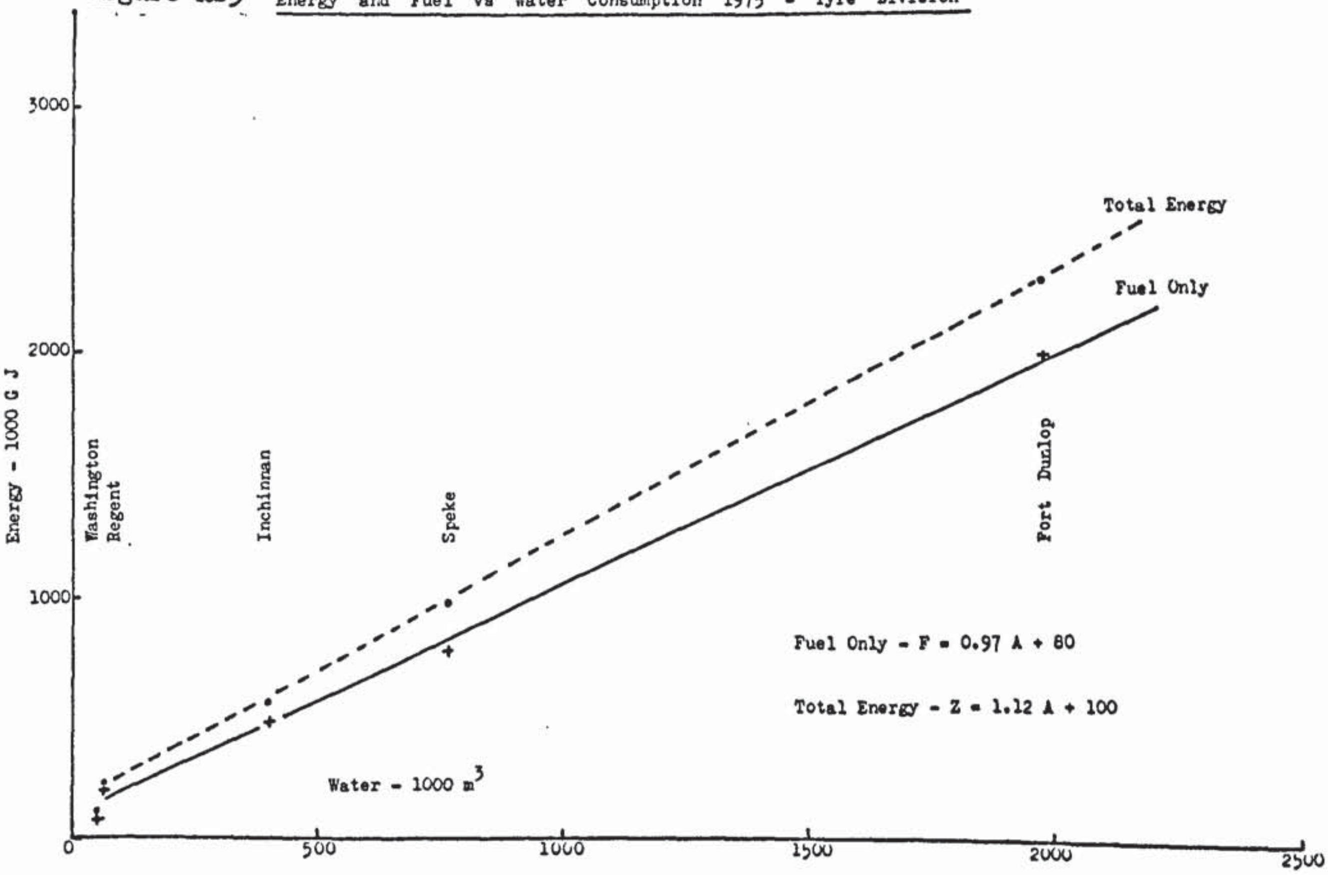


Figure A25 Energy and Fuel vs Water Consumption 1975 - Tyre Division



a. A relationship between fuel/energy and town water consumption exists.

b. Low specific consumptions for 1971 (an effect of high production output) are not echoed in town water usage.

c. Inefficiencies in steam raising prior to 1970 are marked.

d. Fuel has a better relationship with town water than energy usage.

B U.K. Tyre Division

One obvious difficulty in forming relationships over a number of years is the tendency for improvements to change consumption patterns. This problem was eleminated when judging inter-factory comparisons based on 1975 data. (Table A 5).

a. The relationship between fuel/energy and water is remarkable - figure A25 .

b. Ignoring the fixed consumption (C.100GJ), energy and fuel increases 1.12 and 0.97 GJ respectively for every 1000 m^3 of water consumed.

c. The relatively higher efficiency of energy use at Washington is apparent.

C Dunlop U.K.

Figures A26 (a) and (b) compare the respective fuel and energy consumptions for the Dunlop company as a whole, based on 1975 data given in Table A 4.

a. Fuel and/or Energy bear some linear relationship to the amount of water used.

Figure A26(a) Fuel vs Water Consumption 1975

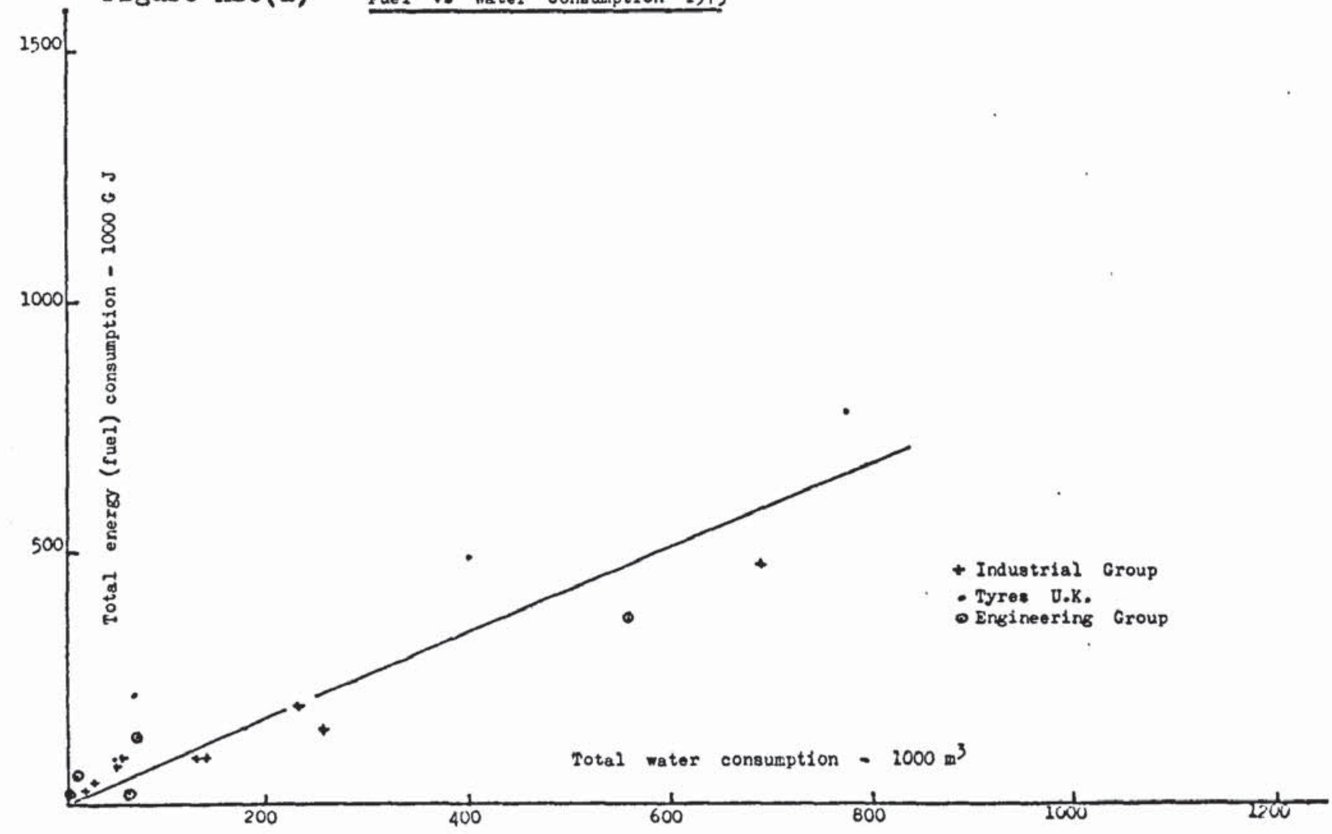
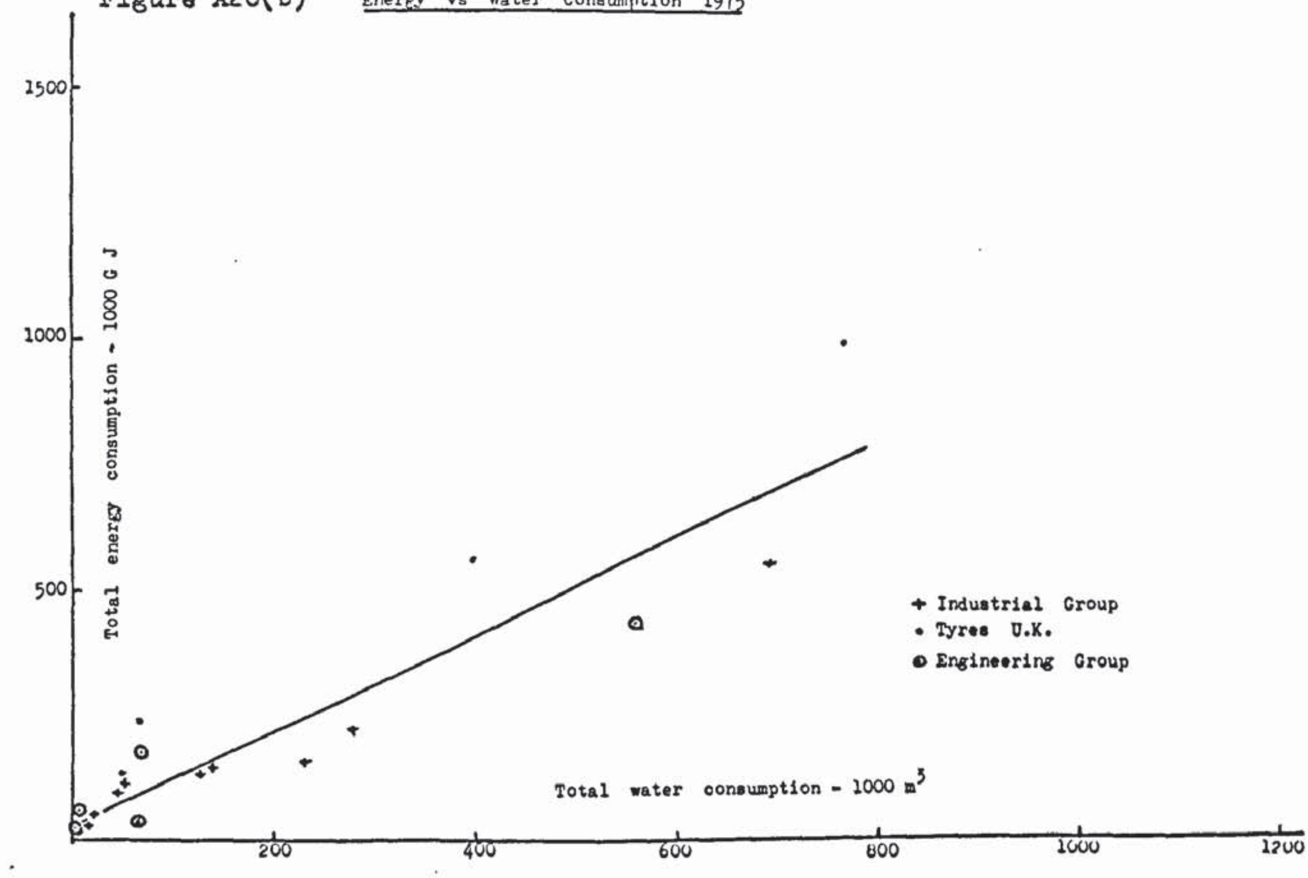


Figure A26(b) Energy vs Water Consumption 1975



b. The fixed fuel/energy overhead is small, probably equal to zero.

c. There is a higher ratio of fuel/energy to water in U.K.T.D. than in other groups, basically due due to the higher energy intensiveness in tyre manufacture.

A3 Results of the Multiple Regression Analysis

The following results were obtained using the SPSS - Multiple Regression Package (154) using data for Fort Dunlop consumptions given in section A 1.

A3,1 Theory

The most important uses of the multiple regression techniquo as a descriptive tool are:

a. to find the best linear prediction equation and evaluate its prediction accuracy.

b. to establish the contribution of a specific variable or set of variables.

The main function of the analysis, therefore, is the evaluation and measurement of overall dependence of a variable on a set of other variables.

The basic theories should already be well understood (142) (154); the general form of the regression being

$$y' = a_o + a_1 x_1 + a_2 x_2 \text{ ———— } a_n x_n$$

where y' represents the estimated value of y, a_o is the intercept, and a_1 are regression coefficients.

As in the case of simple vivariate regression, the total variation of sums of squares in y can be partitioned into two independent components, one that is explained by regression and another that is unexplained. The proportion of variance of y explained (i.e. the goodness of fit) can be evaluated by examining the square of the multiple correlation.

$$r^2 = \frac{\text{Variation in y explained by combined linear influence of the independent variables.}}{\text{Total variation in y}}$$

A3 .2 Tests for Significance

To evaluate the accuracy of the prediction equation or to determine the amount of prediction error associated with predictions, examination of the r^2 statistic indicate proportions of variation explained or unexplained. As for the polynomial regression exercises, standard error of estimate (SEE) can be used:

$$SEE = \sqrt{\frac{\Sigma (y - y')^2}{N}} \quad \text{(for a hand calculation)}$$

Similarly the standard error of each regression coefficient can bededuced and hence the confidence interval. If the sample size is relatively small ($<$ 200), the estimates for a, follow the 't' distribution (142) and not the normal distribution. The sample of 96 taken in the ensuing analysis uses this method. An absolute value of 1.986 (approx) is obtainable for the 't' distribution with

93 degrees of freedom at the 95% confidence level.

Alternatively overall significance may be determined by examining the F ratio (154):

$$F = \frac{r^2 / k}{(1-r^2/ \; (N - k - 1)}$$

where r^2 = overall multiple correlation coefficient

k = number of independent variables.

If the computed F value is larger than the statistical tables critical value for a given significance level, the null hypothesis that $a_i = o$ is rejected for a significance level of 0.05, indicating that there is a 95% probability that the relationship is not due solely to chance, the F value for 2 and 93 degrees of freedom would need to be greater than 3.86 (absolute).

In both cases of the F and t distribution, these methods of significance measurement can be applied to individual regression coefficients as well as the overall equation (154).

A3 .3 Interpretation of Results

The results are to be interpreted as follows:

a. Overall Equation

- The Mean and Standard Deviation of the dependent variable are given at the top of each analysis.
- R is the multiple correlation coefficient.
- R^2 is the square of the multiple correlation coefficient.
- St. Dev. is the standard deviation of the fitted values to the actual.

- A Significance value of 0.05 represents a 95% probability that the relationship is not due to chance.
- Analysis of variance represents all information relevant to tests of R^2.
- Step Variable represents information about each variable, showing the additive effective of each successive step in the analysis.
- Finally each variable and regression coefficient (B) is analysed in turn, giving standard errors, F and T values, Confidence intervals, and significance.
- The BETA value is the partial-regression coefficient assuming one or other value to be nullified.

A3.4 RESULTS A - DEPENDENT VARIABLE = TOTAL ENERGY (Z)

Independent variables - Production Output (W)
Ambient Temperature (T)

a) Overall Equation

Energy (Z) Mean = 234.1 Std. Dev. = 78.2

Independent Variables:

Multiple R = 0.8609 R^2 = 0.7412

Std. Dev. = 40.2301

Significance = 0.000

Analysis of Variance =	DF	Sum of Squares	Mean Square	Overall F
Regression	Z	431000.5	215500.3	133.1
Residual	93	150516.8	1618.5	

Step Variable	Multiple R	R^2	Significance
Temperature (T)	0.4280	0.1832	0.000
Production (W)	0.8609	0.7412	0.000

Equation: $Z = 40.7310 + 41.4219W - 2.7727\ T$

b) Variables in Equation

	Temperature (T)	Production (W)	Constant
Regression Coefficient(B?	- 2.7728	41.4219	40.7310
Standard Error of (B)	0.6830	2.9254	19.0120
F Value	16.4795	200.4895	4.5898
Significance of F	0.000	0.000	0.035
T Value	- 4.0595	14.1594	2.1424
95% lower conf Int.	- 4.1292	35.0127	2.9770
95% upper Conf Int.	- 1.4164	47.2312	78.4850
BETA	- 0.221	0.7748	

c) Comments

- The overall R value greatly improves with the addition of the production to the temperature component.
- The level of significance is sufficient for acceptability ($>$95% confidence level).
- Overall F value of 133.1 is much greater than the 3.9 level required.
- Significance was $>$ 95% confidence level at all steps of analysis.
- Individual F and T values for regression coefficients were all significant, that for the constant being the worst.
- If one independent variable is nullified, there is a marked effect on the regression coefficient of the other.
- Assuming electrical consumption obeys the bivariate relationship given in Table 5.8.6. ($E = 5.19 + 5.06\,W$), the total fuel component (F) is given by:

  $F = (Z-E) = 35.54 + 36.36W - 2.77\,T$

- Based on the assumption that space heating is only needed below a base temperature of 15.5°C ambient. (20i). which is equivalent to an 'inside' temperature of 18.3°C, the additional heat required for the winter amounts to only 15% of the total fuel used. This assumes an average product output of 5 (10^6kg).
  A common winter space heating contribution is 45% at 4°C average temperature, which is much higher than the 15% calculated. However, at 15.5°C it is common in practice for the space heating load to be as high as 32% of total load. With account being made for additional heat loss from the process and assuming this base, re-calculation of space heating requirements becomes $>$ 43% which is a closer estimate. It is impossible, therefore, to arrive at a value for space heating load calculated directly from the regression equation and without prior knowledge of factory practices.

- If it is assumed that only 4% of energy inputs are retained in product manufacture (16), using the equation.

  $$Z = 40.73 + 41.42\,W - 2.77\,T$$

  it is possible to determine the equivalent temperature at which heat/energy loss would be zero. At 86°C ambient, therefore, losses from non-optimal operation, leaks, inadequate insulation etc., for plant, equipment, distribution pipework and buildings would be nil. This can be defined as the Equivalent Average Site Temperature (EAST).

- Some 20% of the energy used under average conditions is attributable to fixed overhead. This contrasts with the 18% deduced from the bivariate regression of total energy vs production. Non-optimal operation, poor maintenance, surface losses etc. constitute this overhead. Reviewing the confidence intervals, the fixed overhead has the greatest uncertainty varying from 40% to 1% of average consumptions. In contrast, the variation attributed to the two independent variables is smaller.

A3.5 RESULTS B - DEPENDENT VARIABLE = TOTAL ENERGY (Z)

Independent variables - Production Output (W)
Degree Days (D)

a) Overall Equation

Energy (Z): Mean = 2341 Std. Dev = 78.2

Independent variables:

Multiple R = 0.9186 R^2 = 0.8439

Std Dev. = 31.2471

Significance = 0.000

Analysis of Variances	DF	Sum of Squares	Mean Square	Overall F
Regression	Z	490713.8	245356.9	251.2
Residual	93	90803.4	976.4	

Step Variable	Multiple R	R^2	Significance
Degree Days (D)	0.65878	0.4340	0.000
Production (N)	0.91861	0.8439	0.000

Equation: Z = - 17.3702 + 36.6624 W + 0.2715D

b) Variables in Equation

	Degree Days (D)	Production (W)	Constan
Regression Coefficient (B)	0.2715	36.6624	-17.3702
Standard Error of (B)	0.2887	2.3466	12.1911
F Value	88.4744	244.1028	2.0301
Significance of F	0.000	0.000	0.158
T Value	9.4061	15.6238	- 1.4248
95% low conf int.	0.2142	32.0026	-41.5792
95% upper conf int.	0.3288	41.3222	6.8388
BETA	0.4129	0.6858	

c) Comments

- The overall R value improves with addition of the production to the degree day component but not as markedly as that for temperature.
- The level of significance is acceptable (>95% confidence level), being higher than that for temperature.
- The overall F value of 251.3 is much greater than both the 3.9 level required and that for temperature.
- Significance was >95% confidence level at all steps of analysis.
- Individual F and T values were significant for the independent variable regression coefficients but not for the constant.
- Nullifying independent variables produces the greatest effect when D = 0.
- Assuming electrical consumption obeys the bivariate relationship given in Table 5.8.6 (E = 5-19 + 5.06W), the total fuel component (F) is given by:

$$F = (Z-E) \quad = \quad -12.18 \ + 31.60\ W \ + 0.27D.$$

- It is impractical to have a negative constant of -17.37 since at D = W = 0 there would be a reverse flow of energy from the factory. Since the significance of this value is outside the 95% confidence level at 84%. an adjusted equation will need to be used.

The reasons for the negative constant are:

a) The space heating is not turned off at D = 0,but constituted a level of 32% of total fuel load, thus enforcing the need to subtract a sum from the production component.

b) Heat losses from plant and equipment still occur after D=0, thus having similar effects.

c) It is possible that at low W, the relationship becomes non linear.

In theory, at D=0 there should be no need for space heating; thus F = 145.82. But c 32% space heating is required, thus this can be split into:

F. (prod) = 99.16

F. (S.L) = 46.66 which appears as a constant.

Hence the revised equation is given by:

$$F = 34.48 + 19.83\,W + 0.27D$$

Including Electricity

$$Z = 39.67 + 24.89\,W + 0.27D$$

Alternatively the constant can be left as zero, in which case:

$$Z = 5.19 + 36.66W + 0.27D.$$

These revised equations, however, lack credibility and cannot provide accurate results. Once again, it is impossible to arrive at a level of space heating load calculated directly from the initial regression equation.

A3.6. RESULTS C - DEPENDENT VARIABLE = STEAM (S)

Independent variables - Production Output (W)
Ambient Temperature (T)

a) Overall Equation

Steam (S) : Mean = 56.3 Std. Dev. = 17.3

Independent Variables:

Multiple R = 0.8346 R^2 = 0.6966

Std. Dev. = 9.6284

Significance = 0.000

Analysis of Variance:	DF	Sum of Squares	Mean Square	Overall F
Regression	Z	19796.4	989.2	106.7
Residual	93	8621.6	92.7	

Step Variable:	Multiple R	R^2	Significance
Temperature (T)	0.5631	0.3170	0.000
Production (W)	0.8346	0.6966	0.000

Equation; S = 26.7766 + 75523W - 1.0852T

b) Variables in Equation

	Temperature (T)	Production (W)	Constant
Regression Coefficient (B)	-1.0852	7.5523	26.7766
Standard Error of (B)	0.1635	0.7001	4.5502
F Value	44.0699	116.3543	34.5299
Significance of F	0.000	0.000	0.000
T Value	-6.6385	10.7867	5.8847
95% lower conf. int	-1.4098	6.1619	17.7408
95% upper conf. int.	-0.7606	8.9426	35.8123
BETA	-0.3933	0.6391	

c) Comments

- The overall R value improves with the addition of production to the temperature component although this is lower than the value for total energy.
- The level of significance is acceptable (> 95% confidence level).
- Overall F value is less than for total energy but greater than the 3.9 level required.
- Significance was >95% confidence level at all steps of analysis.
- Individual F and T values for regression coefficients were all significant.
- If one independent variable is nullified, there is a marked effect on the regression coefficient of the other.
- Assuming no space heating requirement below 15.5°C ambient (18.3°C internal temperature) (20i), the additional steam required for the winter amounts to only 21% of the total consumption at a average output of 5 (10^6kg). However for similar reasons to the total energy case, space heating of 32% being common in the summer, re-calculation of the space heating requirements renders a closer estimate of 46%. Once again it is impractical to suggest that a value for space heating can be calculated directly from the regression equation.
- Assuming only 4% of the energy inputs are retained in the product manufacture (16) using the equation:

$$S = 26.78 + 7.55\ W - 1.09T$$

the EAST value is put at 57C. This is lower than the values calculated for total energy (86°c) and total fuel (75°c) but since, steam is the largest source of heat supply the 57°C value is believed more accurate.
- Some 56% of the steam used under average conditions ($W=5(10^6$kg) and $T=15.5$°C) is attributable to fixed overhead. This contrasts strongly with the 18% deduced from the results of bivariate regression of steam vs production. It is suspected that a fairly large portion of this high value is attributable to the 32% summer space heating effect.
- Reviewing the confidence intervals, variation of error appears to be distributed evenly throughout all regression coefficients with slight bias towards the temperature component.

A3.7 RESULTS D - DEPENDENT VARIABLE = STEAM (S)

Independent variable - Production Output (W)
Degree Days (D)

a) Overall Equation

Steam (S) : Mean = 56.3 Std. Dev = 17.3

Independent Variables:

Multiple R = 0.9392 R^2 = 0.8821

Std dev. = 6.0028

Significance = 0.000

Analysis of Variance:	DF	Sum of Squares	Mean Square	Overall F
Regression	Z	25066.9	12533.4	347.8
Residual	93	3351.2	36.0	

Step Variable	Multiple R	R^2	Significance
Degree Days (D)	0.8022	0.6436	0.000
Production (W)	0.9392	0.8821	0.000

Equation: $S = 4.9001 + 6.1824\ W + 0.0894\ D$

b) Variables in Equation

	Degree Days (D)	Production (W)	Constant
Regression Coefficient (B)	0.0894	6.1824	4.9001
Standard Error of (B)	0.0055	0.4508	2.3420
F Value	259.6432	188.0851	4.3789
Significance of F	0.000	0.000	0.039
T Value	16,1134	13.7144	2.0926
95% lower conf. int.	0.0783	5.2872	0.2501
95% upper conf. int.	0.1004	7.0776	9.5516
BETA	0.6147	0.5281	

c) Comments

- The overall R value improves with the addition of production to the temperature component giving the highest value for the four correlations.

- The level of significance is acceptable (>95% confidence level).

- The overall F value is greater than the 3.9 level required and is the highest value for the four cases.

- Significance was >95% confidence level at all steps in the analysis.

- Individual F and T values for regression coefficients were significant, the poorest values being for the constant.

- If one independent variable is nullified, there is a marked effect on the regression coefficient of the other.

- Unlike the total energy - degree day analysis, the constant is positive representing 9% of steam consumed at average conditions of W=5 (10^6k) and D=205. This appears to be a little low for fixed steam overhead. The bivariate regression value for steam vs production was 18%. In theory, steam consumption vs degree days should pass through the origin (20i). In practice, however, with heating being left on at values of $D \leqslant 0$, some overhead might be expected. The low value contrasts strongly with the 56% obtained in the previous case for temperature.

- Assuming no space heating requirement at D=0, the additional steam required for the winter amounts to 34%, which is a more accurate figure, but fails to account for the 32% summer base load. This wouldinflate the winter space heating load to 41% of the total.

- Reviewing the confidence intervals, variation of error is greater for the regression constant.

APPENDIX B

THERMOGRAMS FOR STUDIES MADE OF PLANT AND EQUIPMENT

----- Plates 8A to 8Q

Table B.1 QUANTITATIVE TEMPERATURE MEASUREMENT

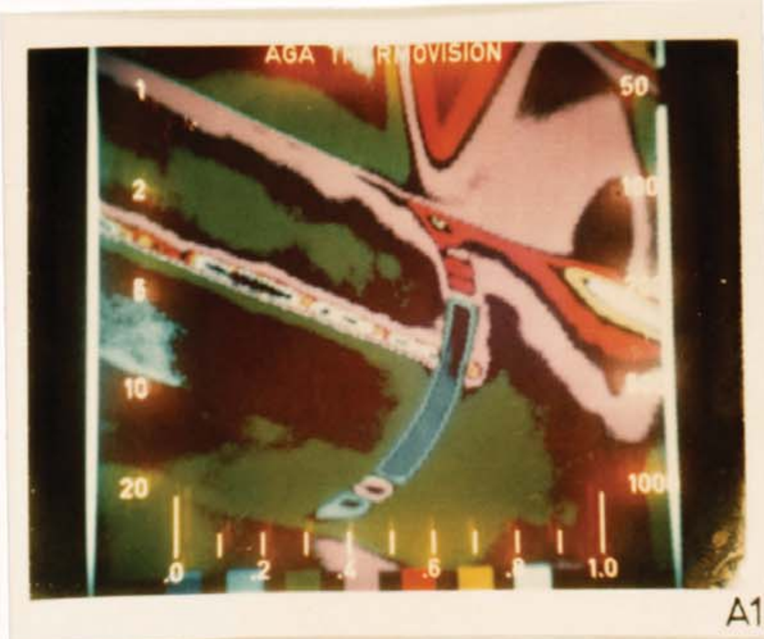
PHOTO No:	DESCRIPTION	MATERIALS	COLOURS	Ai	BLACK Io	BODY To °C	Eo	REAL Ai/Eo	BODY Io	REAL To °C	COMMENTS
PLATE 8A											
A1	Reference = G, Tr = 25 Equation 4	Ir = 26, f1.8, S=50									
	Metal band - dirty	Oxidised galvanised iron	DB	-14	12	1	0.28	-48	-22		Unable to measure real temps of low emissivities using this equation.
			LB	- 7	19	16		-23	3		
			P	7	33	33		25	51	47	
			R	14	40	39		48	72	62	
	White insulation covering	Fabric	LB	- 7	19	16	0.90	- 7	19	16	
			G	0	26	25		0	26	25	
			P	7	33	33		8	34	34	
			R	14	40	39		15	41	40	
			Y	21	47	44		23	49	47	
			W	28	54	50		31	57	51	
	Concrete wall - dirty	Plaster	G	0	26	25	0.90	0	26	25	
			P	7	33	33		8	34	35	
	Cardboard shade	Paper	P	7	33	33	0.90	8	34	35	
			R	14	40	39		15	41	41	
A2	Reference = G, Tr = 25 Equation 4	Ir = 26, f1.8, S=50									
	White magnesia insulation	Magnesia	R	14	40	39	0.90	15	41	41	
			Y	21	47	44		23	49	47	
			W	28	54	47		31	57	52	
	White fibreglass insulation	Fibreglass	G	0	26	25	0.90	0	26	25	
			P	7	33	33		8	34	35	
			R	14	40	39		15	41	40	
			Y	21	47	44		23	49	47	
	Concrete wall - dirty	Plaster	G	0	26	25	0.90	0	26	25	
			R	14	40	39		15	41	40	
	Cardboard cover	Paper	R	14	40	39	0.90	15	41	40	
			Y	21	47	44		23	49	47	

PHOTO No:	DESCRIPTION	MATERIALS	COLOURS	Di	BLACK Io	BODY To °C	Eo	REAL Ai/E	BODY Io	To °C	COMMENTS
PLATE 8B											
A5	Reference - DB, Tr - 39 Equation 4	Ir - 39, f1.8, S - 1000									
	White fibreglass insulation	Fibreglass	DB	0	39	39	0.90	0	39	39	
			LB	260	299	122		289	328	125	
			G	270	309	124		300	339	128	
			P	410	449	143		455	494	148	
			Y	540	579	157		600	639	163	
	Mild steel pipe - dirty	Oxidised steel	W	910	949	190	0.95	958	997	194	
PLATE 8C.											
B1	Reference - DB, Tr - 25, Equation 4	Ir - 15, f3.6, S - 500									
	Dirty fibreglass some with covering	Fibreglass fabric	DB	0	15	25	0.90	0	15	25	
			LB	70	85	127		74	89	128	
	Mild steel pipe - dirty	Oxidised steel	W	455	470	235	0.95	479	494	239	
	Metal band - dirty	Oxidised galvanised iron	L.B.	70	85	127	0.28	250	265	190	Effect of reflection
PLATE 8D											
B2	Reference - Y, Tr - 200, Equation 4	Ir - 130, f5.1, S - 50									
	Mild steel pipe - dirty	Oxidised steel	P	-14	116	186	0.95	-14	116	186	Reference only estimated
			R	- 7	123	190		- 7	123	190	
			Y	0	130	200		0	130	200	
			W	11	141	203		11	141	203	
B3	Reference - L.B, Tr - 25, Equation 4	Ir - 20, f2.5, S - 200									
	Mild steel flange - dirty	Oxidised steel	W	152	172	128	0.95	160	180	131	
	White insulation covering	Fibreglass - Fabric	G	28	48	71	0.90	31	51	73	
			P	54	74	89		60	80	94	
	Metal bands - dirty	Oxidised galvanised steel	LB	0	20	25	0.28	0	20	25	Shows effects of emissivity and reflections plus failure of equation
			R	80	100	102		286	306	157	
	Fibreglass - dirty		P	54	74	89	0.90	60	80	94	
			R	80	100	102		89	109	104	
			Y	108	128	112		120	140	118	
			W	152	172	128		169	189	133	
	Aluminium cladding - dirty	Oxidised aluminium	LB	0.0	20.0	25	031	0.0	20.0	25	

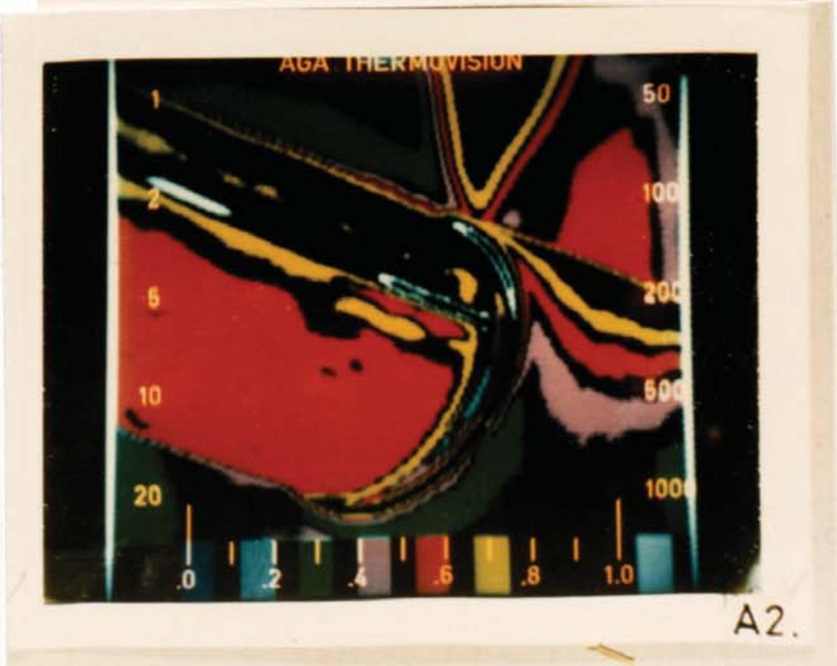
PHOTO No:	DESCRIPTION	MATERIALS	COLOURS	Ai	BLACK Io	BODY To °C	Eo	REAL Ai/E	BODY Io	To °C	COMMENTS
PLATE 8E											
B4	Reference = DB, Tr = 25, Equation 4	Ir = 26, f1.8, S = 1000									
	White insulation covering	Fabric	DB	0.0	26	25	0.90	0.0	26	25	
	Mild steel flange, welds and bracket	Oxidised steel	G	270	296	121	0.95	284	310	123	
			P	410	436	142		432	458	145	
			R	540	566	156		568	594	159	
			Y	690	716	170		726	752	173	
			W	1070	1096	203		1126	1152	206	
PLATE 8F											
C1	Reference = DB, Tr = 25, Equation 4	Ir = 26, f1.8, S = 1000									
	Mild steel pipe and trap - dirty	Oxidised steel	G	270	296	121	0.95	284	310	123	
			W	1060	1086	202		1116	1142	207	
	Brass tap - dirty	Oxidised brass	LB	140	166	94	0.6	233	259	112	Note effect of emissivity
			P	410	436	142		683	709	169	
			Y	690	716	170		1150	1176	209	
	Concrete wall - dirty	Plaster	DB	0	26	25	0.9	0	26	25	
PLATE 8G.											
A17	Reference = LB, Tr = 25, Equation 4	Ir = 26, f1.8, S = 1000									
	Mild steel pipes and traps - dirty	Oxidised steel	P	300	326	126	0.95	316	342	128	
			R	420	446	143		442	468	146	
			Y	550	576	157		579	605	160	
			W	680	706	169		716	742	172	
	Concrete floor - dirty	Plaster	LB	0	26	25	0.9	0	26	25	
PLATE 8H											
A15	Reference = LB, Tr = 25, Equation 4	Ir = 26, f1.8, S = 1000									
	Background general	Oxidised steel	LB	0	26	25	0.95	0	26	25	
	Mild steel pipe and valve - dirty	Oxidised steel	G	140	166	94	0.95	147	173	95	
			P	310	336	127		326	352	130	
			R	420	446	143		442	468	146	Lower emissivity
			Y	550	576	157		579	605	160	
			W	680	706	169		716	742	172	
	Asbestos - wrap lagging		G	140	166	94	0.9	156	182	97	

PHOTO No:	DESCRIPTION	MATERIALS	COLOURS	Ai	BLACK Io	BODY T°C	Eo	REAL Ai/Eo	BODY Io	T°C	COMMENTS
<u>PLATE 8J</u>											
D1 & D2	Reference = DB, Tr = 25, Equation 4	Ir = 26, f1.8, S = 200									
	Black rubber	Rubber	P	82	108	78	0.9	91	117	80	
			R	108	134	87		120	146	89	
			Y	136	162	93		151	177	95	
			W	178	204	102		198	224	106	
	Steel Chassis - dirty	Oxidised steel	DB	0	26	25	0.95	0	26	25	
			LB	28	54	50		29	55	51	
			G	54	80	64		57	83	66	
			P	82	108	78		86	117	79	
<u>PLATE 8K & 8L</u>											
E1 & E2 E3 & E4	Reference = DB, Tr = 25, Equation 4	Ir = 26, f1.8, S = 1000									
	Black rubber	Rubber	DB	0	26	25	0.9	0	26	25	
	Steel chassis - dirty	Oxidised steel	DB	0	26	25	0.95	0	26	25	
			LB	140	166	94		147	173	96	
			G	270	296	121		284	310	123	
			P	410	436	142		432	458	145	
			R	540	566	156		568	594	159	
			Y	680	706	169		716	742	172	
			W	900	926	187		947	973	192	
<u>PLATE 8M</u>											
A1	Reference = DB, Tr = 70, Equation 4	Ir = 93, f1.8, S = 1000									
	Steel chassis - dirty	Oxidised steel	DB	0	93	70	0.95	0	93	70	
			LB	110	203	102		116	209	104	
			G	200	293	120		211	304	123	
			P	310	403	137		326	419	139	
			R	420	513	150		442	535	153	
	Steel chassis - dirty	Oxidised steel	Y	500	593	158	0.95	526	619	161	
			W	590	683	167		621	714	170	
<u>PLATE 8O</u>											
A7	Reference = G, Tr = 70, Equation 4	Ir = 93, f1.8, S = 500									
	Steel chassis - dirty	Oxidised steel	G	0	93	70	0.95	0	93	70	
			P	85	178	97		89	182	99	
			R	140	233	109		147	240	110	
			Y	210	303	122		221	314	124	

PHOTO No:	DESCRIPTION	MATERIALS	COLOURS	Ai	BLACK Io	BODY To °C	Eo	REAL Ai/Eo	Io	To °C	COMMENTS
PLATE 80											
F1 & F2	Reference = Y, Tr = 180, Equation 4	Ir = f5.1, S = 100									Reference temperature estimated.
	Steel platten and mould housing - dirty	Oxidised steel	DB	-68	37	120	0.95	-72	33	119	
			LB	-54	51	136		-57	48	135	Temperatures at low isotherm levels could not be accurately determined.
			G	-41	64	146		-43	62	145	
			P	-27	78	163		-28	77	160	
			R	-14	91	176		-15	91	173	
			Y	0	105	180		0	105	180	
			W	22	127	193		23	128	193	
	Aluminium mould - dirty	Oxidised aluminium	LB	-54	51	136	0.31	-174			Although there would be some tempeature variation, emissivity variance was the dominant effect.
			G	-41	64	146		-132			
			P	-27	78	163		- 87			
			R	-14	91	176		- 45	60	145	

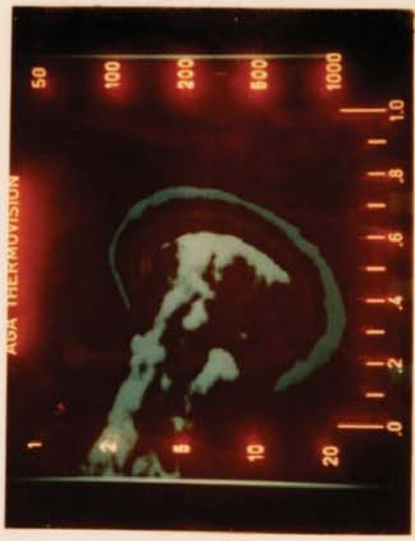

AGA THERMOVISION
1
2
5
10
20
50
1000
.0
.2
.4
.6
.8
1.0

A1.

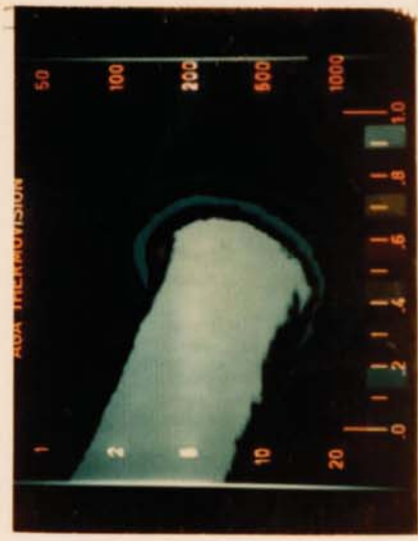

AGA THERMOVISION
1
2
5
10
20
50
.0
.2
.4
.6
.8
1.0

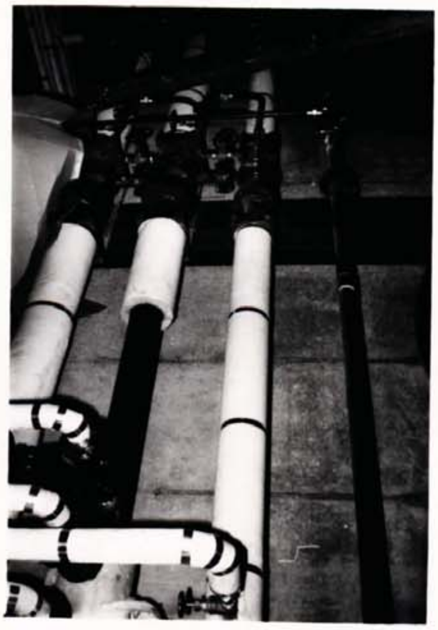
A2.

A3.

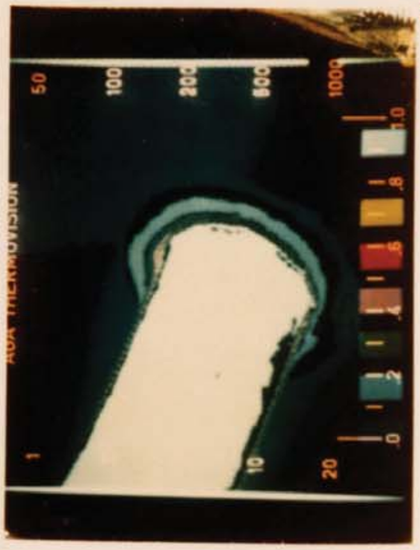


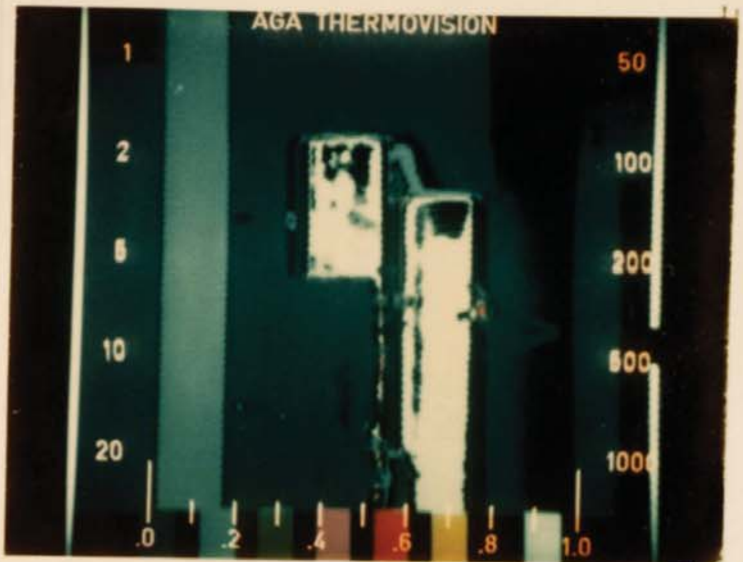
A5.



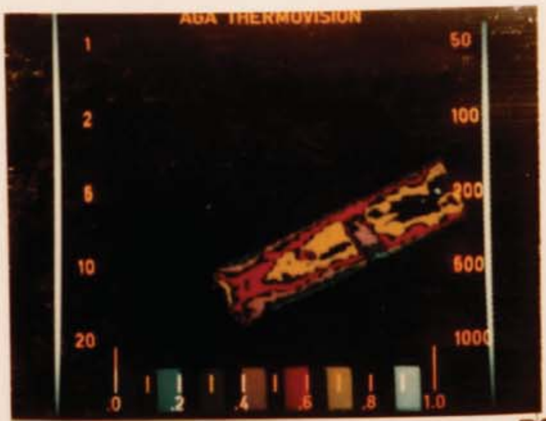


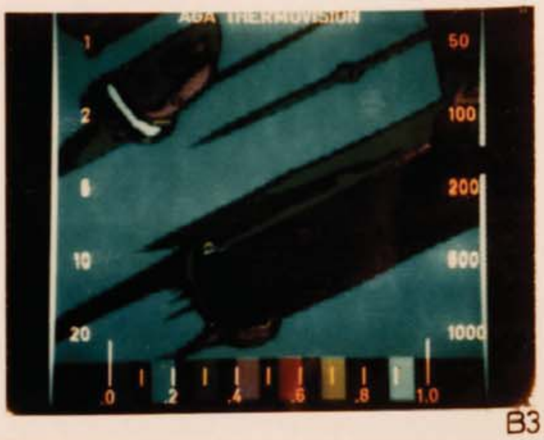
A4.

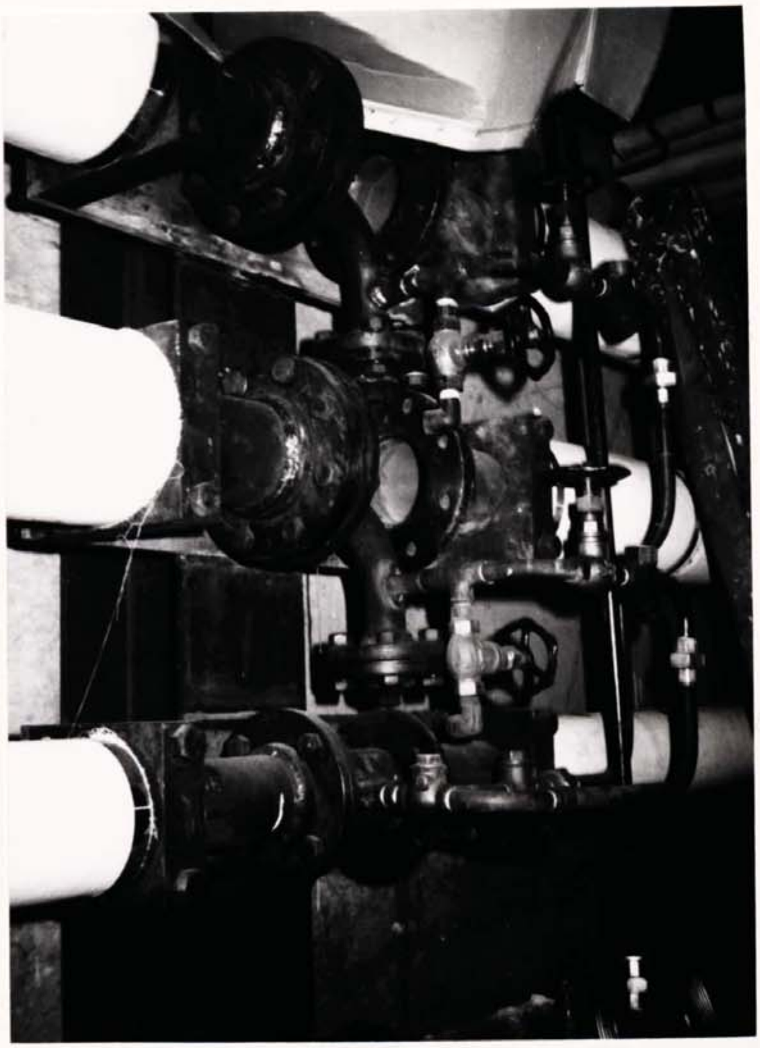


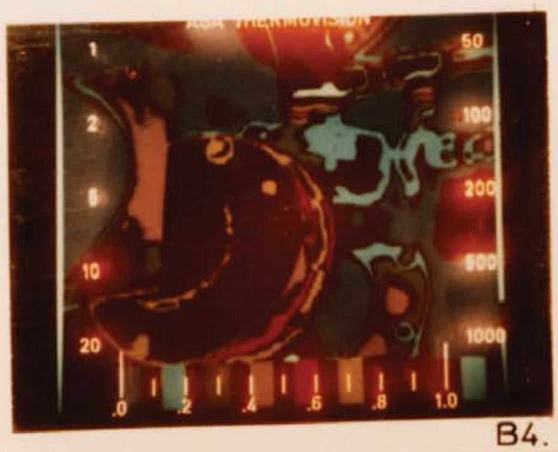


B1.

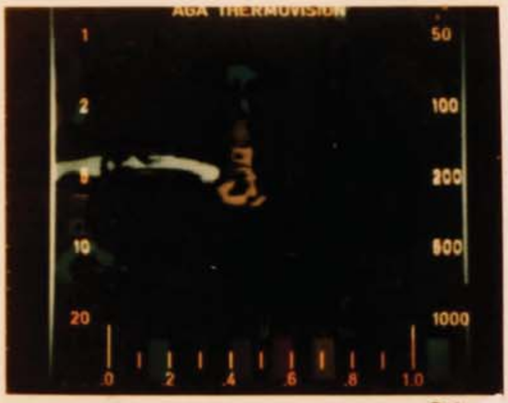

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
B2.


1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
B3.

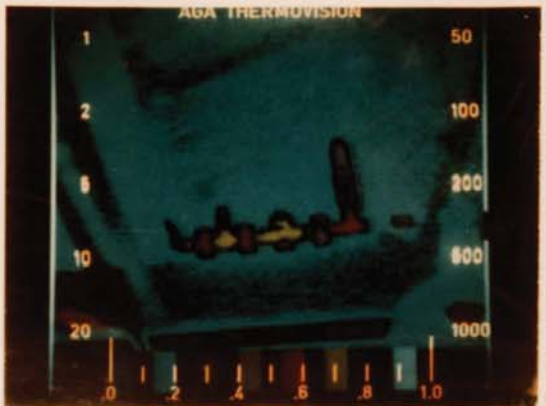




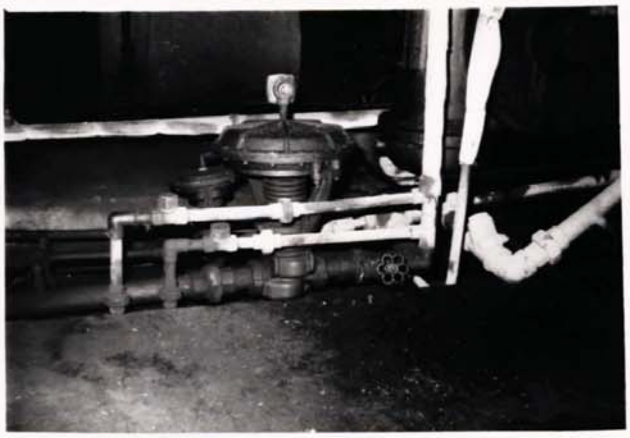
B4.


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

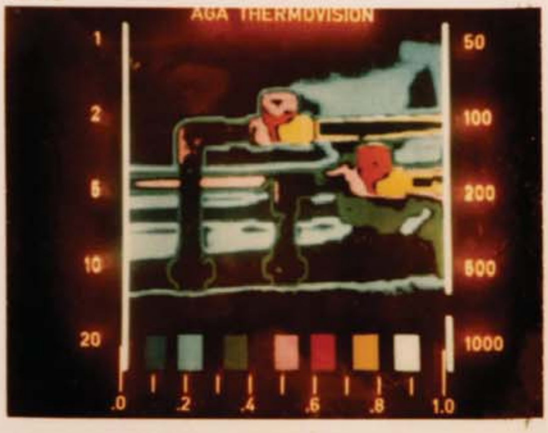
C1


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

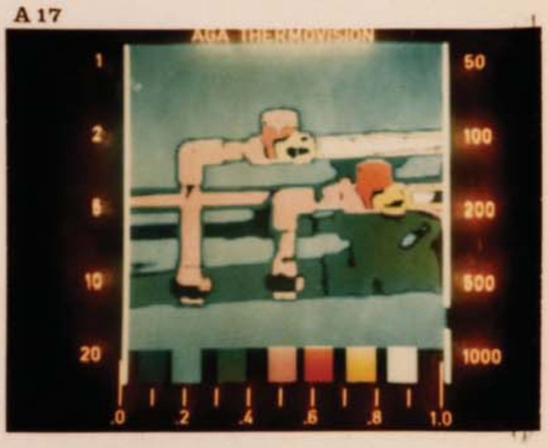
C2.

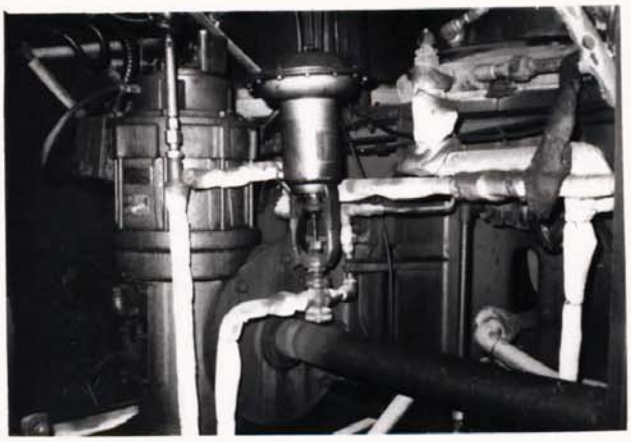


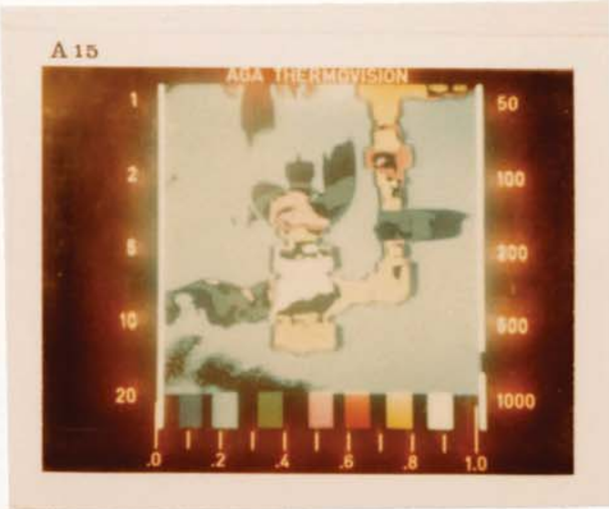
A 16


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

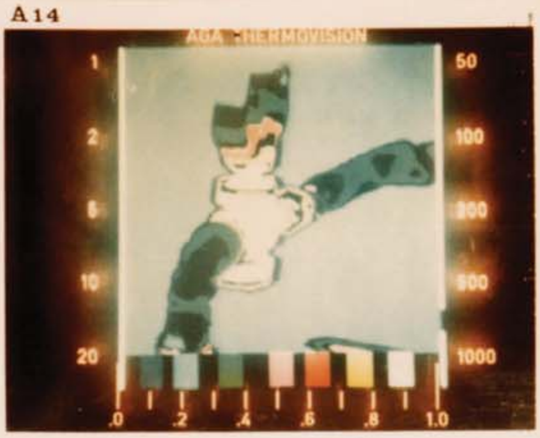
A 17

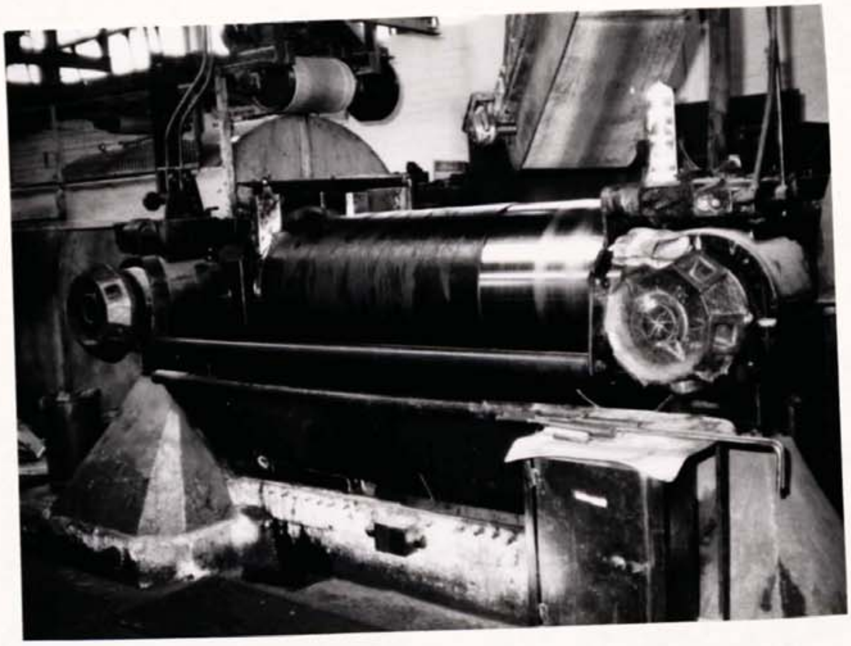

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

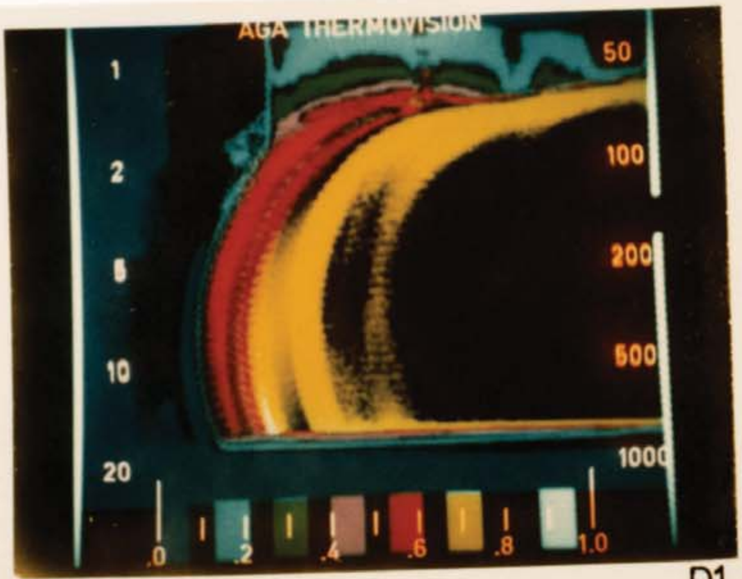



A 15
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

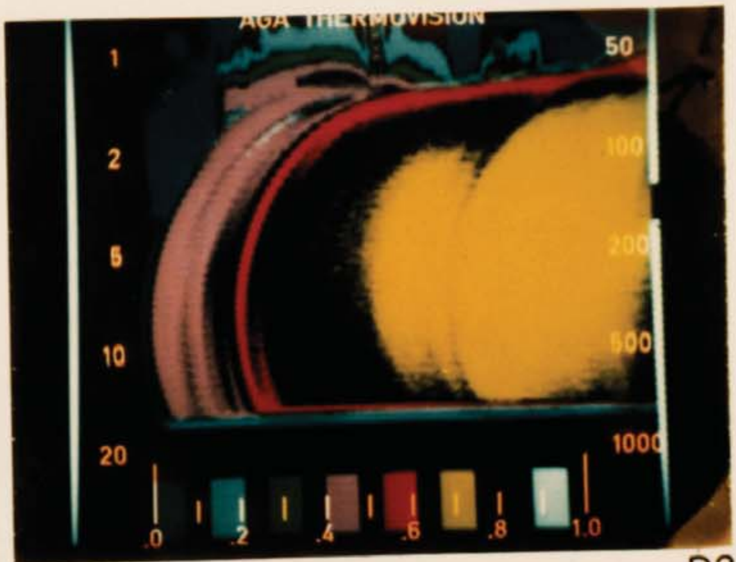
A14





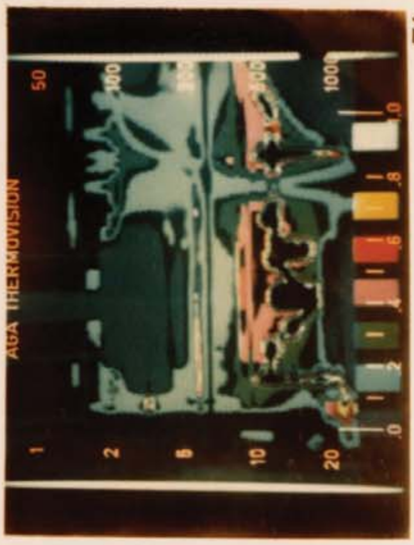

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

D1.

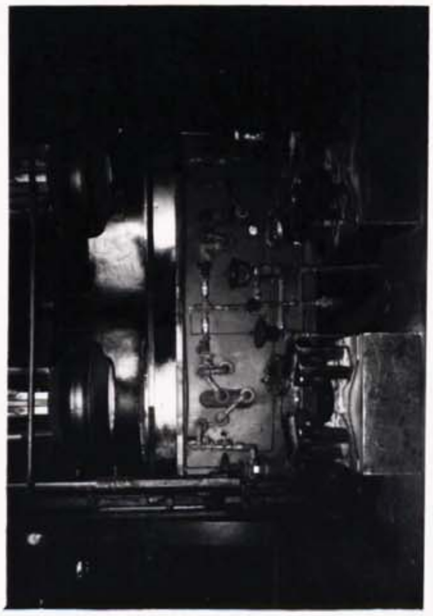

AGA THERMOVISION
1
2
5
10
20
50
1000
.0
.2
.4
.6
.8
1.0

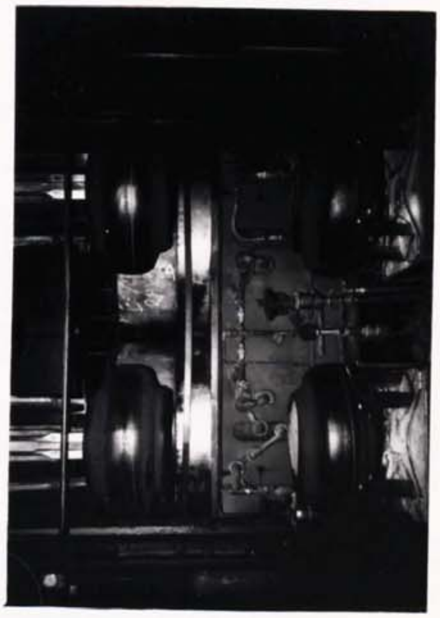
D2.

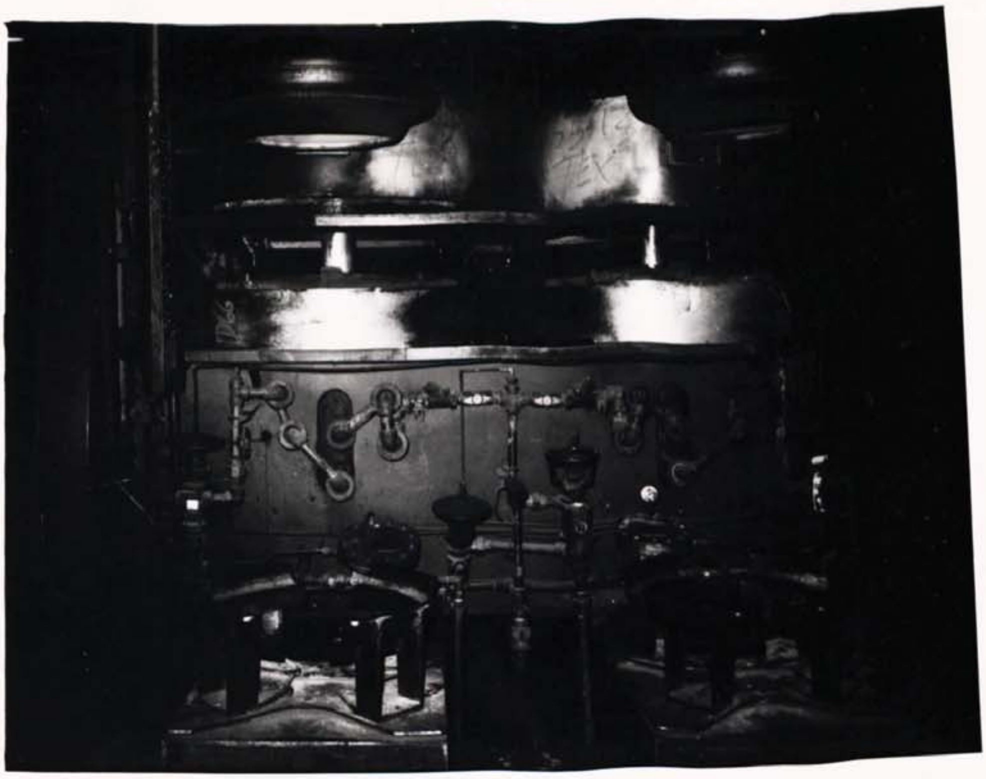
E2.

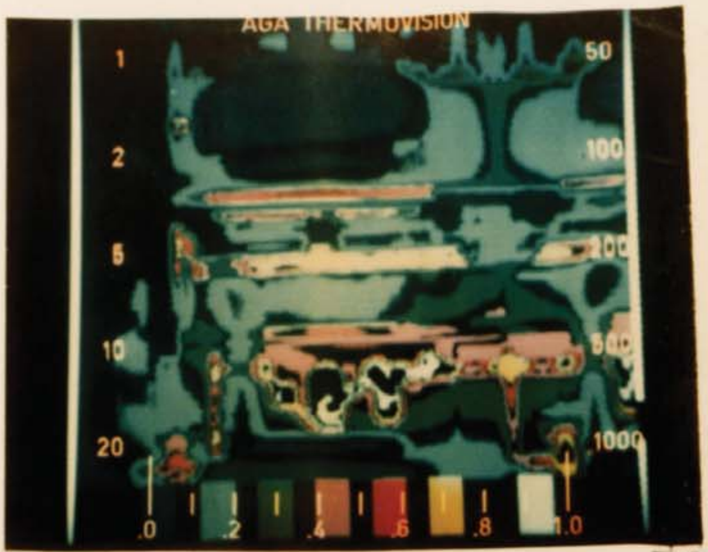


E1.

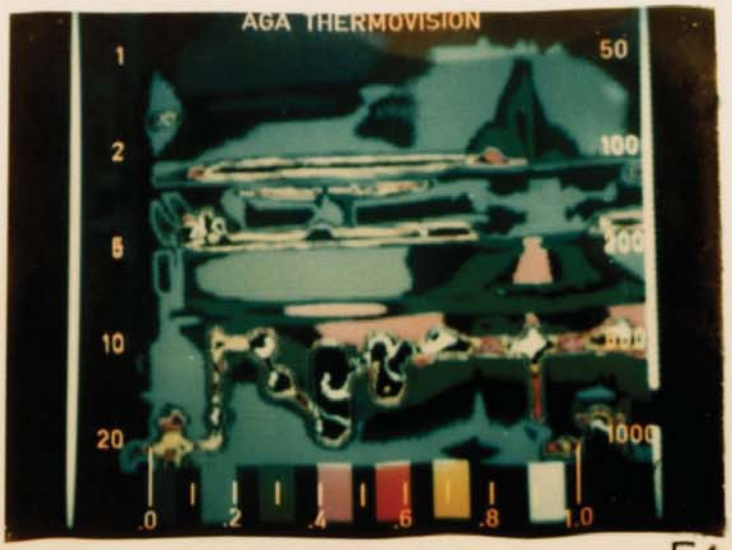







AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

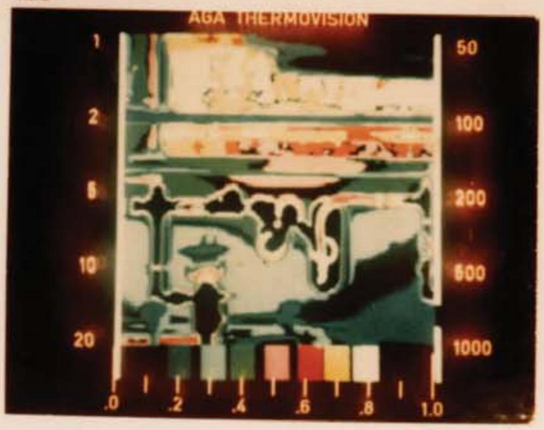
E3.

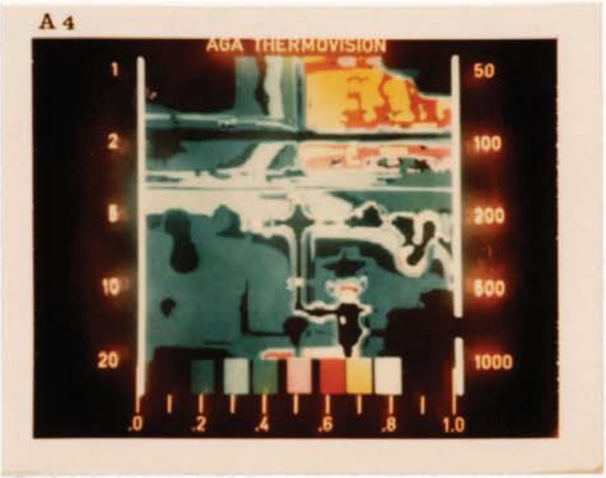

AGA THERMOVISION
1
2
5
10
20
50
100
200
1000
.0
.2
.4
.6
.8
1.0

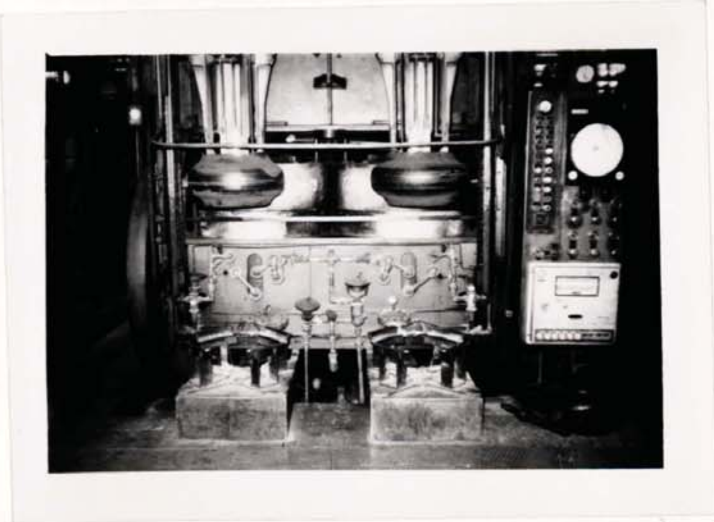
E4.

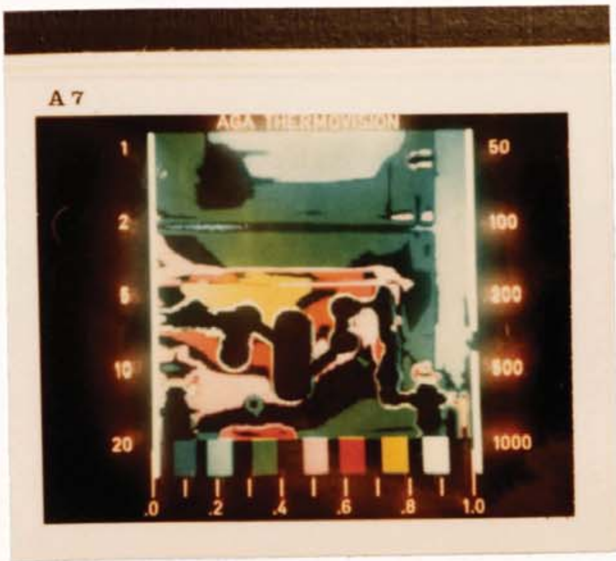
8L

A1

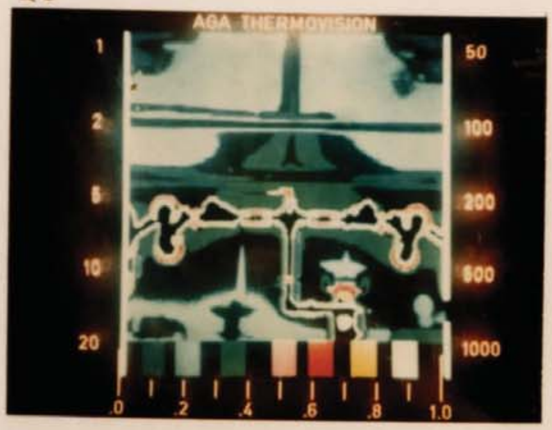


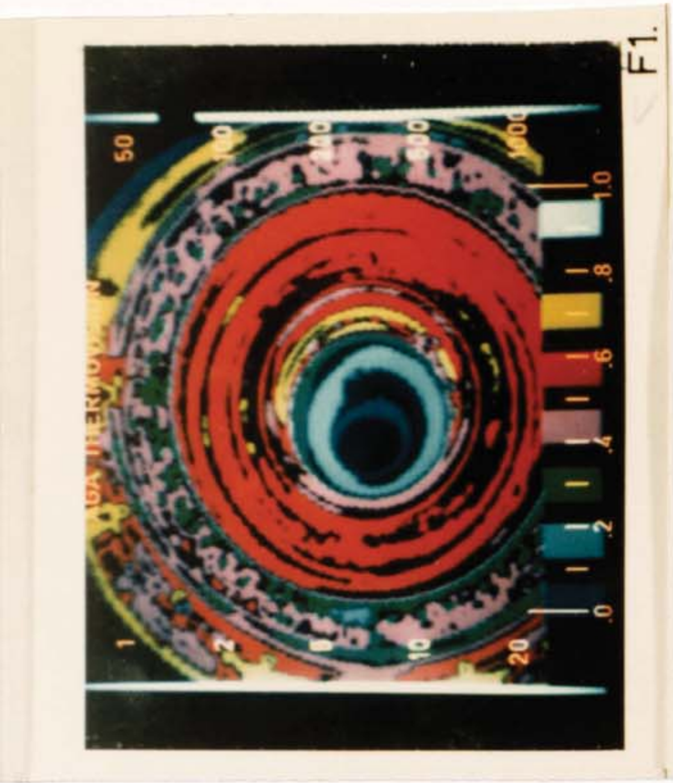

A 4
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0



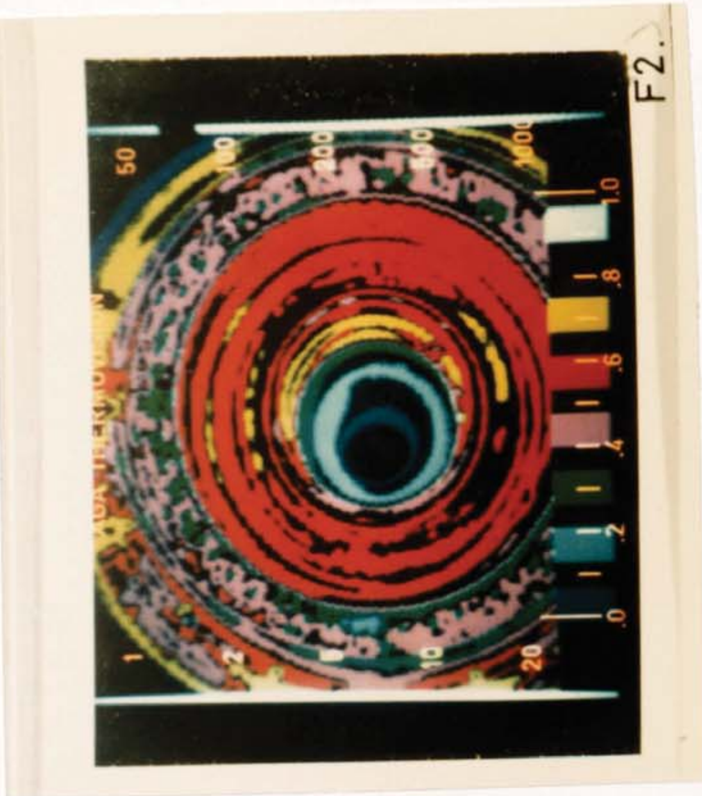

A 7
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

A 8

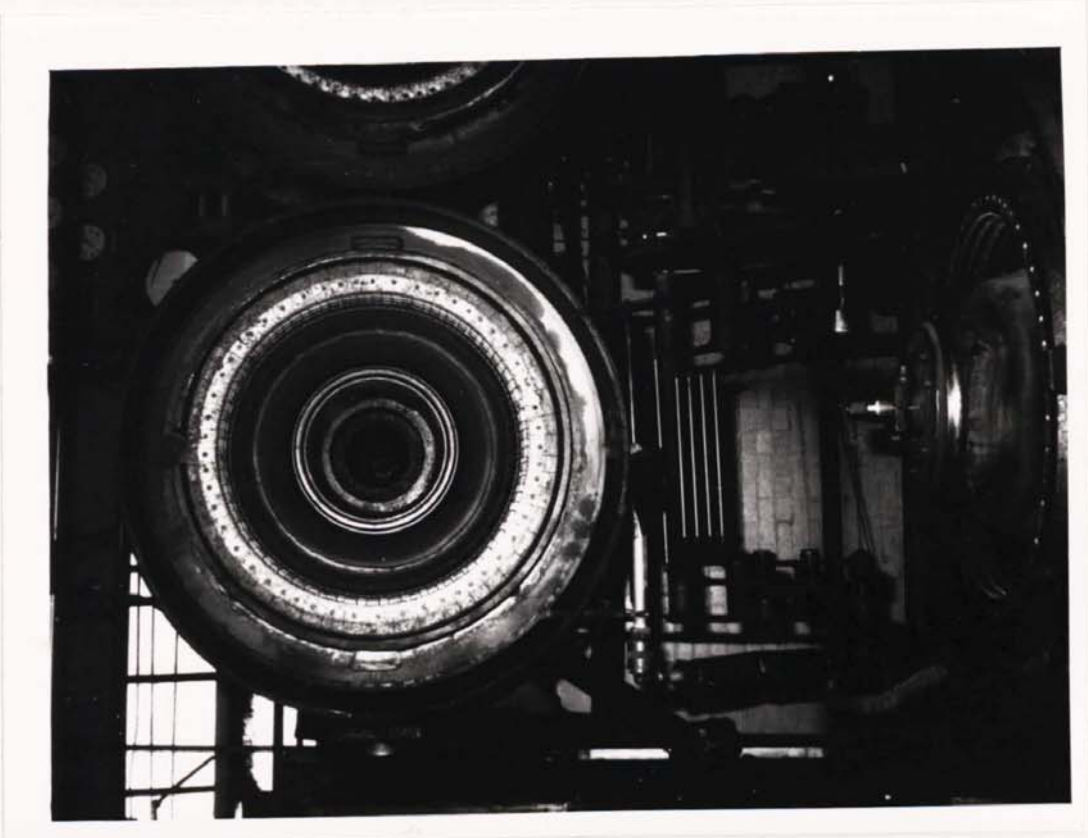




F1.



F2.



APPENDIX C

THERMOGRAMS FOR THE TYRE 5 ENERGY BALANCE

----- Plates 9.4A to 9.4I

C.1 DATA RECORD FOR TYRE 5 ENERGY BALANCE

DATE : TUESDAY 12TH JULY 1977

Table C.1. Steam Measurements

1.1 FLOW - meter readings in kg. of steam

- readings made every half hour

Time	Main Flow	Flaps Flow	Tyre 5 Flow
0935	-	-	-
0935 - 1425	42222	6737	35485
1155 - 1225	4368 *	697 *	3671 *
1225 - 1255	4368 *	697 *	3671 *
1255 - 1325	4368 *	697 *	3671 *
1325 - 1355	4368 *	697 *	3671 *
1355 - 1425	4368 *	697 *	3671 *
1425 - 1455	4313	254	4059
1455 - 1525	4222	222	4000
1525 - 1555	4222	254	3968
1555 - 1705	10760	572	10188
* = for this period ½ hourly ave	4368	697	3671 *
Total 1425 - 1705	23517	1302	22215
Hourly Average 2.67 hours	8809	488	8320

1.2 CONDITION - as delivered from boiler house

	Before experiment Time	Before experiment Reading	After experiment Time	After experiment Reading	Average
Temperature - C					278.3
Pressure - bar					22.4
Total flow - kg.	0930 Mon 11th	34713611	0925 Tue 12th	36470210	73447 kg/hr (23.92 hrs)

TABLE C.2 COLD HYDRAULIC WATER MEASUREMENTS

2.1 FLOW RATE - as measured to the cooling tower

= 54.55 m3/hr. average

2.2 TEMPERATURE - as measured by thermometer

	Before experiment Time	Before experiment Reading	After experiment Time	After experiment Reading	Average
Hot Side - C	1410	22.0	1650	24.5	23.3
Cold Side - C	1410	15.0	1650	16.0	15.5
Difference - C		7.0		8.5	7.8

TABLE C.3 PRODUCTION OUTPUT

FINISHED PRODUCT - kgs. output over period (of 24hrs)
= 67691
= 2820 kg/hr

TABLE C.4 CONDENSATE MEASUREMENTS

- meter readings in m3 from Tyre 1 pit for flow
- temperature in C from boiler house

	Before experiment		After experiment		Average
	Time	Reading	Time	Reading	
Temperature	0950	89	1645	88	88.5
Flow Rate	0950	179886	1645	179945	8.6 m^3/hr

TABLE C.5 TEMPERATURE RELATIVE HUMIDITY AND WIND RECORDS

5.1 Ambient air temperature on roof of Tyre 5 (average) - C - 14.8

General ambient temperature from Elmdon Airport - C - 15.3

5.2 Tyre 5 internal temperatures, average over period:

- Above presses - C - 29.0
- Above making - C - 26.2
- Central ground level - C - 20.2

5.3 Relative humidity - Tyre 5 - to be read at hourly intervals from wet & dry bulb hygrometer in switch room

Time	Dry bulb Temp. C	Wet bulb Temp. C	Relative humidity %
1416	20.0	15.5	60 (81)
1516	19.0	16.0	72 (83)
1616	19.0	16.0	72 (85)
1700	19.0	16.0	72 (92)
AVERAGE			

Average local relative humidity	- % -	69.0
General relative humidity from Elmdon Airport	- % -	85.7

5.4 General wind condition from Elmdon Airport :

- Wind speed (average over period) - m/min - 269 m/min
- Wind direction - 030 to 040 approx NE

5.5 Comments on weather conditions

1 Dull all afternoon during experiments

2 Average temperatures based on hourly readings taken between 1200 and 1700

3 Relative humidity in brackets - Elmdon Airport. Average R.H. for Elmdon based on hourly readings taken between 1200 and 1700. Average for F.D. based on data available

4 Wind Speed averages over similar time period

TABLE C.6 ELECTRICITY MEASUREMENTS

6.1 TYRE 5 CONSUMPTION - meter readings in kWhr of electricity

- readings made every half hour

Time	303	302	305	307	312	317	318	Tyre 5
→ 1415	-	-	-	-	-	-	-	-
1415-1445	150	4	24	0	7	11	0	112
1445-1515	260	1	26	0	7	13	0	215
1515-1545	150	1	25	0	4	11	0	111
1545-1700	370	0	66	0	10	28	0	266
Total Time 2hr. 45 min								
Total	- 930	- 6	- 141	- 0	- 28	- 63	- 0	- 704 -
Average per hr.	- 248.0	- 1.6	- 37.6	- 0	- 7.5	- 16.8	- 0	- 187.7 -

6.2 TOTAL SITE CONSUMPTION - as metered in the power house in kWhr over the period = 400,000 kWhr
426,000 kvalr

Table C.7

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENT - TYRE 5 ENERGY BALANCE

Photo No.	Description	Materials	Colours	Di	Black Body Io	To °C	Observations	Comments on Interpretation
PLATE 9.4A								
C 1	Reference = G, Tr-21 Equation 4	Ir = 23, F1.8, S-10 L = - -					Variation of temperatures Measured between mortar and brickwork	
	Brickwork and Mortar - dirty	Brick-dirty	DB LB G	-2.6 -1.3 0	20 21 23	17 19 21		
C 2	Reference = W, Tr = 27 Equation 4	Ir =28, F1.8, S = 10 L = - -					- Higher heat loss from roof and windows	
	Brickwork and mortar - dirty	Brick = dirty	G P	-5.4 -3.7	22 24	21 23		
	Pipe - dirty	Cast iron oxidised	P R	-3.7 -2.6	24 25	23 25		
	Window - dirty	Glass - dirty	P	-3.7	24	23		
	Roofing - dirty	Asbestos - dirty	P R	-3.7 -2.6	24 25	23 25		
PLATE 9.4B								
C 3	Reference = W, Tr = 26 Equation 4	Ir = 27, F1.8, S = 10 L = 54						
	Brickwork and mortar - dirty	Brick - dirty	G	-5.4	22	21		
C 4	Reference = W, Tr = 26 Equation 4	Ir =27, F1.8, S = 10 L = 54					- Higher heat loss through roof and windows. Highest internal temperature (white) seen through open windows on right of picture.	
	Brickwork and Mortar - dirty	Brick - dirty	G	-5.4	21	19		
	Window Frame - dirty	Mild Steel-Oxidised	P R W	-3.7 -2.6 0	23 24 27	21 23 26	- Higher temperature than plate 9.4A. due to effect of heat loss from presses	
	Window - dirty	Glass - dirty	P R W	-3.7 -2.6 0	23 24 27	21 23 26		
	Interior of building		W	0	27	26		
	Roofing - dirty	Asbestos - dirty	R	-2.6	24	23		

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENT - TYRE 5 ENERGY BALANCE

Photo No.	Description	Materials	Colours	Di	Black Body Io	To °C	Observations	Comments on Interpretation
PLATE 9.4C								
C 5	Reference = Y, Tr = 90 Equation 4	Ir =150, Fl.8, S=200	L = 60				- Note temperature variation in pressure vessel plus large loss to atmosphere up pipe	
	Mild steel tank and pipework - dirty	Mild Steel - Oxidised	Y	0	150	90		
			W	24	174	96	- Unlagged pressure vessel	
C 6	Reference = G, Tr = 25.5 Equation 4	Ir = 26, Fl.8, S=50	L = 60					
	Brickwork and Mortar - dirty	Brick - dirty	LB	- 6.5	20	26	- Remarkably high rate of heat transfer to wall. In addition, interior pipework also heating wall.	
			G	0	26	25.5		
			P	8.5	35	35		
			R	14.0	40	39		
			Y	30.5	47	44		
			W	27.0	53	49		
	Mild steel pipework - dirty	Mild steel-Oxidised	LB	- 6.5	20	16		
			G	0	26	25.5		
			P	8.5	35	35		
PLATE 9.4D								
C 7 & C 8	Reference = W, Tr= 25.5 Equation 4	Ir=26, Fl.8, S = 5	L = 72				- Roof temperatures were highest with greater heat loss through glass	
	Brickwork and mortar - dirty	Brick - dirty	LB	-3.4	22.6	21		
			G	-2.7	23.3	22	- High temperatures shown at base of building caused by heat loss from condensate pipework in trench	
			P	-2.0	24.	23		
			R	-1.3	24.7	24		
			X	-0.7	25.3	25		
			W	0	26	25.5		
	Window Frame - dirty	Mild Steel-Oxidised	LB	-3.4	22.6	21		
	Window - dirty	Glass - dirty	G	-2.7	23.3	22		
			P	-2.0	24	23		
	Roofing - dirty	Asbestos - dirty	P	-2.0	24	23		
			R	-1.3	24.7	24		
PLATE 9.4E								
C 9 & C10	Reference = W Tr = 24.5 Equation 4	Ir = 25.5, Fl.8 S=5	L = 360				- High temperature of exhaust steam pipe	

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENT - TYRE 5 ENERGY BALANCE

Photo No.	Description	Materials	Colours	Di	Black Body Io	Black Body To °C	Observations	Comments on Interpretation
PLATE 9.4E Cont'd C 9 & C10	Brickwork & Mortar - dirty	Brick - dirty	DB	-4.0	21.5	19.5	- Apparent cooler temperature of window	
			LB	-3.4	22.1	20.5		
			G	-2.7	22.8	21		
	Black insulated pipework - dirty	Mild Steel-Oxidised	P	-2.0	23.5	22		Insualtion taken at emissivity of pipework
			R	-1.3	24.2	23		
			Y	-0.7	24.8	24		
			W	0	25.5	24.5		
PLATE 9.4F								
C11	Reference = W, Tr = 23.5 Equation 4	Ir=24.5, Fl.8, S= 5	L = 360				- Demonstration of the cooling effect of air on Brickwork	
	Brickwork & Mortar - dirty	Brick - dirty	LB		22.1	20.5		
			G		22.8	21		
			P		23.5	22		
			R		24.2	23		
	Window - Clean (Room Interior)		P		23.5	22		Temperature of glass could not be measured with the IR optics used.
PLATE 9.4G								
C12 & C13	Reference = Y, Tr = 23 Equation 4	Ir=24, Fl.8, S=5	L = 162				- Higher temperatures recorded at upper levels. Open window slats show internal temperature	
	Brickwork & Mortar - dirty	Brick - dirty	LB	-2.8	21.2	19		
			G	-2.1	21.9	20		
			P	-1.3	23.3	21	- High temperatures also shown at ground level caused by hot pipes in trench.	
			R	-0.7	24	22		
	Window - dirty	Glass - dirty	P	-1.3	23.3	21		
			R	-0.7	24	22		
PLATE 9.4H								
C14 & C15	Reference = Y, Tr = 21.5 Equation 4	Ir=23, Fl.8, S = 5	L = 156				- Greater heat loss through the glass than the brickwork	

i)

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENT - TYRE 5 ENERGY BALANCE

Photo No.	Description	Materials	Colours	Di	Black Body Io	Black Body To °C	Observations	Comments Interpretation
PLATE 9.4H. Cont'd								
C14 & C15	Brickwork & Mortar - Dirty	Brick - dirty	P	-1.3	21.7	19.5		
	Window - Clean (Room interior)		R	-0.7	22.3	20.5		Temperature of Glass could not be measured with the IR optics used.
			Y	0	33.0	21.5		
	- heating pipe	Mild Steel-Oxidised	W	0.6	23.6	22.5		
	Window Frame - dirty	Painted Mild Steel	G	-2.1	20.9	18		
			P	-1.3	21.7	19.5		
PLATE 9.4I								
B31-32-33	Reference = DB, Tr = 15 Equation 4	Ir 19, F1.8, S = 5	L =				- Highest roof temperatures over the moulding section	
	Roofing - dirty	Asbestos - dirty	DB	0	19	15		Possibility of attenuation effects
			LB	0.7	19.7	16		
			G	1.3	20.3	17		
			P	2.1	21.1	19		
			R	2.7	21.7	20		
			Y	3.4	22.4	21		
			W	4.0	23.	22.		

C.2 · DATA RECORD FOR TYRE 5 AIR CHANGES

DATE: 24th May 1978

TABLE C.8 STEAM MEASUREMENT

8.1 FLOW

- meter readings in kg. of steam
- readings made every half hour

Time	Main Flow	Flaps Flow	Tyre 5 Flow
1130	1935647	183654	1751993
1200	1939639	184289	1755350
Total	3992	635	3357
Hourly Average	7984	1270	6714

8.2 CONDITION - as delivered from boiler house

	Before experiment		After cxperiment		Average
	Time	Reading	Time	Reading	
Temperature - C					278.3
Pressure - bar					22.4

TABLE C.9 COLD HYDRAULIC WATER MEASUREMENTS

9.1 FLOW RATE - as measured to the cooling tower

= 54.55 m3/hr. average

9.2 TEMPERATURE - as measured by thermometer

	Before experiment		After experiment		Average
	Time	Reading	Time	Reading	
Hot Side - C	1100	18.6			18.6
Cold Side - C	1100	14.4			14.4
Difference - C		4.2			4.2

TABLE C.10 PRODUCTION OUTPUT

FINISHED PRODUCT - kgs. output over period

= 60043 kg in 24 hrs.

= 2502 kg/hr average

TABLE C.11. CONDENSATE MEASUREMENTS

- meter readings in m3 from Tyre 1 pit for flow
- temperature in C from boiler house

	Before experiment		After experiment		Average
	Time	Reading	Time	Reading	
Temperature	1120 (24th)	82	10.04 (25th)	82	82
Flow Rate					

TABLE C.12 TEMPERATURE, RELATIVE HUMIDITY & WIND SPEED RECORDS

12.1 Ambient air temperature on roof of Tyre 5 (average) - C - -

General ambient temperature from Elmdon Airport - C - 12

12.2 Tyre 5 internal temperatures, average over period :

- Above presses - C - 38
- Above making - C - -
- Central ground level making - C - 18
- Bottom of presses - C - 29
- West Road roller shutter door - C - 20

12.3 General wind condition from Elmdon Airport :

- Wind speed (average over period) - m/min - light
- Wind Direction - Changeable

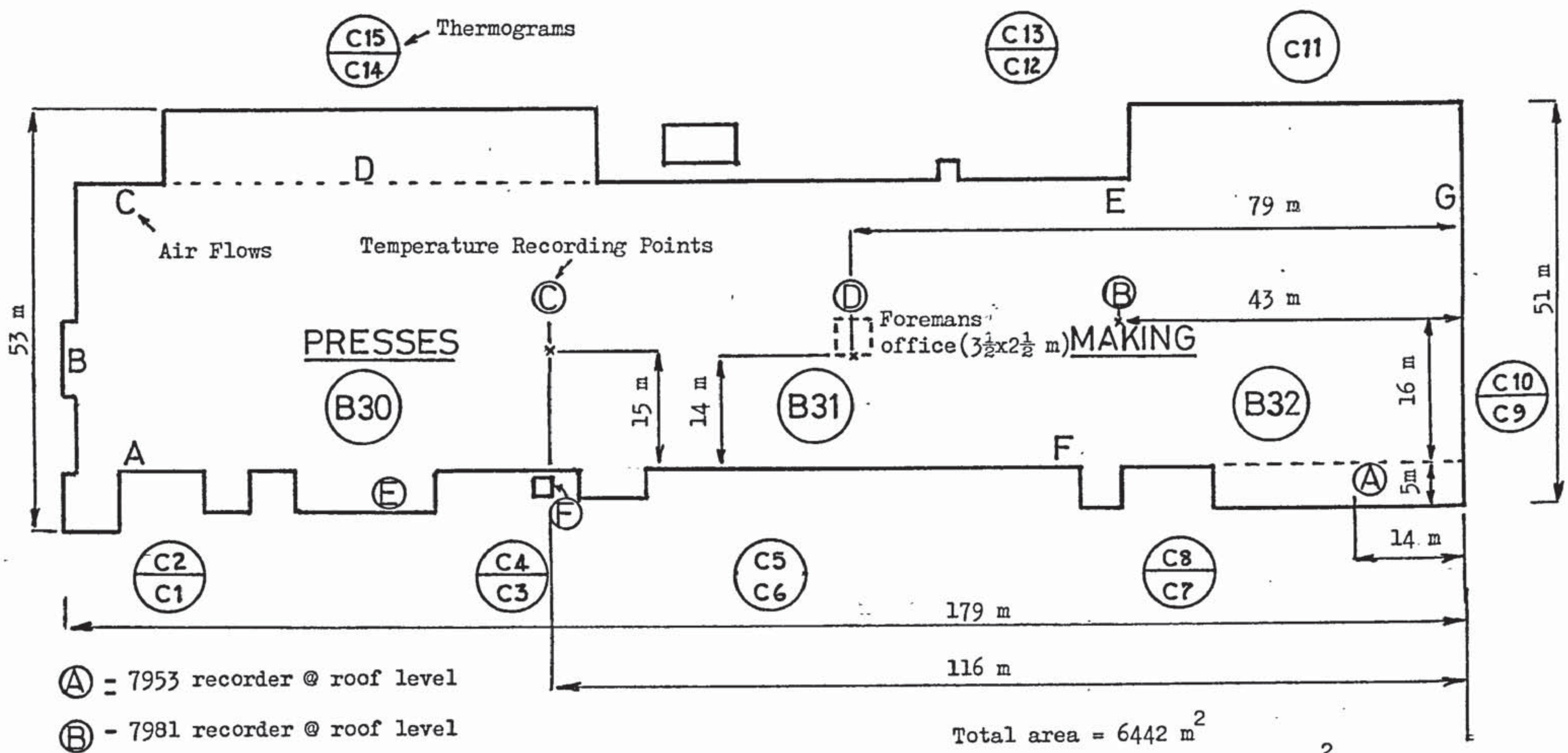
12.4 Comments on weather conditions

Changeable wind conditions gave variation of draughts through doors.

TABLE C.13 MEASUREMENT OF DRAUGHT VELOCITY

Position No. Figure 9.4.14	Draught Wind Speed m/sec	Dimensions ft.	Aperture Size m^2 (x0.0929)	Vol. Flow m^3/sec.
A	2.0-3.0	12½ x 4	4.65	9.30 - 13.95
B	3.0-3.5	6 x 7	3.90	11.70 - 13.65
C	4.0	1½ x12½	1.74	6.96
D	3.2	10 x 6	5.57	17.82
E	3.0-4.0	7 x 3	1.95	5.85 - 7.80
F	1.0-2.0	7 x 1	0.65	0.65 - 1.30
G	(2.0)	11 x10	10.22	(20.44) exiting

Figure C.14 Plan of Temperature Recording Points, Thermograms, and Air Flow Measurements: Tyre 5



Ⓐ = 7953 recorder @ roof level

Ⓑ - 7981 recorder @ roof level

Ⓒ - 7986 recorder @ roof level

Ⓓ - R142434 recorder @ ground level

Ⓔ - hygrometer @ ground level

Ⓕ - mercury thermometer @ ground level

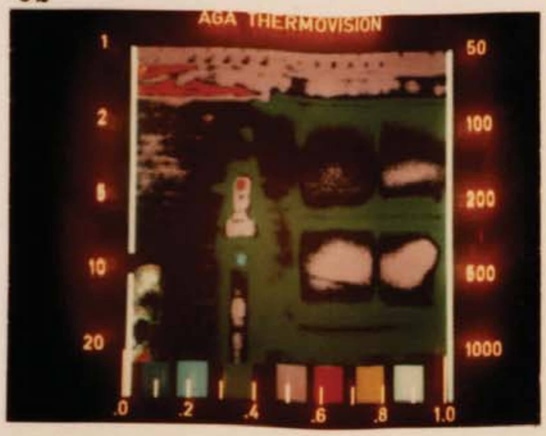
Total area = 6442 m^2

Main production area = 4994 m^2

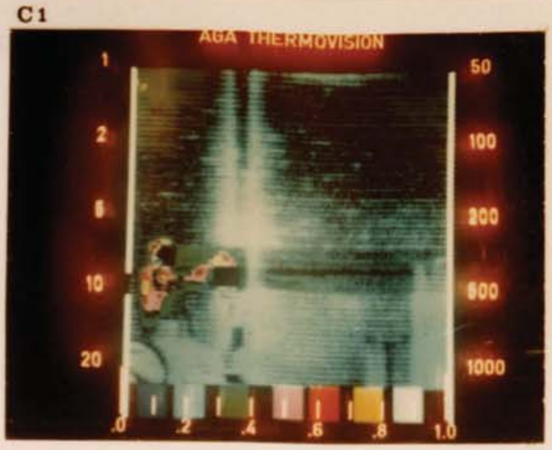
Press area = 2943 m^2

Building volume = 27842 m^3

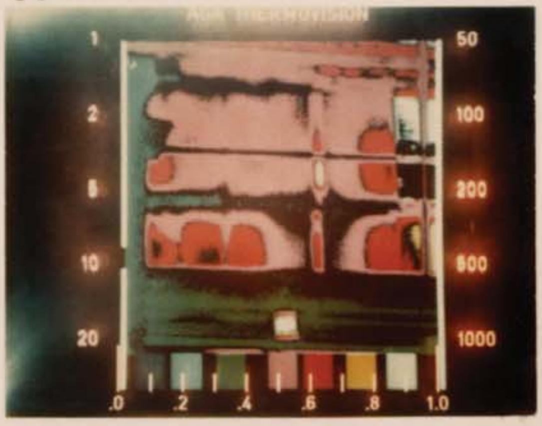
C2


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

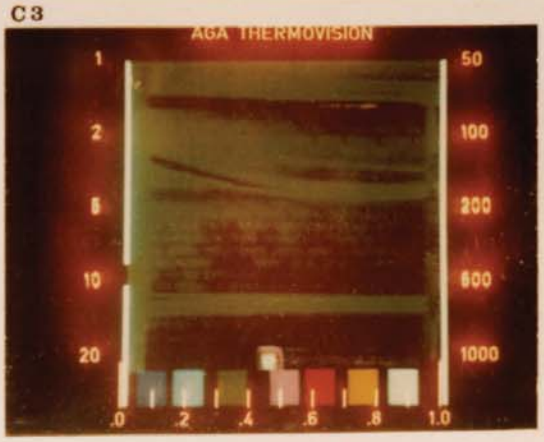
C1

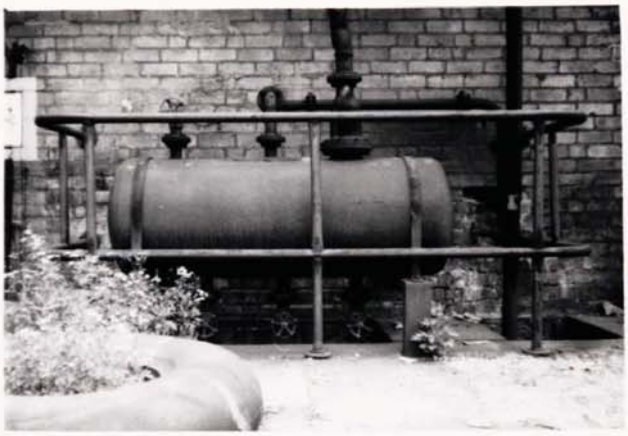

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

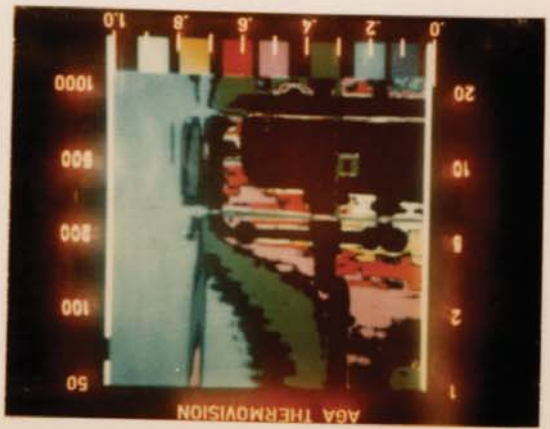
C4


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

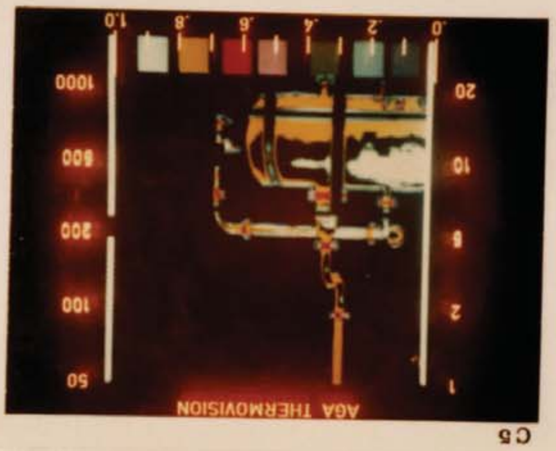
C3


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0



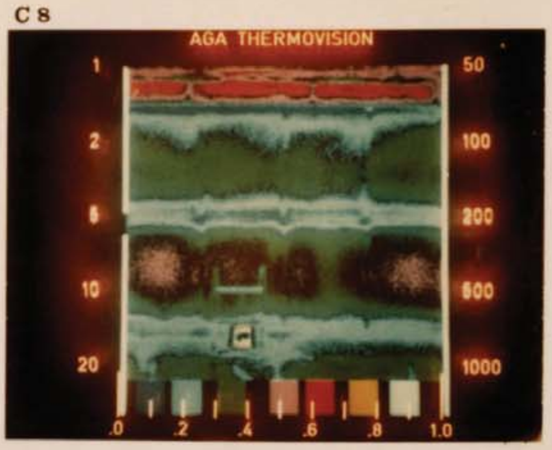


C 6

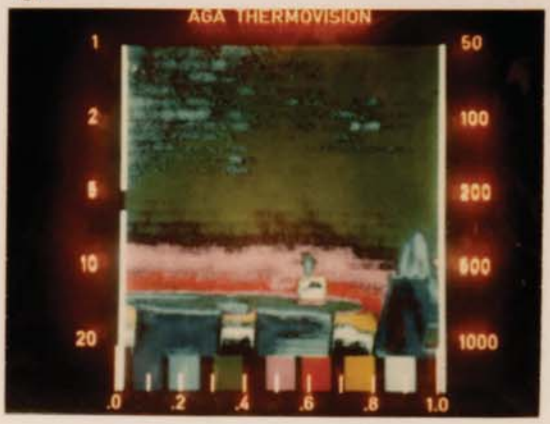


C 5

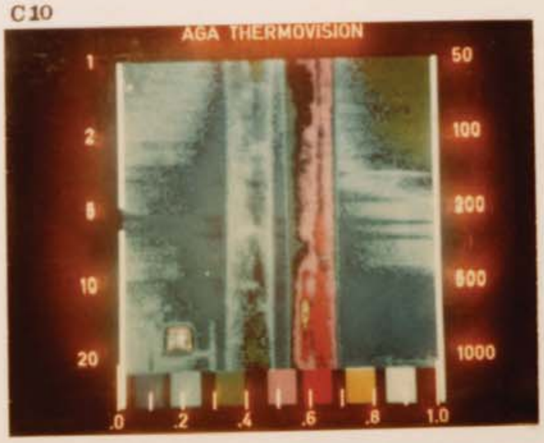
C 8


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

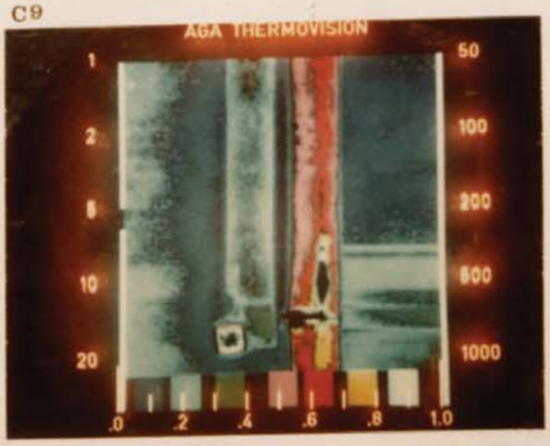
C 7

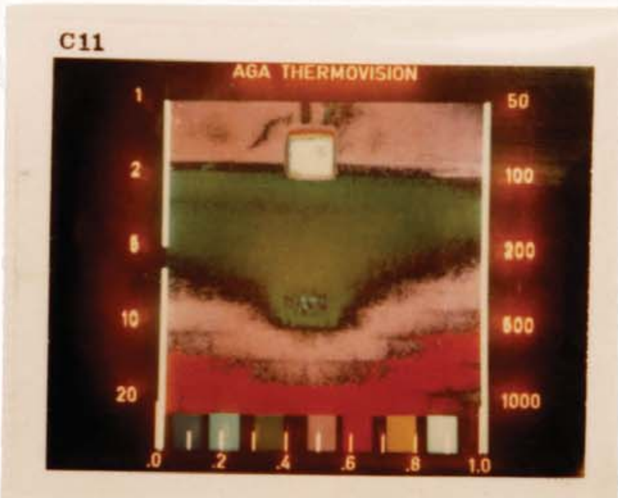

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

C10

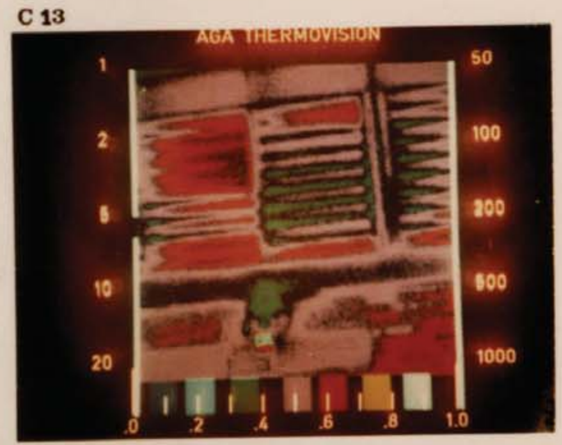

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

C9

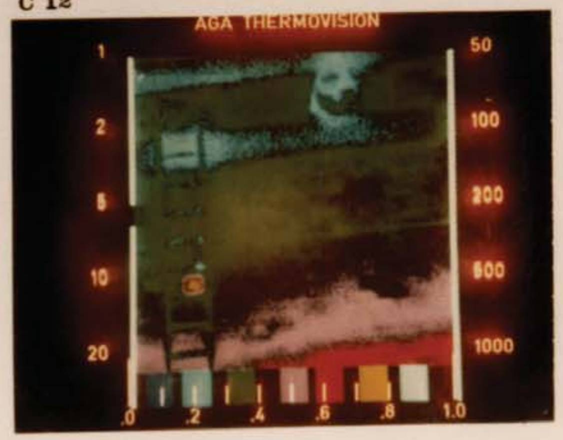

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

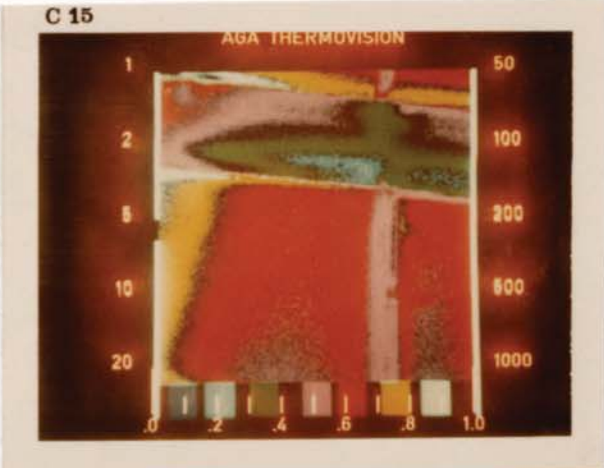

C11
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

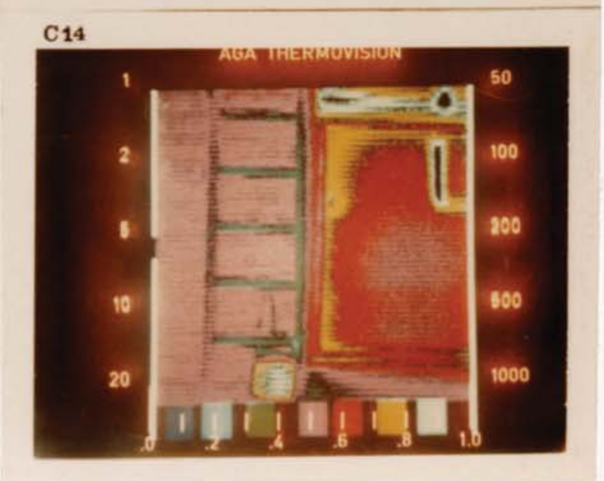
C 13


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

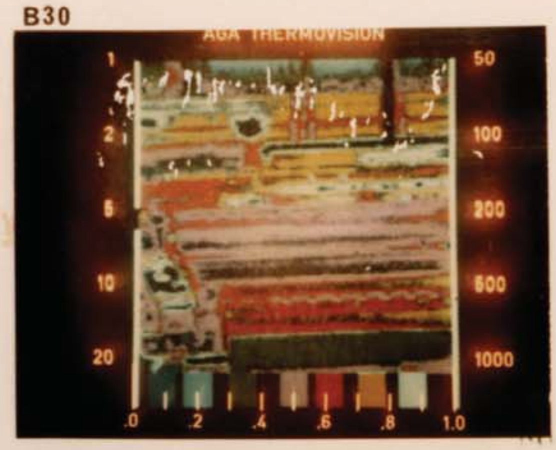
C 12


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

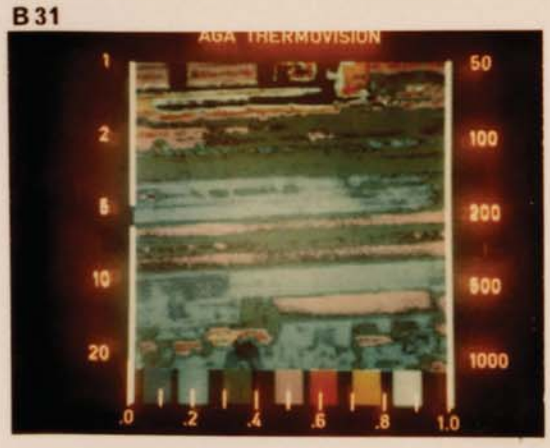

C 15
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0


C14
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

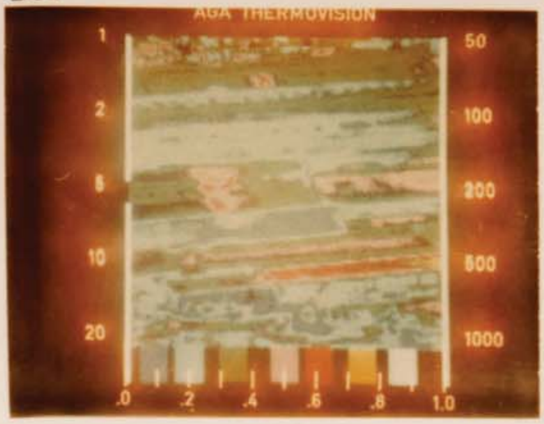
B30


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B 31


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B 32


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

APPENDIX D

THERMOGRAMS FOR THE STEAM MAIN STUDY

------ Plates 9.5A to 9.5I

D.1 DATA RECORD FOR WEST ROAD STEAM MAIN

DATE : 23rd August 1977

TABLE D.1 STEAM MEASUREMENTS

1.1 FLOW - into each department

- meter readings in kg. of steam

Department metered.	Before experiment Time 23.8.77	Reading	After experiment Time 23.8.77	Reading	Total steam kg/hr
New Mill	1340	634830	1610	638957	1651
C.M.S.	1335	60639	1608	60642	1
LP	1332	60107028	1605	60155101	19229
T.5	1342	357370	1615	377279	7964
F.P.D.	1345	26262081	1617	26262081	Faulty meter
T.6	1347	40621899	1622	40645155	9690
T.2	1350	74559000	1625	74582851	9938
T.7	1350	31735246	1627	31744149	3710
Remainder					28817
Total from boiler house	-	-	-	-	81000

1.2 CONDITION - as delivered from boiler house

	Before experiment		After experiment		Average / Total
	Time	Reading	Time	Reading	per hour
Steam					
Temperature - C					285
Pressure - bar					22.3
Total flow - kg.					81000

Condensate ret. @ 24.7% of Boiler House Output

Temperature - C					87.2
Total flow - m3					20.1

TABLE D.2 TEMPERATURE, RELATIVE HUMIDITY & WIND SPEED

2.1 General ambient temperature from Elmdon Airport - C - 18.7

2.2 General relative humidity from Elmdon Airport - % - 54

2.3 General wind condition from Elmdon Airport :

- Wind speed (average over period) -m/min- 124
- Wind direction - light easterly

2.4 Comments on weather conditions

Sunny intervals.

GENERAL COMMENT ON MEASUREMENTS

Estimates were made from average weekly consumptions for the total boiler steam.

D.2 DATA RECORD FOR WEST ROAD STEAM MAIN

DATE : 28th September 1977

TABLE D.3 STEAM MEASUREMENTS

3.1 FLOW - into each department

- meter readings in kg. of steam

Department metered.	Before experiment Time 28.9.77	Before experiment Reading	After experiment Time 28.9.77	After experiment Reading	Total Steam kg/hr.
New Mill	0935	1538277	1325	1541905	918
C.M.S.	0934	61419	1322	65959	1164
T.5	0938	4289796	1320	4320317	7826
F.P.D.	0926	26962380	1332	26979663	4215
T.6	0925	45076747	1335	45132983	13390
T.2	0921	77772923	1337	77797023	5671
T.7	0920	33904071	1340	33922792	4354
Remainder					41084
Total from boiler house.	0937	85234258	1321	85525160	78622

3.2 CONDITION - as delivered from boiler house

Steam

	Before experiment Time	Before experiment Reading	After experiment Time	After experiment Reading	Average/Total per hour
Temperature - C					276
Pressure - bar					22.0
Total flow - kg.					78622

Condensate ret. @ 24.7% of Boiler House Output

	Before experiment Time	Before experiment Reading	After experiment Time	After experiment Reading	Average/Total per hour
Temperature - C					87.2
Total flow - m3					19.5

TABLE D.4 TEMPERATURE, RELATIVE HUMIDITY & WIND SPEED

4.1 General ambient temperature from Elmdon Airport - C - 15.6

4.2 General relative humidity from Elmdon Airport - % - -

4.3 General wind condition from Elmdon Airport :

- Wind speed (average over period) -m/min- 531
- Wind direction - -

4.4 Comments on weather conditions

Overcast

GENERAL COMMENTS ON MEASUREMENTS

Table D.5

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENTS - WEST ROAD STEAM MAIN

Photo No.	Description	Materials	Colour	Di	Black Io	Body °C	Eo	Real Di/Eo	Body Io	Real To °C	Comments
PLATE 9.5A.											
D 4	Reference - DB, Tr=20 Equation 4	Ir=22, Fl.8 S - 50									Prominent effects of sunlight
	Sky	Ambient Air	DB	0.0	22	20	1.0	0.0	22.0	20	
	Gantry - Painted	Aluminum Paint	LB	6.0	28	28	0.6	10.0	32.0	32	
	Flnges - dirty	Mild Steel-Oxidised	R	26.5	48.5	47	0.95	27.9	49.9	39	
			Y	33.0	55.0	51		34.7	56.7	52	
	Air main - white insulation cladding	Treated Fabric	LB	6.0	28	28	0.6	10.0	32.0	32	
	Steam main - Aluminium cladding	Aluminium-dirty	G	12.5	34.5	35	0.31	40.3	62.3	55	
F 2	Reference - LB, Tr=16 Equation 4	Ir=19.5, Fl.8, S =20									Reference doubtful
	Sky	Ambient Air	LB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry-Painted	Aluminium Paint	LB	0.0	19.5	16	0.6	0.0	19.5	16	
	Flanges - dity	Mild Steel-Oxidised	Y	11.0	30.5	31	0.95	11.6	31.1	31	
			W	13.4	32.9	32		14.1	33.6	33	
	Steam main - Aluminium cladding	Aluminium-dirty	G	2.6	22.1	20	0.31	8.4	27.9	28	
			P	5.8	25.3	25		18.7	38.2	38	
PLATE 9.5B											
F 3	Reference=DB, Tr=16 Equation 4	Ir=19.5, Fl.8, S =10									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry - Painted	Aluminium Paint	G	2.6	22.1	20	0.6	4.3	23.8	23	
	Flanges - dirty	Mild Steel - Oxidised	W	8.0	27.5	27	0.95	8.4	27.9	28	
	Air main - white insulation cladding	Treated fabric	G	2.6	22.1	20	0.6	4.3	23.8	23	
	Steam main - aluminium cladding	Aluminium-dirty	G	2.6	22.1	20	0.31	8.4	27.9	28	
			P	4.2	23.7	22		13.5	33.0	33	
			R	5.3	24.8	24		17.1	36.6	36	

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENTS - WEST ROAD STEAM MAIN

Photo No.	Description	Materials	Colour	Di	Black Body Io	Black Body To °C	Eo	Real Di/Eo	Body Io	Real To °C	Comments
PLATE 9.5B Cont'd											
	Reference -G, Tr=16 Equation 4	Ir=19.5, F1.8, S = 20									Reference doubtful
F 1	Flanges etc - dirty	Mild Steel-Oxidised	R	5.4	24.9	24	0.95	5.7	25.2	25	
			Y	8.4	27.9	28		8.8	28.3	29	
	Steam Main - Aluminium cladding	Aluminium - dirty	P	3.2	22.7	21	0.31	10.3	29.8	30	
			R	5.4	24.9	24		17.4	36.9	36	
PLATE 9.5C											
F 5	Reference = DB, Tr=16 Equation 4	Ir, 19.5, F1.8, S = 10									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry-Painted	Aluminium Paint	G	2.6	22.1	20	0.6	4.3	23.8	23	
	Flanges etc - dirty	Mild Steel-Oxidised	R	5.3	24.8	24	0.95	5.6	25.1	25	
			Y	6.8	26.3	26		7.2	26.7		
			W	8.0	27.5	27		8.4	27.9	28	
	Steam main - Aluminium cladding	Aluminium - dirty	P	4.2	23.7	22	0.31	13.5	33.0	33	
			R	5.3	24.8	24		17.1	36.6	36	
			Y	6.8	26.3	26		21.9	41.4	40	
			W	8.0	27.5	27		25.8	45.3	43	
D1	Reference = DB, Tr=20 Equation 4	Ir=22, F1.8, S = 50									Prominent effect of sunlight
	Sky	Ambient Air	DB	0.0	22.0	20	1.0	0.0	22.0	20	
	Gantry-Painted	Aluminium Paint	G	12.5	34.5	35	0.6	20.8	42.8	41	
	Flanges etc - dirty	Mild Steel-Oxidised	R	26.5	48.5	47	0.95	27.6	49.6	39	
			Y	33.0	55.0	51		34.7	56.7	52	
			W	39.5	61.5	54		41.5	63.5	57	
	Air Main - White insulation cladding	Treated Fabric	G	12.5	34.5	35	0.6	20.8	42.8	41	
			P	20.5	42.5	42		34.2	56.2	52	
			R	26.5	48.5	47		44.2	66.2	58	
			Y	33.0	55.0	51		55.0	77.0	63	
	Steam Main - Aluminium cladding	Aluminium - Dirty	G	12.5	34.5	35	0.31	40.3	62.3	55	
			P	20.5	42.5	42		66.1	88.1	68	
			R	26.5	48.5	47		85.5	107.5	76	
			Y	33.0	55.0	51		106.5	128.5	81	

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENTS - WEST ROAD STEAM MAIN

Photo No.	Description	Materials	Colour	Di	Black Body Io	Black Body To °C	Eo	Real Di/Eo	Body Io	Real To °C	Comments
PLATE 9.5D											
F 4	Reference = DB, Tr=16 Equation 4	Ir=19.5, F1.8, S = 10									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry-Painted	Aluminium Paint	G	2.6	22.1	20	0.6	4.3	23.8	23	
	Air Main - White insulation cladding	Treated Fabric	G	2.6	22.1	20	0.6	4.3	23.8	23	
			P	4.2	23.7	22		7.0	26.5	26	
	Steam Main - Aluminium cladding	Aluminium-Oxidised	G	2.6	22.1	20	0.31	8.4	22.9	28	
			P	4.2	23.7	22		13.5	33.0	33	
			R	5.3	24.8	24		17.1	36.6	36	
			Y	6.8	26.3	26		21.9	41.4	40	
			W	8.0	27.5	27		25.8	45.3	43	
D 3	Reference = DB, Tr=20 Equation 4	Ir=22, F1.8, S = 50									Prominent effects of sunlight
	Sky	Ambient Air	DB	0.0	22.0	20	1.0	0.0	22.0	20	
	Gantry-Painted	Aluminium Paint	G	12.5	34.5	35	0.6	20.8	42.8	41	
	Air Main - White insulation cladding	Treated Fabric	G	12.5	34.5	35	0.6	20.8	42.8	41	
	Steam Main- Aluminium cladding	Aluminium-Oxidised	G	12.5	34.5	35	0.31	40.3	62.3	55	
			P	20.5	42.5	42		66.1	88.1	68	
			R	26.5	48.5	47		85.5	107.5	76	
PLATE 9.5E											
F 6	Reference = DB, Tr=16 Equation 4	Ir=19.5, F1.8, S = 10									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry-Painted	Aluminium Paint	LB	1.3	20.8	18	0.6	2.2	21.7	19	
	Flanges etc - dirty	Mild Steel-Oxidised	W	8.0	27.5	27	0.95	8.4	27.9	28	
	Air Main-White insulation cladding	Treated Fabric	LB	1.3	20.8	18	0.6	2.2	21.7	19	
	Steam Main-Aluminium cladding	Aluminium-Oxidised	G	2.6	22.1	20	0.31	8.4	27.9	28	

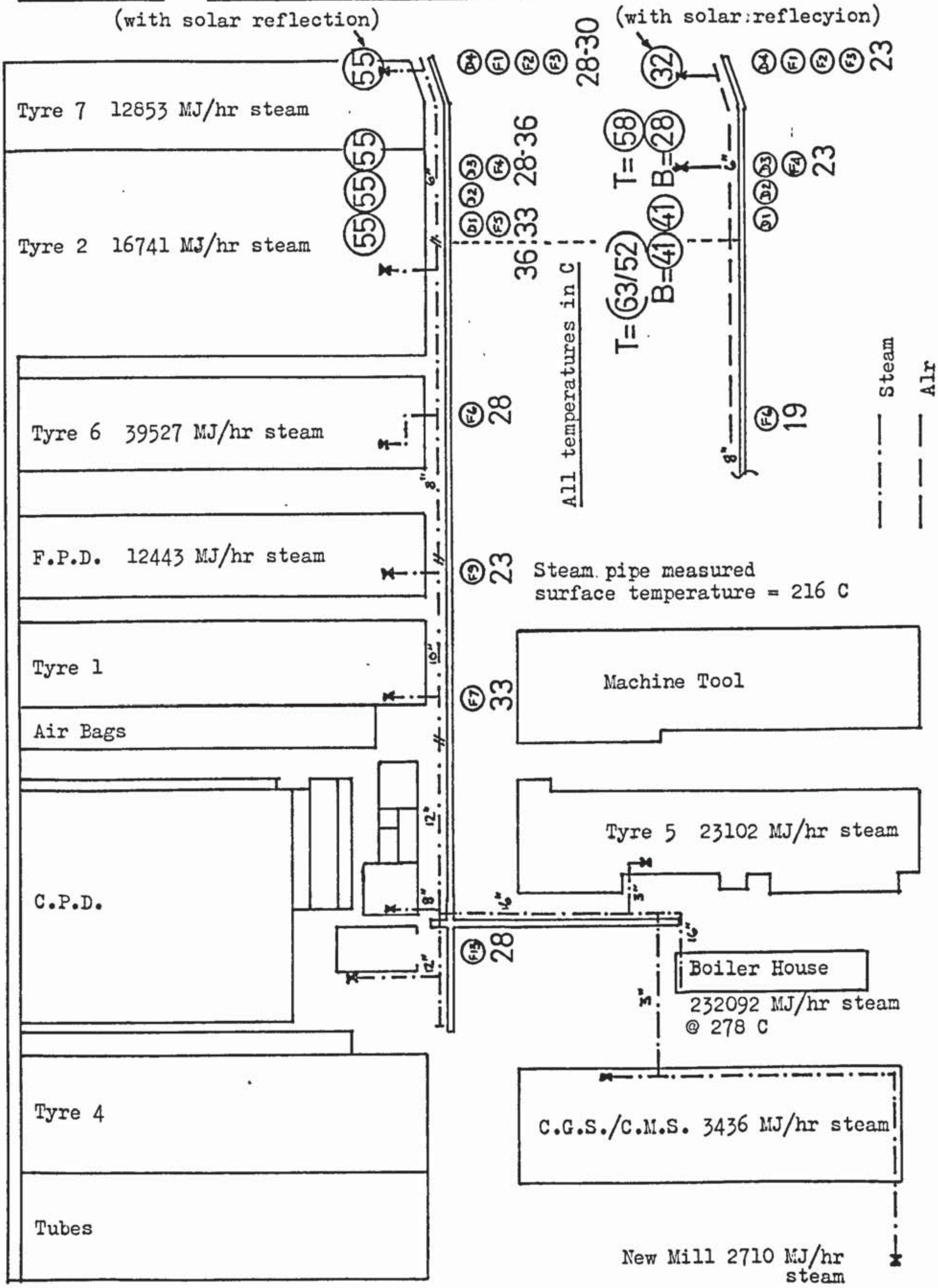
THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENTS - WEST ROAD STEAM MAIN

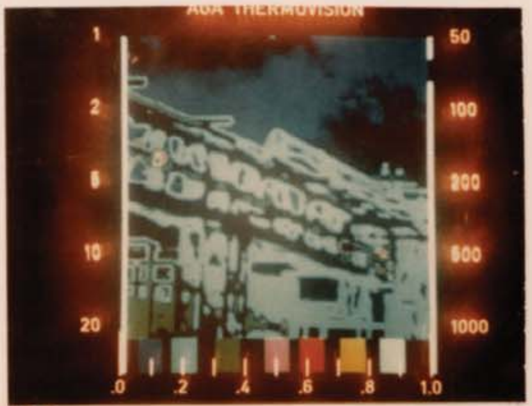
Photo No.	Description	Materials	Colour	Di	Black Io	Body To °C	Eo	Real Di/Eo	Body Io	Real To °C	Comments
PLATE 9.5F											
F 9	Reference - DB, Tr-16 Equation 4	Ir-19.5, F1.8, S-10									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry-Painted	Aluminium Paint	DB	0.0	19.5	16	0.6	0.0	19.5	16	
	Flanges etc - dirty	Mild Steel-Oxidised	W	6.8	27.5	27	0.95	7.2	26.7	26	
	Steam Main - Aluminium cladding	Aluminium-dirty	LB	1.3	20.8	18	0.31	4.2	23.7	23	
			G	2.6	22.1	20		8.4	27.9	28	
			P	4.2	23.7	22		13.5	33.0	33	
			R	5.3	24.8	24		17.1	36.6	36	
PLATE 9.5G.											
F 7	Reference - DB, Tr-16 Equation 4	Ir-19.5, F1.8, S-10									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry-Painted	Aluminium Paint	G	2.6	22.1	20	0.6	4.3	23.8	23	
	Flanges etc - dirty	Mild Steel-Oxidised	P	4.2	23.7	22	0.95	4.4	23.9	23	
			R	5.3	24.8	24		5.6	25.1	25	
			Y	6.8	26.3	26		7.2	26.7	26	
			W	8.0	27.5	27		8.4	27.9	28	
	Steam Main- Aluminium cladding	Aluminium-dirty	P	4.2	23.7	22	0.31	13.5	33.0	33	
			R	5.3	24.8	24		17.1	36.6	36	
F 8	Reference - DB Tr - +16 Equation 4	Ir-+10.0, F3.6, S-500									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Pipe and Flnges - dirty	Mild Steel-Oxidised	Y	340.0	350.0	212	0.95	358.0	377.5	216	
PLATE 9.5H											
D 2	Reference - DB, Tr-20 Equation 4	Ir-22, F1.8, S-50									Prominent effects of sunlight
	Sky	Ambient	DB	0.0	22.0	20	1.0	0.0	22.0	20	
	Gantry-Painted	Aluminium Paint	G	12.5	34.5	35	0.6	20.8	42.8	41	

THERMOGRAPHIC QUANTITATIVE TEMPERATURE MEASUREMENTS - WEST ROAD STEAM MAIN

Photo No.	Description	Materials	Colour	Di	Black Io	Body To °C	Eo	Real Di/Eo	Body Io	Real To °C	Comments
PLATE 9.5H Cont'd D 2	Flanges etc - dirty	Mild Steel-Oxidised	P	20.5	42.5	42	0.95	21.6	43.6	42	
			R	26.5	48.5	47		27.9	49.9	39	
			Y	33.0	55.0	51		34.7	56.7	52	
	Air Main - White insulation cladding	Treated Fabric	G	12.5	34.5	35	0.6	20.8	47.8	41	
			P	20.5	42.5	42		34.2	56.2	52	
			R	26.5	48.5	47		44.2	66.2	58	
	Steam Main - Aluminium cladding	Aluminium-dirty	G	12.5	34.5	35	0.31	40.3	62.3	55	
PLATE 9.5I											
F13	Reference = DB, Tr=16 Equation 4	Ir=19.5, F1.8, S=10									
	Sky	Ambient Air	DB	0.0	19.5	16	1.0	0.0	19.5	16	
	Gantry-Painted	Aluminium Paint	LB	1.3	20.8	18	0.6	2.2	21.7	19	
	Flanges etc - dirty	Mild Steel-Oxidised	W	8.0	27.5	27	0.95	8.4	27.9	28	
	Steam Main- Aluminium cladding	Aluminium-dirty	G	2.6	22.1	20	0.31	8.4	27.9	28	
			P	4.2	23.7	22		13.5	33.0	33	
			R	5.3	24.8	24		17.1	36.6	36	
			W	8.0	27.5	27		25.8	45.3	43	

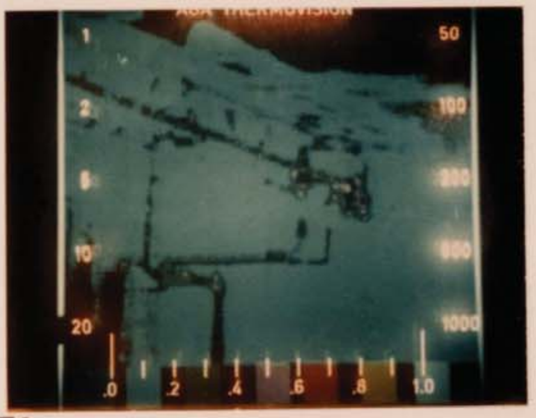
Figure D.6 West Road Steam and Air Main





AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

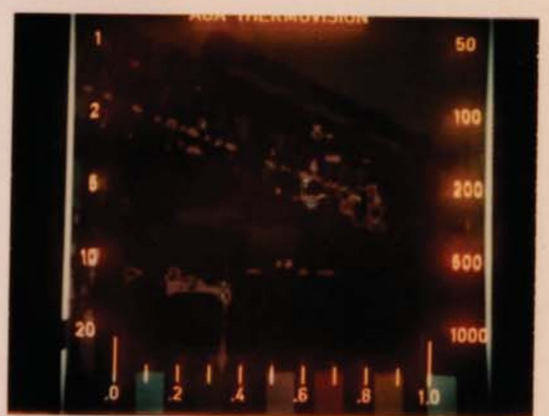
D4



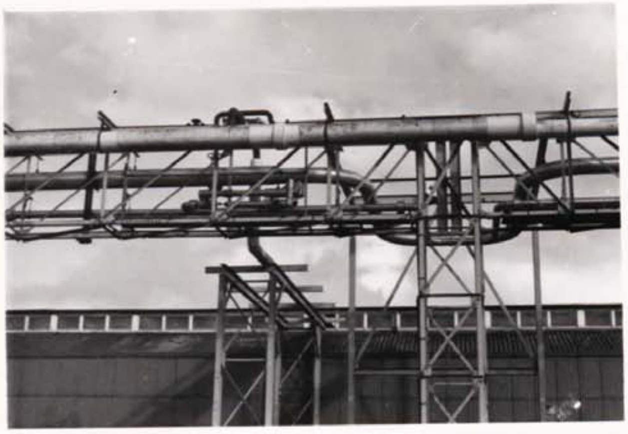
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

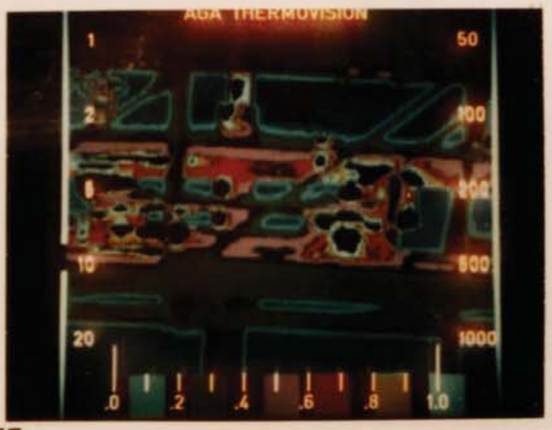
F2

F3

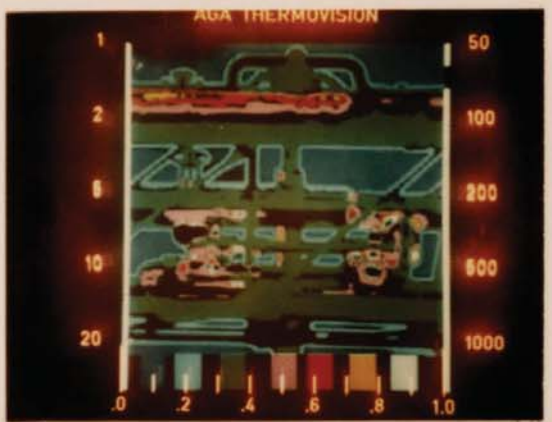


F1

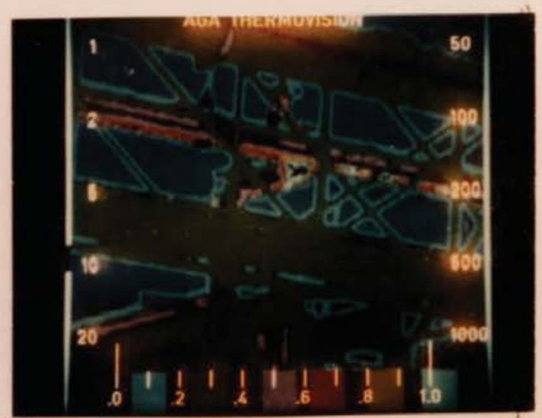



AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

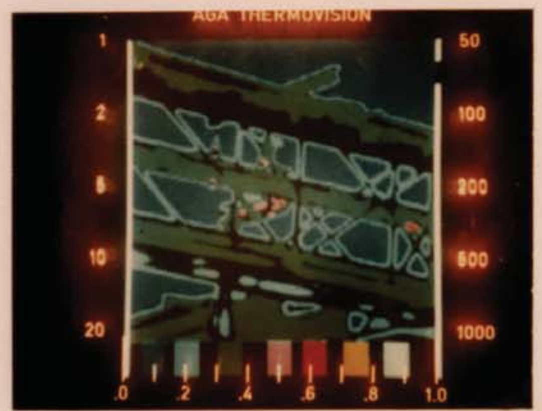
F5


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

D1


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0 .2 .4 .6 .8 1.0

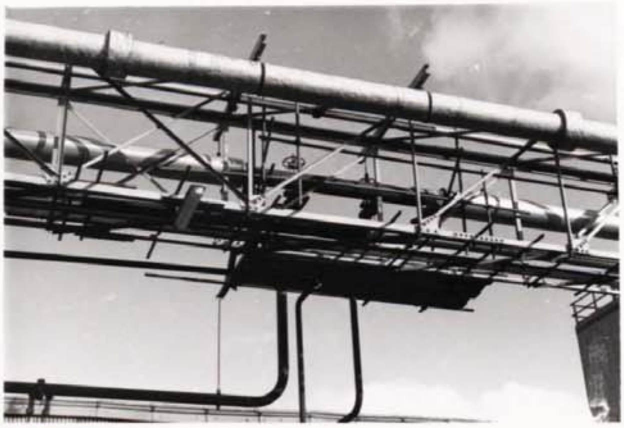
F4

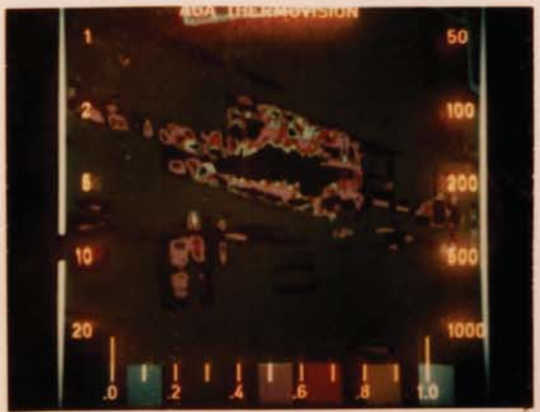

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0 .2 .4 .6 .8 1.0

D3

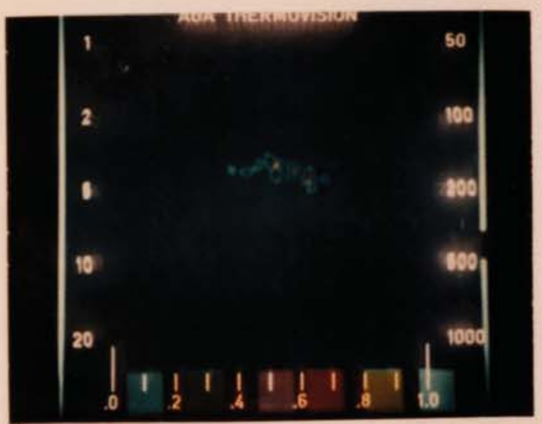
F6

F9

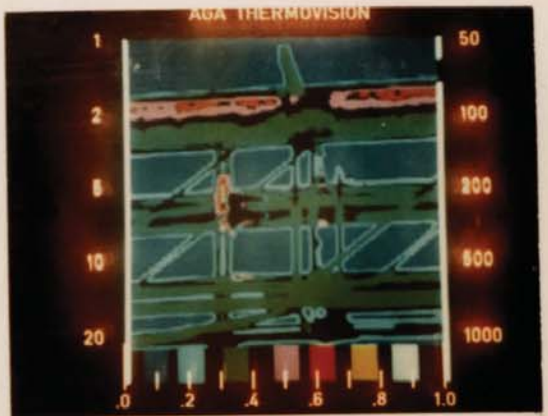



1
2
10
20
50
100
200
1000
.0
.2
.4
.6
.8
1.0

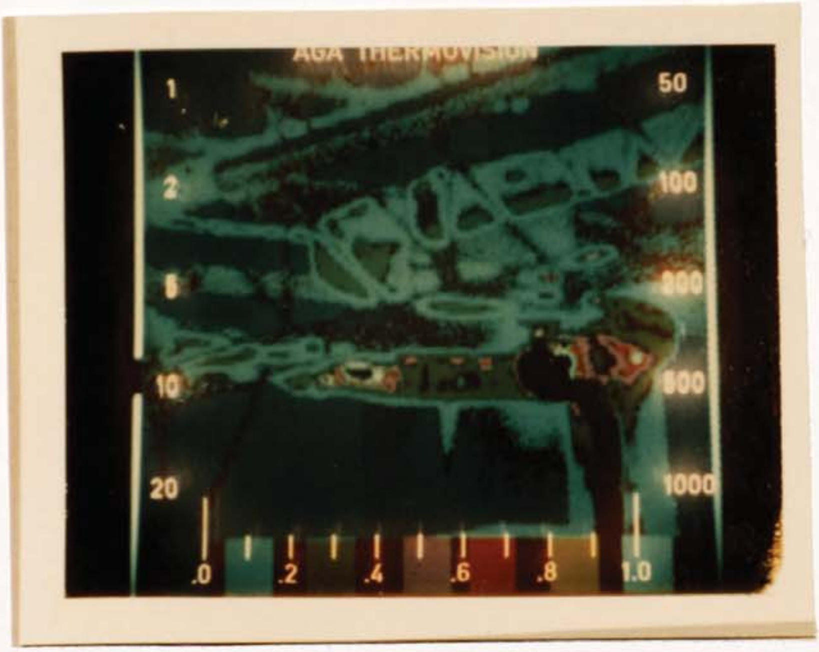
F7


1
2
10
20
50
100
200
1000
.0
.2
.4
.6
.8
1.0

F8



D2


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

APPENDIX E

THERMOGRAMS FOR THE SITE SURVEY

----- Plates 9.6A to 9.6W

E.1 DATA RECORD FOR SITE SURVEYS

Remote sensing positions : 11th July 1977 - Warstone Flats

24th August 1977 - Commercial Offices

Although recorded, due to the conclusions drawn for the Tyre 5 energy balance, documentation of measured flows of energy on the site was unnecessary.

Table E.1 Temperature, Relative Humidity and Wind Speed

as recorded from Elmdon Airport.

	11th July 1977	24th August 1977
Ambient temperature - ^{o}C	14.8	12.4
Relative humidity - %	79	361
Wind speed (average over period) - m/min	216.2	494
Wind direction -	040 - 060	Strong S.E.
Comment	dull and overcast	rain and cloud with gusty high wind.

Table E.2

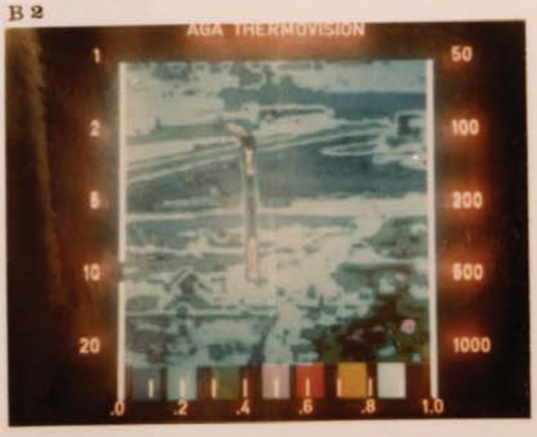
THERMOGRAPHY QUANTITATIVE TEMPERATURE MEASUREMENTS - SITE

Photo No.	General Description	F no.	S	L	Reference Colour	Tr °C	Temperature Description	DB	LB	Black Body Temperature = To in °C G	P	R	Y	W	Comments
B 1	Aero-remould; S road	1.8	5		DB	15	Grass	15	16	17	19	20	21	22	
B 3	Incinerator	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B 4	Heavy Gang	1.8	10		LB	15	Trees	13	15	17	20	22	23	25	
B 5	Dutch Barn; Flaps; Steel Stores	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B 6	Dynamometer	1.8	5		DB	15	Grass	15	16	17	19	20	21	22	
B 8	NM: CMS: T.5; MT	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B 9	T.5; MT; Steel erectors	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B10	Stacks; CMS; BH; T.5	1.8	20		G	15	Grass	5	10	15	20	23	27	30	
B11	CMS; BH; T.5; MT	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B12	MT; Pipefitters; Steel erectors	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B14	CO; Tubes; T.4; T.5; MT	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B15	T.4; T.5; MT; Grind; Pipefitters Steel erectors; Building	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B16	PH; T.1; MT; Grind; FPD; Building	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B17	CO; Canteen; Tubes; T.4; CPD; PH	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B18	Canteen; T.4; CPD; T.1: FPD	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B19	FPD; Building	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B20	FPD; T.6 Training; Building	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B21	NO; TH; LY & LT; FPD; T.6	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B22	TH; RC; FPD; T.6	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B23	FPD; T.6; Training	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B24	OTB; THQ; SO; T.6;T.2	1.8	10		LB	15	Grass	13	15	17	20	22	23	25	
B25	T.8; OTB; TD&PR	1.8	20		G	15	Grass	5	10	15	20	23	27	30	
B26	TD&PR; THQ	1.8	20		G	15	Grass	5	10	15	20	23	27	30	
B27	THQ; SO; T.2; T.7	1.8	20		G	15	Trees	5	10	15	20	23	27	30	
B28	HB; EB; SO; T.7	1.8	10		LB	15	Trees	13	15	17	20	22	23	25	
B29	Base Stores; T.7	1.8	10		LB	15	Trees	13	15	17	20	22	23	25	

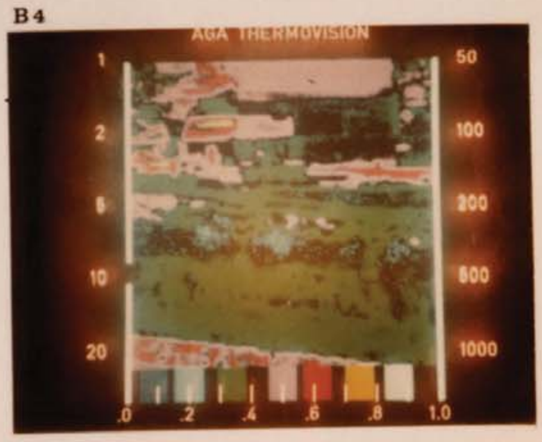
THERMOGRAPHY QUANTITATIVE TEMPERATURE MEASUREMENTS - SITE

Photo No.	General Description	F No.	S	L Max	Reference Colour	Temperature Tr	Temperature Description	DB	LB	Black Body Temperature = To in °C G	P	R	Y	W	Comments
E 1	Stacks	1.8	20	570	DB	13	Ambient	13	18	21	26	29	31	34	
E 2	Stacks, Incinerator	1.8	20	570	DB	13	Ambient	13	18	21	26	29	31	34	
E 3	CMS, Tubes	1.8	20	570	DB	13	Ambient	13	18	21	26	29	31	34	
E 4	CMS, Tubes	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E 5	BH, T.4, Tubes	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E 6	MT, T.5, T.4, Tubes	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E 7	PH, T.4	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E 8	MT, T.4	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E 9	PH, CPD, T.4	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E10	FPD, CPD, T.4	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E11	T.6, CPD, T.4	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E12	FPD, CPD, T.4	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E13	FPD, CPD, T.4	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E14	T.6, FPD, CPD, T.4, Tubes, SO	1.8	10	570	DB	13	Ambient	13	16	18	20	21	24	26	
E15	Base Stores, THQ, Buying, OTB, LY&LT	1.8	5	570	DB	13	Ambient	13	15	16	17	18	19	20	
E16	Base Stores, OTB, LY&LT, Medical	1.8	5	570	DB	13	Tree	13	15	16	17	18	19	20	
E17	Steam Main, TD&PR, RC LY&LT	1.8	5	570	DB	13	Tree	13	15	16	17	18	19	20	
E18	BB, TD&PR, RC, T.8, LY&LT	1.8	10	570	DB	13	Tree	13	16	18	20	21	24	26	
E19	BB, T.8, LY&LT	1.8	5	570	DB	13	Ambient	13	15	16	17	18	19	20	
E20	NO, TH, Canteen	1.8	10	570	DB	13	As E.14	13	16	18	20	21	24	26	
E21	Corridor, T.4, Tubes	1.8	10	570	DB	13	As E.14	13	16	18	20	21	24	26	
E22	T.4, Tubes	1.8	10	570	DB	13	As E.13	13	16	18	20	21	24	26	
E23	T.4, Tubes	1.8	10	570	DB	13	As E.12	13	16	18	20	21	24	26	
E24	T.4, Tubes	1.8	10	570	DB	13	As E.11	13	16	18	20	21	24	26	

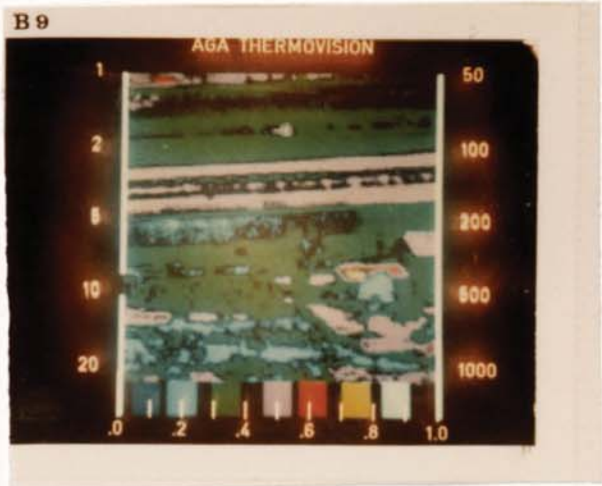
B 2


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B 4


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

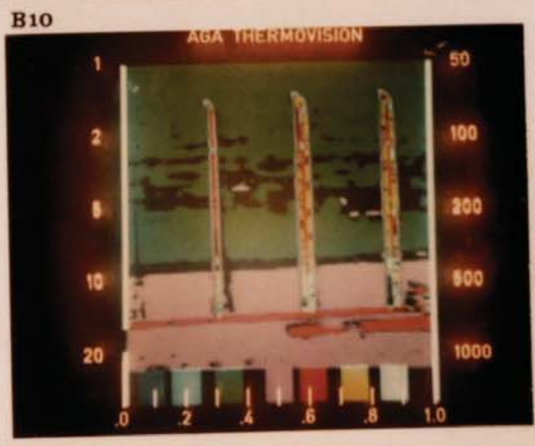
9.6 A


B9
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

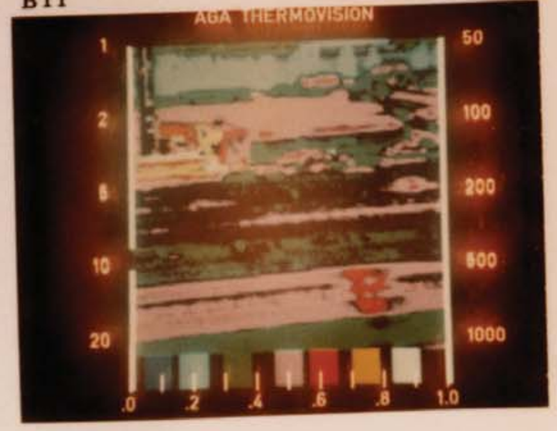
B 8


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

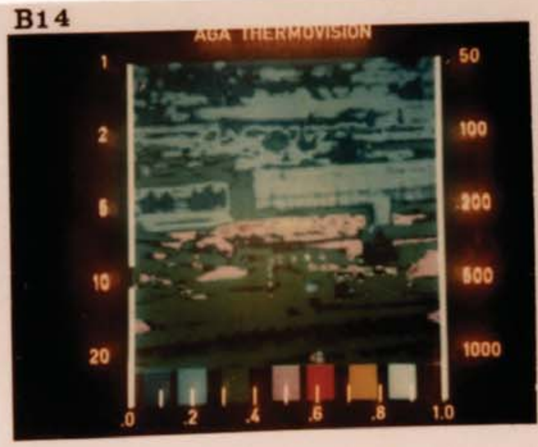
B10

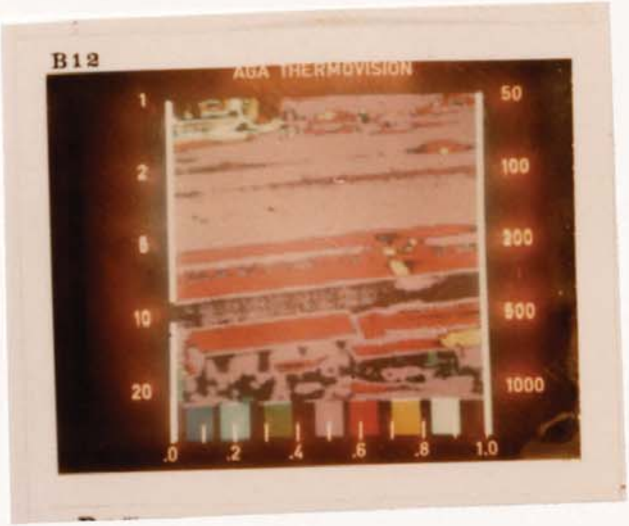

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B11

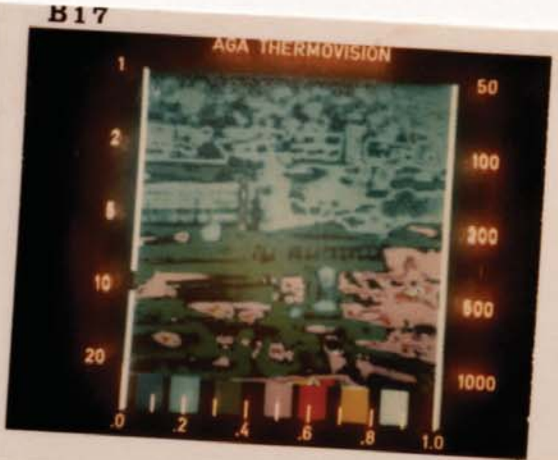

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B14


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0


B12
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B17


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

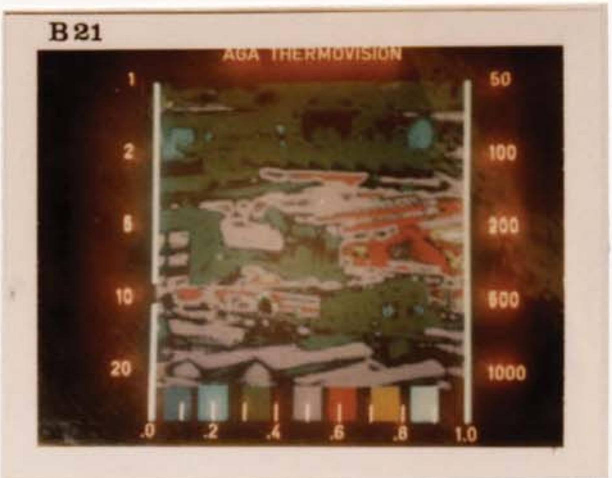
B18


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

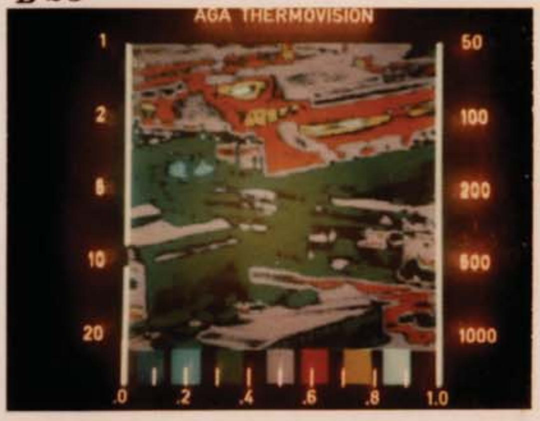

B16
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0


B19
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

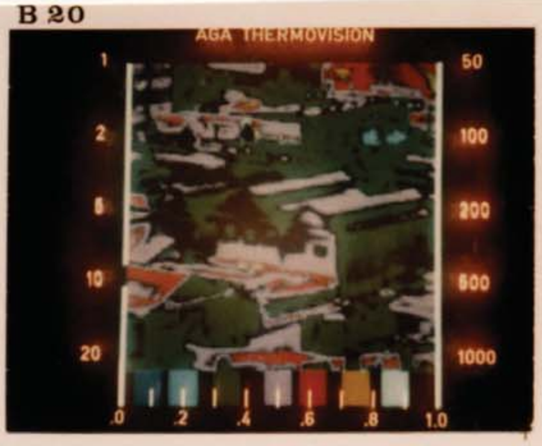

B22
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0


B21
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

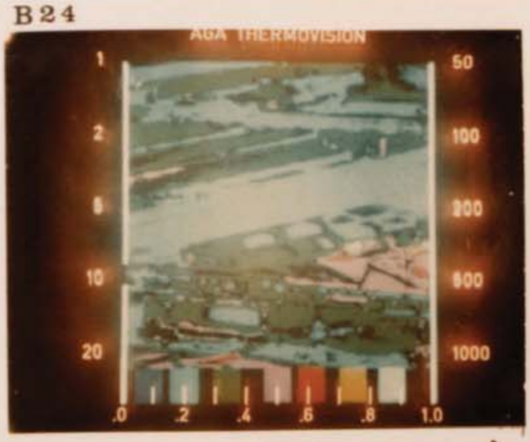
B 23


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B 20

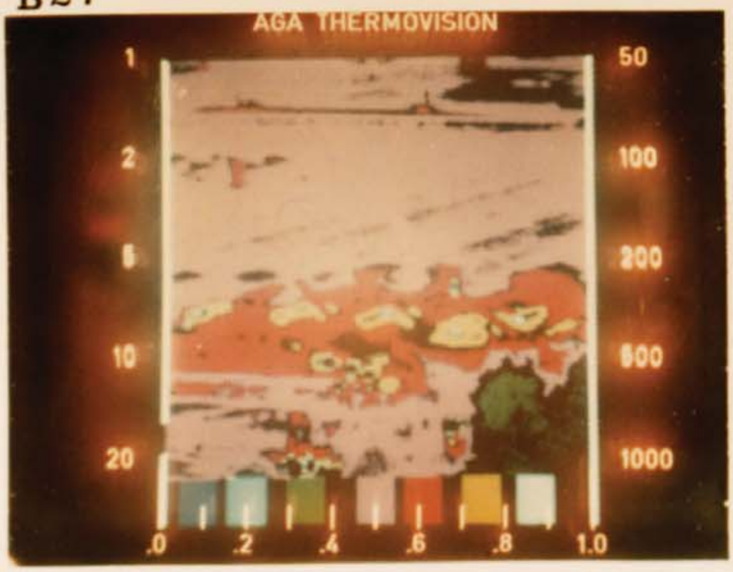

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

B24



AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

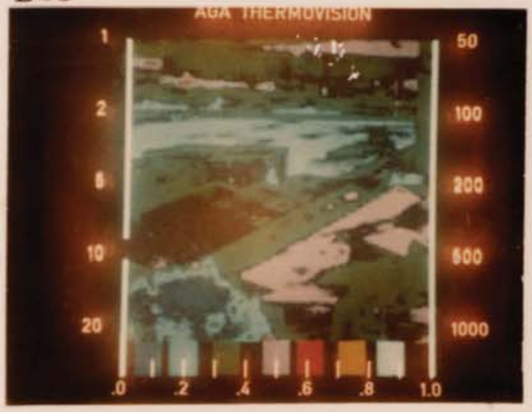
B27



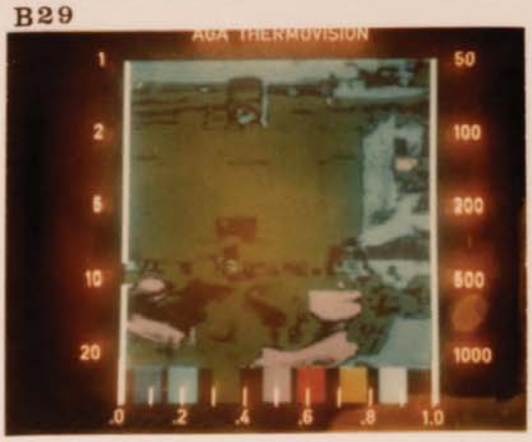
AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

9.6J

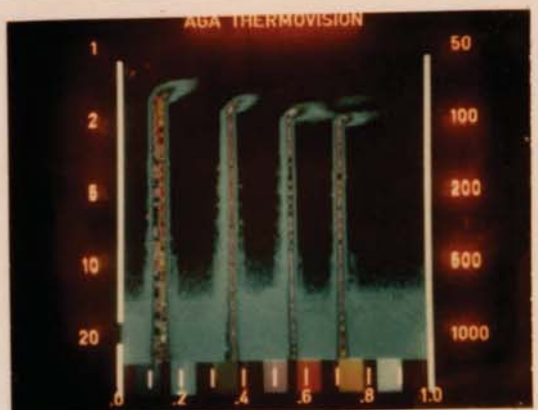
B28


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0 .2 .4 .6 .8 1.0

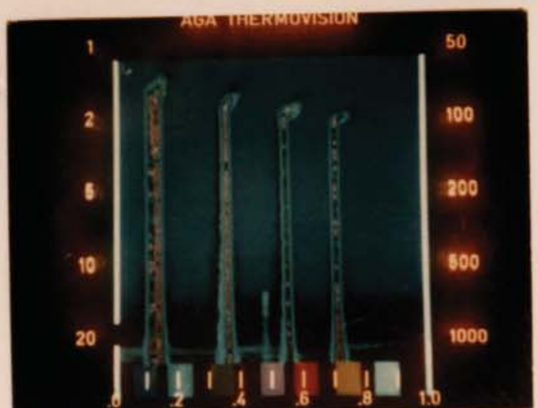
B29


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0 .2 .4 .6 .8 1.0

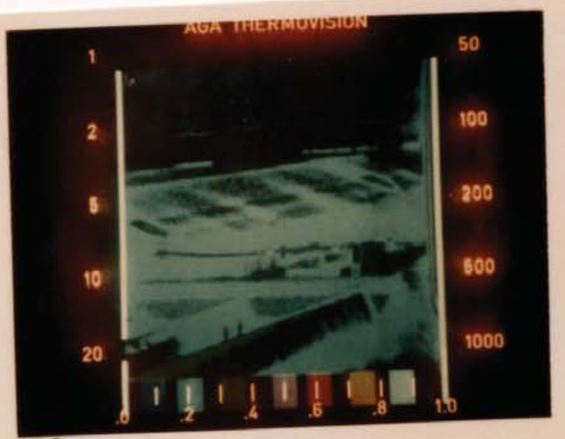
9.6K


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

E1


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

E2

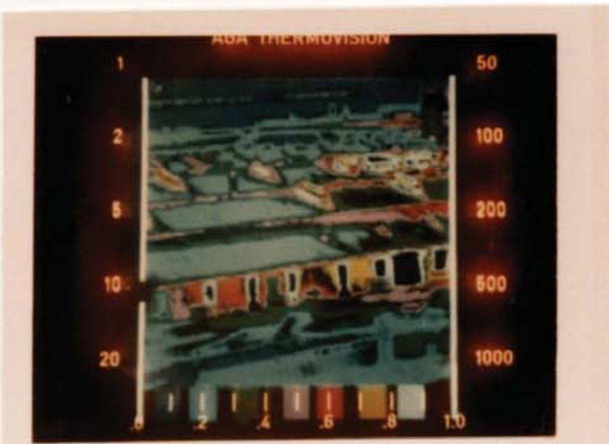

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E3


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E4

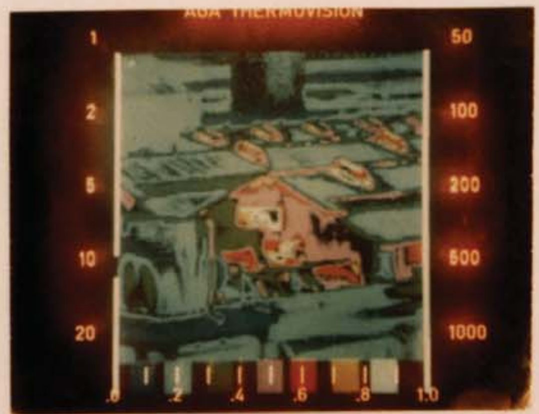
9.6M


1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

E5

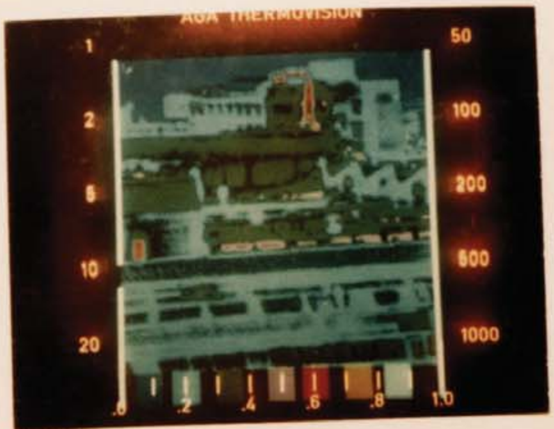

1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

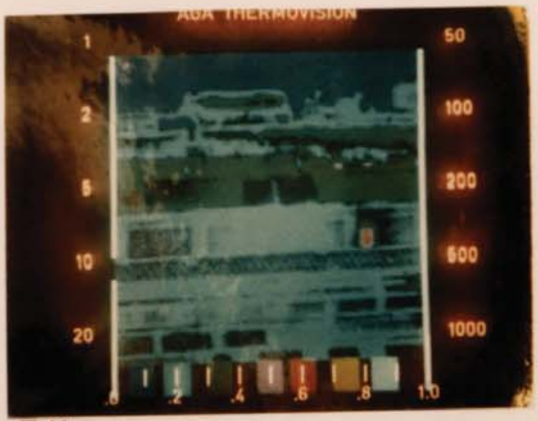
E6

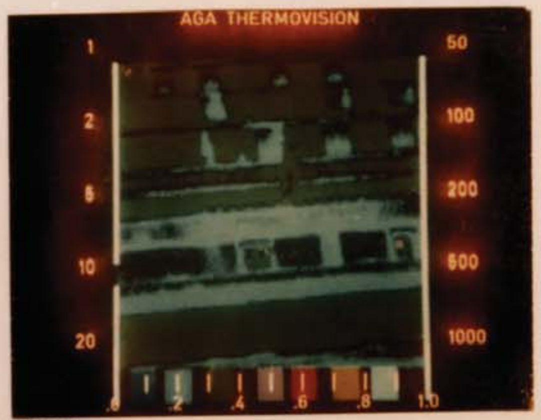

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E7

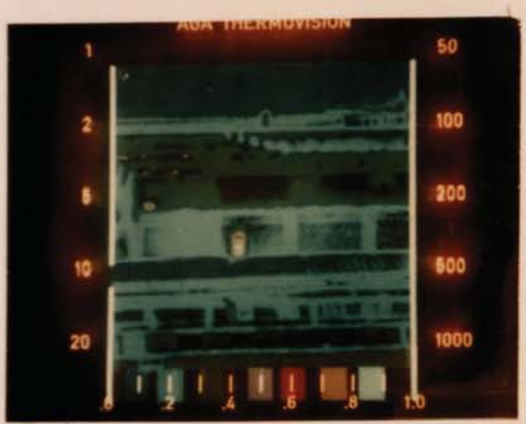

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E8


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E9

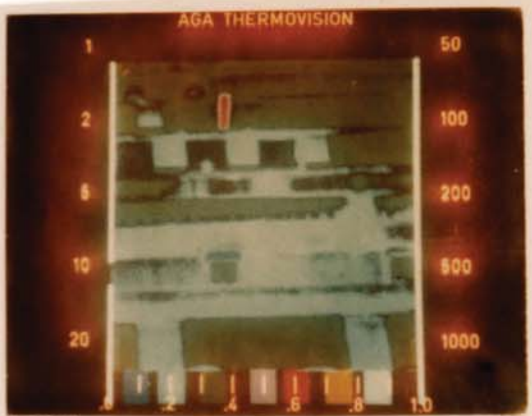

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E10


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E 11


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E 24


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

E 12

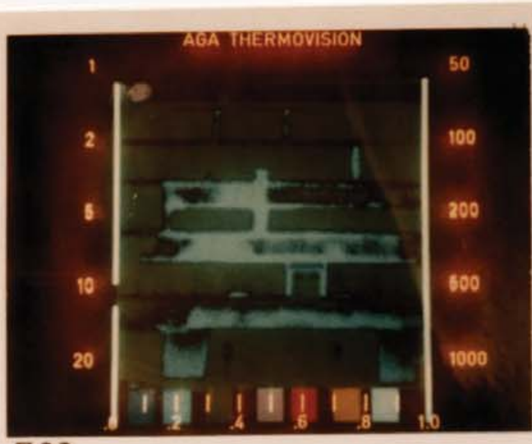

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

E 23

9.6R

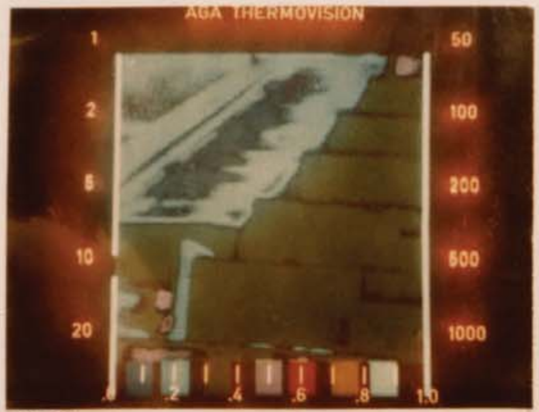

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

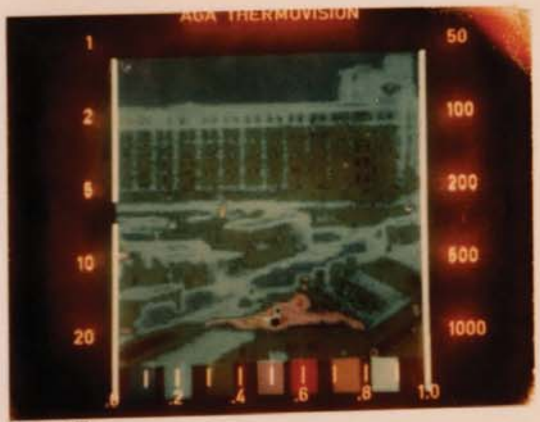
E 13


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0

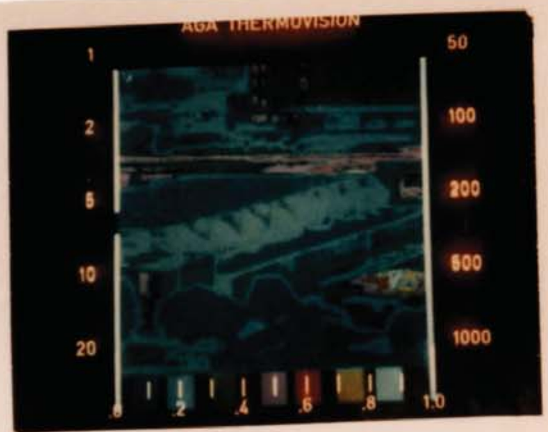
E 22


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E 14

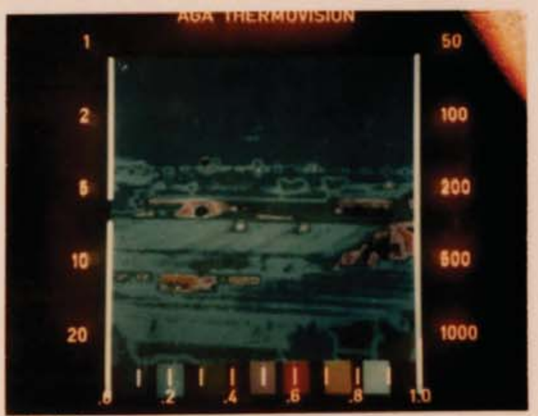

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0
.2
.4
.6
.8
1.0
E 21


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

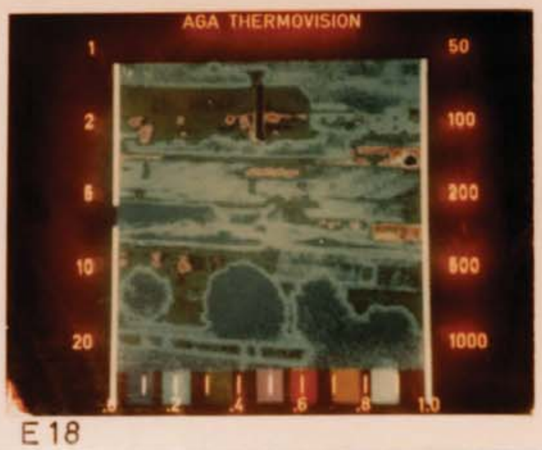
E 15


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

E 16


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0 .2 .4 .6 .8 1.0

E 17

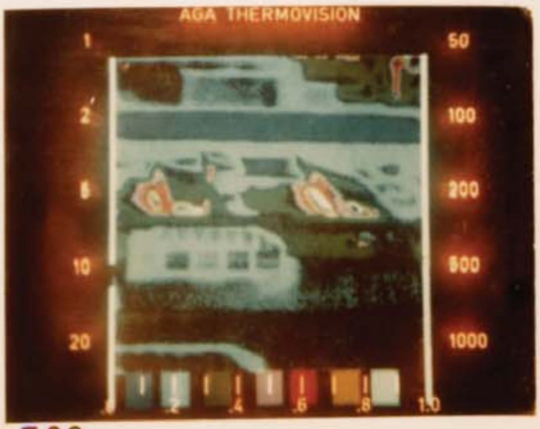

AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.0 .2 .4 .6 .8 1.0

E 18

9.6v


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

E 19


AGA THERMOVISION
1
2
5
10
20
50
100
200
500
1000
.2
.4
.6
.8
1.0

E 20

9.6W

APPENDIX F

REVIEW OF THE GOVERNMENT POLICIES AND ACTIONS

F.1 Review of Government Strategy in the UK

Considerations towards energy conservation have been a part of government strategy since the launch of campaigns to save fuel in the 1940's. The Ministry of Fuel and Power set up mobile laboratories and teams of experts to visit industry with the aim of achieving higher utilisation efficiencies. Publications on the efficient use of fuel, steam and heat resulted from the investigation (6) (9) and the suggested practices became well tried by industry.

It is not surprising that the events of 1973 brought about the instigation of a new government department for energy. Its initial objectives were: (19).

a. To create a climate affording effective incentives for efficient energy use through market forces.

b. To establish greater understanding of the need for greater efficiency and acceptance of the need to act upon it.

c. To encourage contacts between energy consumers and fuel efficiency experts so that knowledge of specific saving procedures could be made known.

d. To review research and development on energy efficiency and to reinforce this when necessary.

e. To legislate where appropriate.

The role of the department was, therefore, to provide the incentive backed by technical information; the decisions as to which actions were taken were to be made by the consumer since the government itself controlled only 1% of the UK primary energy directly. (32). Effort was to be spread over a period of time, during which a primary objective was the need to change attitudes. This required a co-ordinated approach involving co-operation between all parties within the industrial environment, i.e. management and trade unions. Education at all levels was to be enforced by maintaining and increasing the number of courses, seminars and conferences, and by making use of existing professional institutions (27), so as to improve awareness. In accordance with previous views (2), the department advocated assessment of projects on a cost-benefit basis, involving social, and environmental as well as economic aspects. Through adoption of market force control, with energy prices reflecting true cost and the necessary technical back-up, the goal was a 10% saving by 1985. (32).

F.2 Actions Taken since 1973

The first positive action taken by the Department of Energy (D.E.) came in June 1974 when the Advisory Council on Energy Conservation (ACEC) was set up to provide advice on short and long term strategies, and to encourage and sustain the national effort.

Recommendations were made resulting in a number of actions. A wide range of literature, reports and surveys, previously deemed confidential were published. Further attitude surveys were carried out in August 1974, producing information on current public attitudes towards energy.

Three problems were highlighted:

a. Mostly public awareness of the need to save was low and advice on saving procedures was lacking (31).

b. Implementation of energy conservation in industry was slow due to resistance to action, poor communication structure and rapid decline in available finances.

c. The majority of industries were not energy intensive which often meant energy projects ranked low in priority.

This formed the basis of a 12 point plan put forward by the department in December 1974. (Table F.1.) A summary of official government activities is given in Table F.2.

F.3 Research and Development

The Research Requirements Board of the DOI was given the responsibility of looking at the efficient use of energy in industry. A committee for Energy Thrift in Industry was set up in June 1974 under specific terms of reference (30).

With the aid of £1.7m budget set aside each year, early findings suggested an apparent resistance of industry to any form of government investigation. Consequently, a second stage was set up involving industrial research associations, whose existing contacts with industry being better, would hopefully produce more effective results. Investigations commenced through the Industrial Energy Thrift Scheme (28) (30). This evolved a three year study of volunteering industries to promote good 'housekeeping' and increased action towards improved efficiency. The effort was aimed at large firms and included one day visits by a group of experts. A third stage investigation of selected energy intensive industries was to be made under the Energy Audit Scheme (30) which was to carry out a more detailed analysis of energy

Figure F.1

DEPARTMENT OF ENERGY 12 POINT INTERIM PROGRAMME OF MEASURES TO SAVE ENERGY - DECEMBER 1974

1. A loan scheme for energy saving investment in industry.

2. The next round of oil price increases to be weighted on petrol to discourage imports of motor spirit or crude oil used to produce motor spirit.

3. Progress on further reductions in the lead content of petrol to be deferred, pending a review, to prevent further increases to produce motor spirit.

4. Up to £5m. a year investment by the Property Services Agency in the next few years to cut the fuel bill for Government buildings by 20 per cent, or £20m.

5. Urgent talks with public authorities outside central Government on the scope for, and ways of achieving, energy saving.

6. A reduction in maxium speed limits on single carriageways to 50mph, and on dual carriageways, other than motorways, to 60mph.

7. A compulsory limit on the heating level in buildings, apart from homes, of $20^{o}C$ ($68^{o}F$).

8. An appropriate doubling in the standard of thermal insulation required in new dwellings.

9. A request to Boards of Directors, to include a statement of fuel expenditure and steps, taken to save energy in Company Annual Reports to make clear their commitment to energy-saving within their own firm and to make someone responsible for achieving it.

10. A request to Management and Unions to make energy-saving a regular subject for discussion in joint consultation, leading to effective action.

11. Restrictions in the New Year on the use of electricity for external display and advertising during daylight hours.

12. A Government backed publicity campaign to inform and advise consumers on how they can help themselves and the nation by using energy more carefully and efficiently.

Figure F.2 **PROGRESS OF GOVERNMENT ACTIONS & POLICY**

1940 & After	Teams set up to investigate energy utilisation efficiency. Publications of Efficient ways of using energy.
1972	Publication of 'Energy For the Future' - Institute of Fuel.
OCT 1973	Oil Price Increase - 'Energy Crisis' Policy to reduce consumption by (1) market forces (2) feeding knowledge or saving procedures. Increased activity by DOE and DOI. Demand for increased Government activity in energy considerations.
APR 1974	Instigation of Energy Technology Support Unit - Harwell. Investigation of sources of information on energy conservation. Publication of reports and recommendations. Instigation of the Department of Energy.
JUNE 1974	Instigation of Advisory Council on Energy Conservation. Co-ordinated approaches to energy savings brought into action. Public awareness thought to be essential. Instigation of Committee for Energy Thrift in Industry. Policy to be self sufficient by 1980. Introduction of Energy Management. Energy Policy to include: (1) available sources (2) conservation.
AUG 1974	Review of energy related advisory services for industry. Implementation of Social attitudes survey on energy matters.
NOV 1974	Financial aid policy for financing programmes. Changes in behavioural adjustments towards energy use thought to be necessary. Increasing of energy prices policy to achieve realistic positions.
DEC 1974	Announcement of 12 point interim plan. New thermal insulation standards for buildings. Government Loan scheme instigated. (29) Revision of speed limits on roads.
JAN 1975	Co-ordinated policy discussion with Local Authorities on savings. Publicity Campaign Launched 'Energy Sense is Common Sense' - Save it. All items of 12 point plan in operation or completed.
JUNE 1975	Publicity campaign orientated towards industry with availability of saving check lists.
JULY 1975	Domestic Publicity Campaign Launched.
OCT 1975	Domestic Publicity Campaign Reminder.
DEC 1975	Industrial Publicity Campaign Fully Launched.
JAN 1976	Publication of saving techniques for industry - Efficiency Booklets. Publication of check lists for Domestic Sector.

use in those companies.

More specific work was to be carried out by research establishments and associations, involving particular industrial problems, and by universities and other bodies. An Energy Support Unit was set up at Harwell to look at new sources of energy and methods of producing savings. The Rubber and Plastics Research Association (RAPRA) was placed under contract to the EEC Commission on Energy to study the energy content of products and materials. Finally, large industrial users such as the British Steel Corporation were expected to maintain their own programmes.

F.4 Industry

Early investigations revealed that different industries operated at varying efficiencies of utilisation and that certain sectors were not able to carry out an effective quantitative analysis (26). As a result, little was known of industrial usage outside the energy intensive industries. Companies often realise savings were possible but did not know where or how to make them. The Industrial Energy Thrift Scheme was to overcome this problem but it received poor reception.

The Department of Energy also made available a wide range of technical information and publications. The policy was to dissuade industry from conveying increased prices to the final consumer. This was to be achieved through publicity, availability of technical knowledge and incentive. 'Energy Saving in Industry' (20b) outlined the basic approach with reference to the 12 point plan (items 9 and 10 on table F.1). Further publications (20a.b.c. etc) provided more specific measures. Mostly the formats were based on general needs and incentives to save backed with technical information in the form of checklists and detailed accounts. In all cases, lists of consultant organisations and relevant literature were given.

F.5 Concluding Comments

Improvements resulting from actions and policies described in this section have been achieved in the domestic, transport and those industrial sectors having a relatively high consumption. For the major part of industry, savings have been slight. The initial government policy of providing financial incentive and technical knowhow may have failed from companies not being geared towards energy considerations; there being a stronger emphasis on other activities such as production efficiency. The obvious reason is the low cost of energy related to other expenses. In many cases outside the energy intensive operations, energy flow patterns and quantitative analysis were unknown, which made conventional procedures difficult to apply. Tighter monitoring and control was necessary.

In theory the Industrial Thrift Scheme should have provided the answers to some of the above questions. In the first report, however, the recommendations were dubious (30). Although technological advancement is necessary, emphasis on this alone evades the real problems of implementing the actions (see Chapter II). One day factory visits produce insufficient evidence on which to base recommendations. Similarly, detailed investigations of only the large users and the energy intensive operations are fruitless since a great deal is already known of these industries. A more useful exercise would have been the investigation of smaller less intensive companies. Clearly there is a need to subdivide and study industry in the sectors exhibiting different energy usage.

The failure of the strategy cannot be entirely attributed to government actions. Industry has not made use of the potential advantages produced by either the Loan Scheme, or the Thrift Scheme. There appears to be scepticism of any government aid or activity; an attitude which must be questioned. Saving energy is not an individual activity, but one which must combine with the efforts of other operations. It has become an increasingly sophisticated art requiring many disciplines (26). Attitudes must change if successful conclusions are to be reached. Government emphasis has been on long, medium and short term technical improvement. These may not provide the solution to all of the problems.

The 'Save it' campaign has had some success in the domestic sector. It is difficult to attribute this to publicity alone since it is believed to be partially due to economic recession, better weather conditions and energy price increases (26). The campaign was not clearly defined as regards industry. It was initiated at the wrong time of the year, namely in the summer quarter in preference to autumn. Continuity appeared to be lacking. All of which, together with the lack of more detailed knowledge and understanding of industrial energy use, has produced little conviction.

Government policies were correct in their instigation with the objectives laid out being of sound principles. Pricing policy has brought different forms of energy onto realistic levels in accordance with those outside the UK. The tendency, however, has been to increase the prices of manufactured products, so further measures may be required. Demand for greater government control through legislation is possible but unlikely. Certainly a higher level of awareness and involvement in conservation through education, training and improved communcation at all levels are most likely to produce useful results. First of all, however, there must be a greater understanding of the use of energy in industrial sectors.

APPENDIX G

A MODEL OF ENERGY CONSERVATION IN INDUSTRY

Having already discussed highlighted problems facing successful energy saving, it is now a requisit to formulate some form of model showing the mechanism of change and subsequent resistances. To achieve this the ideal model approach has been used.

G.1. The 'Black Box' Diagram

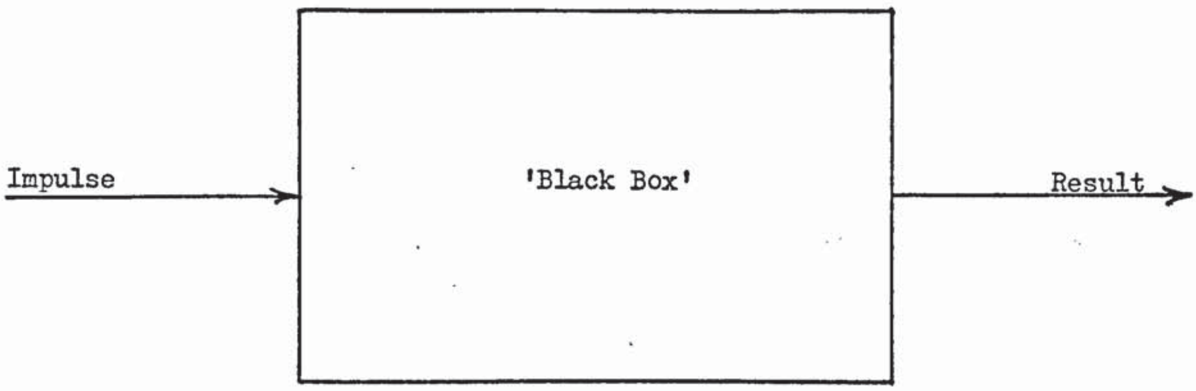
Any system can be represented by a black box which takes on the identity of the system. No change will occur within the system unless there is an incentive to do so. An impulse crossing the boundary may, if internal conditions are susceptive, bring about a change and produce some result. If no result occurs, the attitude within is negative. Figure G.1 shows the basic model.

The identity of the system can be of any size, the boundaries encompassing the entire world, a factory or a simple process.

In the short term since 1973, the overriding factor has been the price increase. When fed into the black box, however, few results have appeared. This indicated a negative system attitude and concluded that the price mechanism above produced ineffectual savings. The reason was probably the passing on of the increased price to the final consumer, the negative attitude, and lack of awareness by employees towards energy. Re-enforced by resultant Government action through publicity and information services (19) (20), two recommendations can be made:

a. to provide information on how to save energy;

Figure G.1 The 'black box' model



Types of Impulse

1. Energy price rise
2. New technology
3. Changes in raw material price and supply
4. Improvements in plant and equipment or processes
5. Political or legislative
6. Financial - excess company funds, strike threats etc.

Types of Results

1. Decreased profitability
2. No change
3. Savings and increased profitability

b. to introduce an energy management structure.

Postulation of the effects of an impulse on the system led to the development of a second model.

G.2. Results of Impulses

It must first be assumed that two types of change may occur in a system.

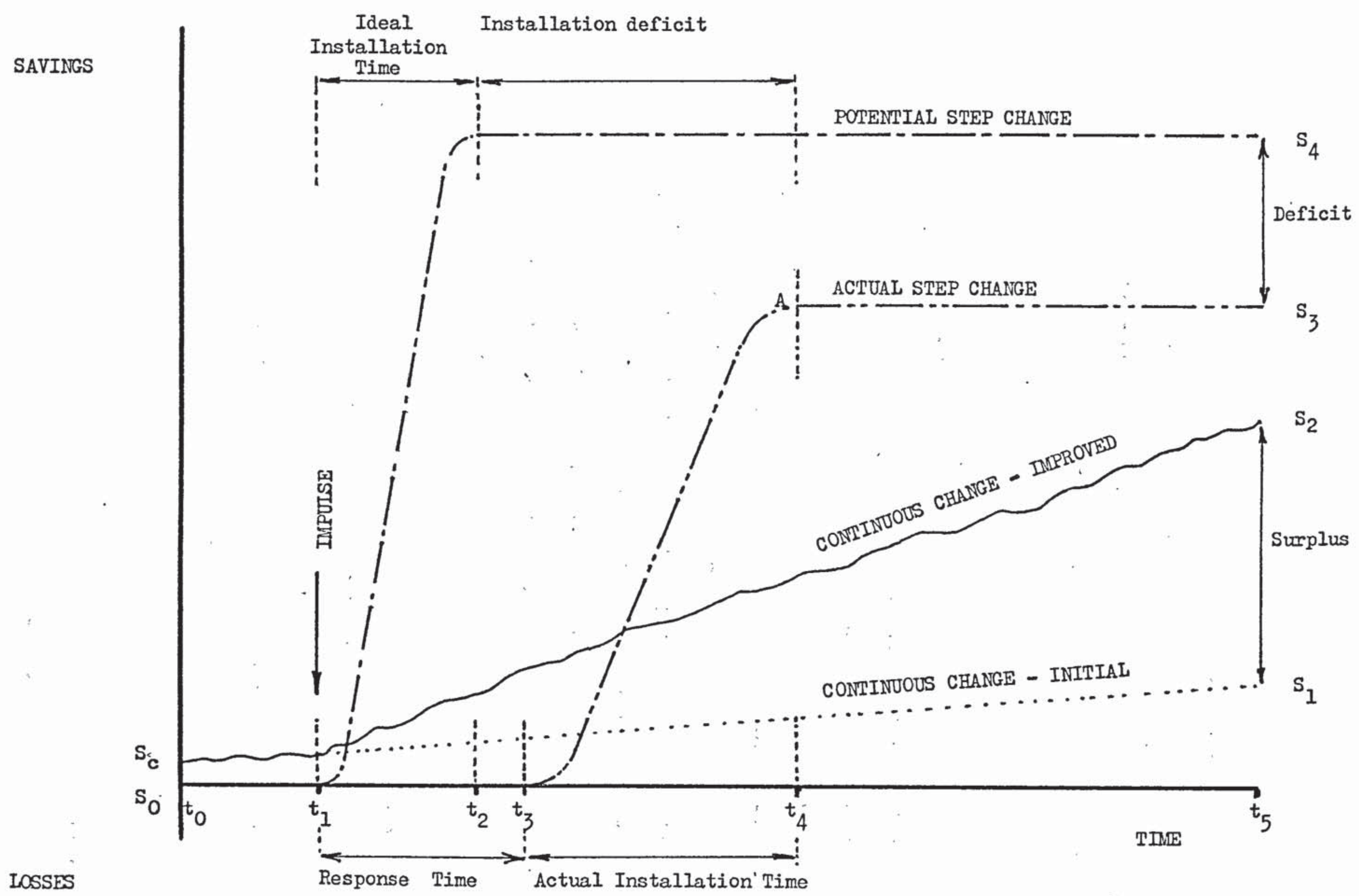
a. the 'continuous' change, (plant modernisation, maintenance and improved housekeeping) - short term actions brought about by good attitudes, progressive management, and a continuous trickle of technology into the company.

b. the 'step' change, the product of an impulse including plant and process improvements - longer term actions, introduced by capital investment and an injection of new technology. An impulse may also affect the continuous change by emphasising the activity and thus increase the gradient of resultant savings. This is shown after time t_1 in figure G.2. Using a graphical representation, various conditions may now be considered.

a. No impulse

At time t_1, prior to any impulse, only three possibilities exist. Firstly a progressive factory, utilising maximum maintenance and plant modernisation facilities together, with efficient control, will already be making a continuous saving 'Sc'. Alternatively, a static plant may do just enough to remain unaltered; no savings resulting. Poor attitude, working practices and maintenance, however, could be such that an actual loss could result. Fort Dunlop

Figure G.2 Results of an impulse on rates of change



appears to be in this third category.

Factories operating under the second and third conditions are contrary to economic growth. Why then do organisations waste energy in this way? The situation is worsened by the continuation of poor attitude towards savings, even after an impulse has resulted.

b. Impulse - no step action

Assume an impulse occurs at time t_1, but for possible financial reasons, brought about by economic recession making capital investment in new plant impracticable, or due to shortage of available technology, there is no step change. The progressive company is likely to increase its continuous energy saving activity producing a surplus saving of (S_2-S_1) after time t_5. As prices rise, the differential becomes larger. It is in the interests of operations such as Fort Dunlop, therefore, to bring about an attitude change towards maintenance and housekeeping.

Price rises or improvements in technology often make previously unattractive projects more feasible. Impulses without step changes can result in a 'potential' loss in the face of competitors. Previously unacceptable projects should, therefore, be re-examined.

c. Impulse - step action

Assume that the impulse occurs at time t_1. From that moment a step change could produce a 'potential' saving S_4. However physical criteria inhibit immediate resultant savings, and so the minimum possible installation time

(t_2-t_1) is represented by the gradient of the line.

In reality, however, the 'actual' step change follows a different path. Explanation can be divided into three parts.

i) Response time - This is defined as the time period from the instance of the impulse to the commencement of installation (t_3-t_1). Company attitudes, availability of finance, return on investment and efficiency of communication are but a few of the controlling factors. Also included here is time required for research and development. Response time will therefore depend on the technical level within the Company.

ii) Actual implementation time - Defined as the period between implementation of the action and final commissioning, it depends on the attitude and motiviation of employees, availability of manpower and materials and the type of operation needed (i.e., safety procedures).

iii) Actual savings achieved - These rarely reach the potential level but are more likely to fall some way below (S_4-S_3). Reasons for such results reflect either incorrect installation or the effects of incorrect specification at the time of the initial feasibility study.

Since 1973, response times have been lengthy, installations having perceptively long period,and actual savings way below potential. Basic problems with communication, attitude, identification of inefficiency and limitations on capital constitute the reasons.

d. <u>Forecasting the Impulse</u>

Resulting from this thinking, conclusions can be drawn with respect to actual versus theoretical savings. Thus at time t_5.

Total potential saving = $S_4(t_5-t_1)$

Total possible saving (accounting for implementation time)

$$= S_4\ (t_5-t_2)$$

Efficiency of effective installation = $\frac{S_4(t_5-t_2)}{S_4(t_5-t_1)} \times 100$

Actual saving = $S_3(t_5-t_4)$

Hence ratio of total potential saving = $\frac{S_3(t_5-t_4)}{S_4(t_5-t_1)}$

And ratio of total possible saving = $\frac{S_3(t_5-t_4)}{S_4(t_5-t_1)}$

It is assumed that energy price does not vary over the period.

If, it was possible to forecast an impulse, the loss of potential savings would be minimised by initiating the implementation of the conservation action so that completion coincides with time t_1. The resultant improved saving would be:

$$= S_3 \left[(t_5-t_4) + (t_4-t_1)\right]$$
$$= S_3 \ (t_5-t_1)$$

Predicting price increases and analysing trend patterns, a function relating to the buying department, are in little evidence in Dunlop. Whilst it is agreed that:

i) the significant benefits of pre-initiated implementation will depend on the life cycle of the conservation action;

ii) the project would have to compete for available finances,

such a proposal could save money.

G.3. The Hydraulic Analogy

Not all problems can be explained by the simple 'black box' model. The 'hydraulic analogy' shows how the behavioural patterns can be represented by a model in which new and existing technology, implementation, and final results are viewed as hydraulic flows; with impulses, feasibilities and incentives considered as pressures. Figure G.3., depicts the general system.

Within the boundary limits of the company lie several clearly defined areas ;

a. the physical company environment in which potential savings are to be made;

b. the management system in which evaluations, recommendations and decisions are carried out;

c. project studies formed from a requirement to search for conservation possibilities, ideas, research and development;

d. technical possibilities within the Company;

e. resistances, gaps and opposing forces towards energy savings; i.e., lack of available equipment or finance, poor attitudes etc.

Impulses and new technical possibilities lie outside the boundary and are not in direct control of the company.

Management acts as a pneumatic pressure regulator, influenced by external forces, and controlling the emphasis on ideas and proposals, thus influencing the flow rate of conservation action through valves 'A', 'B' and 'C'.

a. <u>No impulse</u>

Technical possibilities within the Company include maintenance, plant modernisation and a small number of new ideas. Progressive management will ensure two things:

i) Provision for continuous improvement by allowing these possibilities to be realised in actions and results. This means opening valve C to allow a flow into the physical environment. The degree to which this will occur must depend on availability of facilities (replacement equipment, manpower, finance etc.) and attitude of employees. The latter will fluctuate from time to time and will also be a product of management pressure. Attitude towards energy can therefore differ for management and other employees.

ii) Provision for a continuous trickle of new ideas and knowhow to enter the company's technical possibilities through having valve 'A' cracked open. Continuous flow of this kind will build up pressure in the top tank and will either form a proposal, which will result in a step change, or increase the flow through 'C'.

Static management has valve 'A' shut making no provision for new ideas. The flow through 'C' will not only be reduced, due to fall off in enthusiasm but will gradually decline as a 'vacuum' forms in the feeder 'technology' tank. Fort Dunlop echoes this hypothesis.

Negative management will actually have valve 'C' closed causing a degeneration of the physical and operational environment. This will continue until the resultant inefficiencies will themselves put pressure on management to affect change.

b. Impulse - no step action

Impulses can either be direct, such as price rises, or indirect through technological discovery forcing the existing technical possibilities to generate a 'proposal' pressure on management. The immediate reaction is to generate more enthusiasm and further open valve 'C', thus increasing the rate of continuous change. The extent to which this will occur will depend on the financial feasibility and the attitude of management. This will of course diminish with a less progressive company.

c. <u>Impulse - step action</u>

An alternative management reaction to pressures of this kind will be to open valve 'B' and allow a step change to occur. The rate at which management responds is the response time postulated in section G.2., and the degree of resistances, gaps and opposing forces relates to the implementation time and the level of actual savings/ potential savings achieved.

Should there be an inadequate level of technical possibilities in the feeder tank, management would then initiate project studies to further open valve 'A', increase the pressure in the tank, and generate a proposal.

Through project studies, management can identify potential areas within the physical environment. Identification can be envisaged as flow across the boundary between management control and the physical environment. As with all the pressure paths depicted in Figure G.3., success will depend on a formalised system and good communication. Fort Dunlop, due to the nature of its operation, fails to achieve this. Identification of potential savings must, therefore, be highlighted as a serious deficiency.

Forecasts and pre-emption of an impulse is a product of active management thus producing a step change. The result of a decision to correct a poor physical environment or sudden identification of a major 'hidden' inefficiency

Figure G.3

The Hydraulic Analogy

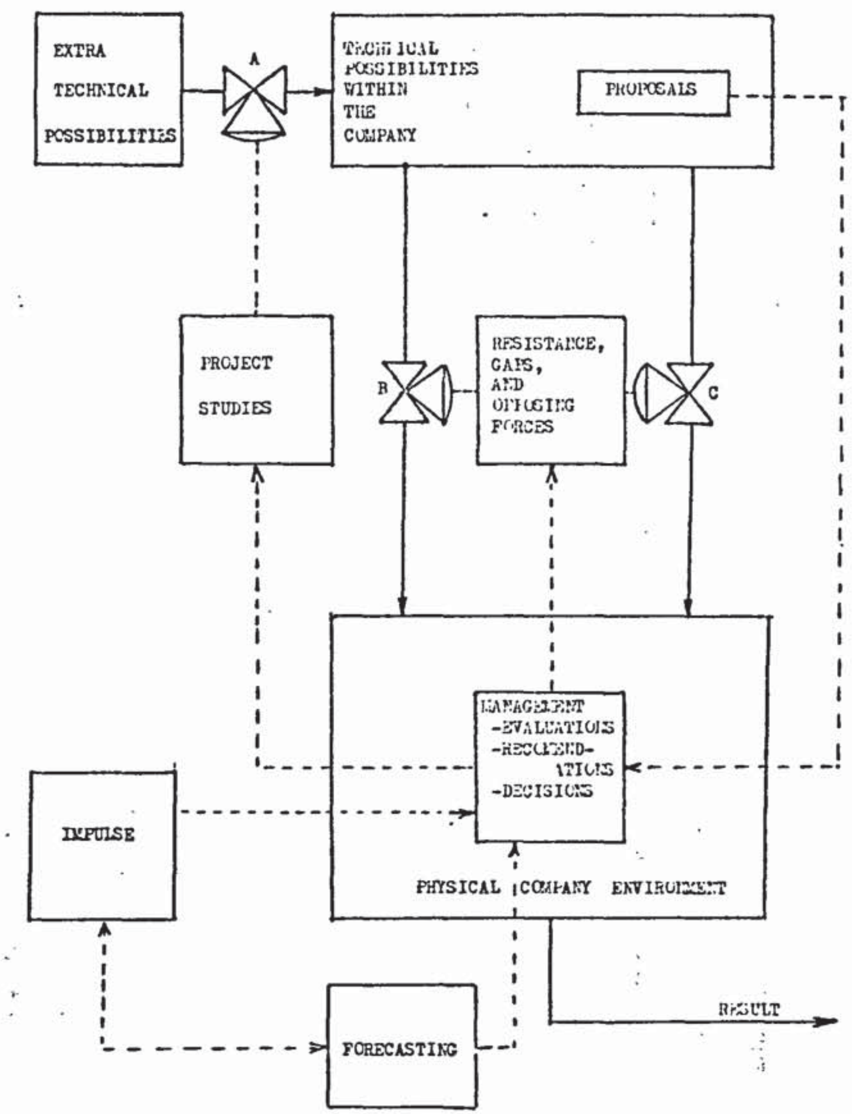
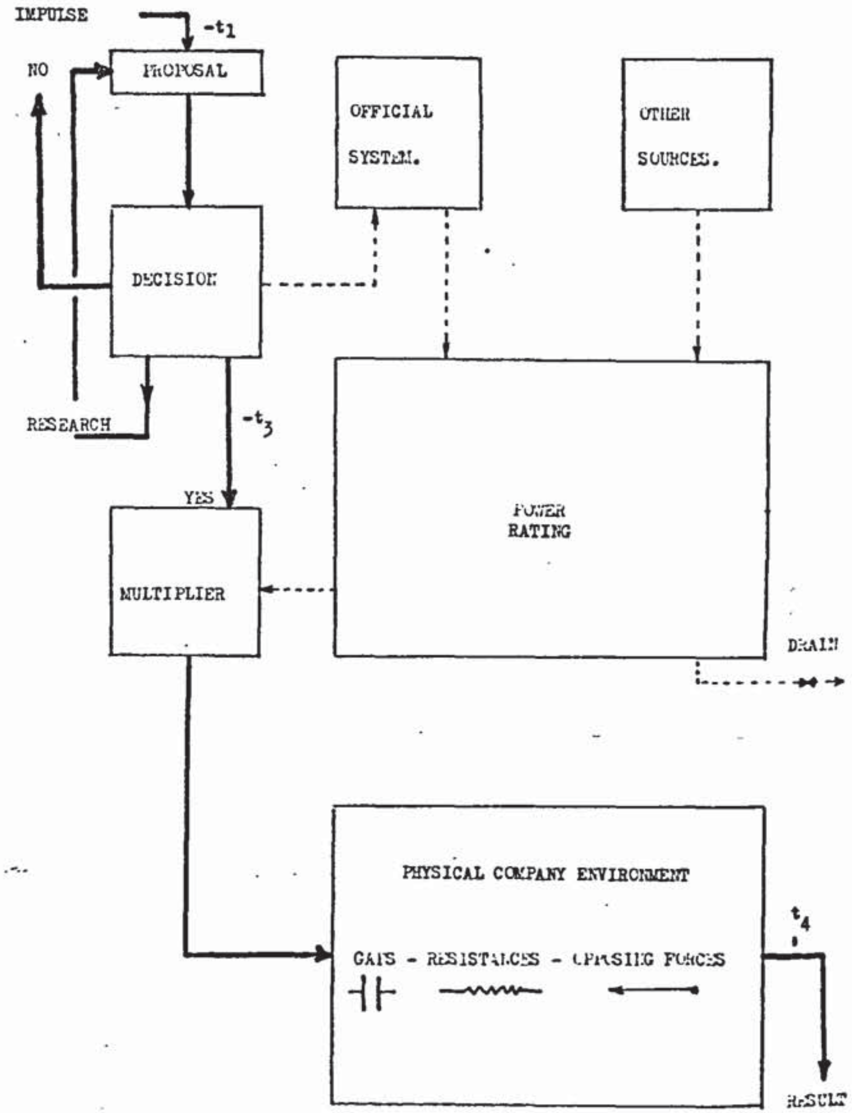


Figure G.4

" FLUSH MODEL "



produces a similar change.

The properties and mechanisms of this model clearly indicate the problems facing industry as a whole. The degree of difficulty will of course relate to individual industries, each having their independent peculiarities. Clearly, however, Fort Dunlop's problems have become better defined.

G.4. The Flush Model

The rate at which conservation potential is converted into results is subject to time factors:

a. response time (t_3-t_1),
b. implementation time (t_4-t_3).

Likewise the degree to which actual savings reach possible savings and the rate of change of continuous improvements will relate to the employee attitudes, effectiveness of installation and project weighting. These effects are best viewed through a new diagram:- the 'Flush Model'. Here the rate at which a proposal reaches fruition can be related to the positive forces and negative resistances influencing implementation. (See Figure G.4).

Response time is made up of two components:

a. identification - the time required to find the potential areas and to generate a proposal;
b. decision - the time required to assess or decide on the proposal feasibility.

Identification of wasted energy usage, must be highlighted as a major problem. The identifying activity will heavily depend on company policy and attitude. Active management for example, will have identified potential areas long before any impulse. In this respect Fort Dunlop appears passive; waiting for an energy price rise to galvanise management into action. The situation is such that the availability of technical knowhow exceeds the rate of identification.

In addition to successful identification, generation of acceptable proposals will reflect the availability of technical knowhow within the company and the effectiveness of movement of information across the company's boundaries. Further factors are the general attitudes of engineers towards energy and the efficiency of internal communications. There is a need for efficient organisation through energy management. (See Chapter III).

Once identified and a solution found, the proposal is fed into the decision making process. Here management undertakes feasibility studies which produce one of three possibilities:

a. acceptance - allowing initiation of implementation
b. deference - reserving final decision following further studies or research
c. rejection.

This activity is critical and depends heavily on policy, general attitude and awareness, and the attractiveness of the proposal.

Should the proposal be accepted, implementation proceeds. Once again achievement of results faces many obstacles, comprised of gaps, resistances and opposing forces, (See Table . G.5). Analogy can be drawn with electrical theory of capacitance, resistance and opposing potential difference. Such obstacles, however, can be overcome if there is sufficient driving force behind the proposal. This is shown in figure G.4., as a power rating, and a product of management decisions, and effects the rate of result achievement by allocating weightings to the proposal in the "multiplier process".

The power rating is dervied from two main components.

a. The official system. Included are available manpower, finance and priority urgency, reflected by the economic attractiveness of the proposal. Management has direct control of these components.

b. Other sources:

  - enthusiasm of employees,
  - influence of management and employees on one another,
  - influence of physical and social factors, such as knowledge of resource depletion.

The state of the organisation and the effectiveness of communication will govern the extent to which the 'multiplier' will weight a proposal. This reflects the economic viability, the type of manufacturing operation and the size of the system.

During implementation management does of course have additional facility of removing the power rating to the proposal by effectively opening a drain or releasing the pressure. Alternatively other proposals may arrive and be given greater priority thus reducing the weighting

Table G.5

EXAMPLES OF OBSTACLES OPPOSING IMPLEMENTATION OF PROPOSALS

1. Resistances

- inefficient organisation and management
- differences in individual employee priorities
- differences in individual approaches
- industrial relations problems
- decreased manpower available
- declining interest by employees.

2. Gaps

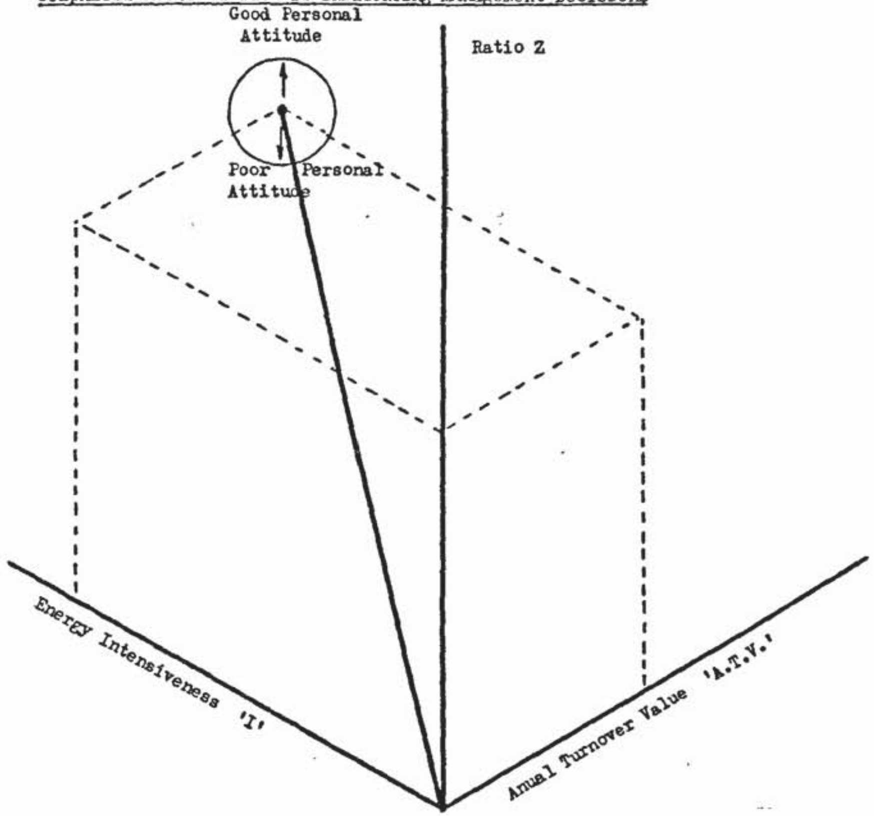
- insufficient knowhow
- lack of contacts, internally and externally
- lack of specific skills
- lack of formal communication channels
- lack of plant, equipment or materials
- lack of design
- lack of manpower
- sudden absence of funds.

3. Opposing Forces

- changes in economic attractiveness
- changes in priorities
- changes in policy or attitude
- redundency by technology improvements.

Figure G.6

Graphical Model of Factors Influencing Management Decisions



Ratio Z = Actual savings achieved / Potential savings possible

Examples

Iron & Steel Industry - high energy intensiveness; high A.T.V.

Cement Industry - very high energy intensiveness; low A.T.V.

Dunlop - low energy intensiveness; high A.T.V.

originally assigned. Returning to the electrical analogy, Management has the facility of regulating the potential difference across the circuit containing capacitors (gaps), resistors (resistances) and inductances/emf's (opposing forces). Thus influencing rate at which current (proposals) will flow. Variation in proposal priority has the same effect as varying the voltage. Complete removal of power rating can be viewed as a short circuit.

G.5. Factors Influencing Management Decisions

Financial incentive, usually measured as a DCF rate of return, exerts greatest influence in acceptance of a proposal. The economic environment, in which managers operate, plays a large part in making positive decisions.

a. Energy Intensiveness

Energy intensiveness can have a direct bearing on the type of change, the degree of improvement and the response/implementation times. It is common to find low activity in companies having low intensiveness since incentives to save are minimal compared with other operational priorities, such as labour and materials cost reduction. High intensiveness produces higher activity since management are more aware of the higher energy cost.

b. Annual Turnover Value

Assuming company/factory size relates to annual turnover, it can be shown that capital intensive energy savings are more difficult to introduce into smaller companies due to the restricted available finance. Larger companies suffer from a different problem having large diverse usage and ill defined consumption. Annual turnover value, therefore, might well give an indication as to the situation. In addition, annual turnover with company profitability may reflect the degree of plant and process modernisation and research activity. Conversely, company growth may direct finances towards new products, at the expense of efficiency in existing plants. Care should be taken, however, not to postulate hypotheses without considering all the factors; a subject for further research.

c. Other Factors

These include:

- political intervention: internal and external
- geological and sociological location
- industrial classification and tradition; private, public or nationalised
- type of product
- type of process, continuous or batch manufacture
- age of plant

Making the assumption that (a) and (b) are major factors in influencing decision, it is possible to represent the ratio of actual energy recovery projects to available potential ('Z') in a graphical model (See Figure G.6). Personal employee/management attitude can be represented as the locus of a point positioned in an 'influence' sphere (i.e., an employee having positive attitudes will raise the ratio to a higher value).

Fort Dunlop exhibits an intermediate intensiveness with a high annual turnover, which points towards relative success in conservation. This is not the case for reasons which may be included in 'Other Factors' shown above.

APPENDIX H

IDENTIFICATION OF INEFFICIENCY THROUGH CLASSICAL THEORY

If the electricity generated in a power station were used to heat a process by means of a heat pump, according to the 2nd law of thermodynamics the ratio of heat of initial combustion to heat delivered is:

$$\frac{Qc}{Qp} \geqslant \frac{1 - To/Tp}{1 - To/Tc} \quad (= 0.12 \text{ at best})$$

Where: Qc = Heat of combustion of fuel, Tc = high combustion temperature, To = atmospheric temperature, Qp = extracted heat from atmosphere, and Tp (= 50°C) = process temperature.

Thus the use of direct combustion of fuel to heat hot water requires approximately eight times as much fuel as would a reversible heat engine - heat pump system. This illustrates that work, as opposed to heat, is intrinsically the most valuable form of energy. In fact the part of fuel which is of value is the extent to which the energy content can be converted to work.

H.1 Thermodynamic Availability

In accordance with Gibbs, and later Keenan (135), if a fuel with total energy (E), volume (V), entropy (S) is reduced to thermodynamic equilibrium with an atmosphere at temperature (To) and pressure (P), the maximum useful work (W) which can be derived by this step is given by:

$$-W = A = E - ToS + pV - \sum_j \mu^j N^j$$

Where: μ = chemical potential of constituents

N = mole numbers of constituents

The quantity A is called the thermodynamic availability of the fuel and is proportioned to its mass. The term $\sum_j \mu^j N^j$ represents the maximum useful work obtainable from the diffusion combustion products. Waste in availability represents a waste of energy.

The first law of thermodynamics guarantees that energy can be neither created nor destroyed. It would hardly seem necessary, therefore, to have a national policy addressed to its conservation. The unfortunate discrepancy occurs in the use of loose therminology, by which "energy" has been substituted for "energy resources". This has led a number of investigators to assess the national use of fuels and to identify wastes and losses of energy resource. Whilst improvement in the use of the resource in industry through good housekeeping etc. can be considered meaningful, "energy" itself is an entirely ambiguous and unsuitable measure of the effectiveness with which it is put to use

H.2 "Availability" and Industry

Awareness of thermodynamic availability is sometimes indirectly expressed by industry through the price mechanism; e.g. preference of space heating by gas compared to electric. Few, if any, however, choose its inclusion as a measurement of efficiency of the plant and equipment or process. So far attention has been drawn to availability losses for power generation devices. Little has been given to losses at the final point of use.

To attain maximum availability would require perfectly reversible equipment and process operations at each stage of the system. Whilst possible in principle, it would require infinite investment in heat transfer apparatus, controls, electric conductor material etc. (56); obviously an unrealistic goal. However, in many instances, wasted availability of devices have not been economically evaluated. One reason is the difficulty in evaluating wastes attributable to deficiencies in components, which function at points far removed from the site of fuel combustion.

In many instances irreversibilities which cause wasted energy are designed into devices in order to reduce initial investment, or because the technical problems of eliminating them are nearly insuperable. Examples are given below.

As a rule, efficiency and price correlate. This is because units with larger heat transfer surfaces, more efficient motors and other design features, which improve efficiency, cost more to manufacture. On the other hand, total operating costs tend to be less for more efficient, higher priced units. This demonstrates how higher energy consumptions can and have been designed into devices in order to reduce initial costs. It also shows how initial costs tend to be more important than operating costs in decisions to purchase equipment. The result has led to a systematic development of inefficient energy use in industry. As a rule therefore, technical measures to correct inefficient use of energy at the point of consumption are economically justifiable when based on the 'life cycle' costs.

H.3 Throttling

Most refrigeration equipment uses a throttling valve to expand the fluid and thus producing the cooling effect. Work is lost by expansion of the fluid by throttling. The consequential loss of cooling capacity can amount to an excess 20% power consumption being designed into the cycle for a given capacity. Throttling, by being a primitive way to expand a fluid, is an exacting way to minimise initial investment at the expense of energy used in operation. (56)

H.4 Heat Exchangers

The rating of heat exchangers offers a simple example of the possible use of thermodynamic availability in evaluating potential saving. Provided that the exterior of a heat exchanger is sufficiently well insulated, no energy need be lost from the device. The exit temperature of the secondary stream, however, will still be lower than the entry temperature of the primary stream due to a loss of thermodynamic availability and hence an energy loss. To reduce this, investment in better heat transfer surface material and fluid flow control is needed. Thus economically rational methods of rating components, such as heat exchangers, can be constructed via the path of thermodynamic availability measurement. Table H.1 shows the ratios of thermodynamic availability required (Ar) to that consumed (Ac) for a number of processes.

Table H.1

Estimates of Ar/Ac for a number of processes (56)

Process		Ar/Ac
Home Heating	(electrical)	0.03
Home Heating	(gas, oil)	0.07
Paper Making		0.10
Kiln Operations		0.25
Vacuum Furnaces		0.25
Water Heating		0.10

In high temperature processes, gains in efficiency may be obtainable through gains in heat transfer and control; whereas in low temperature processes, additonal modification to the basic process is needed (e.g. switching from space heating by direct combustion to heat pumps).

H.5 Resin Curing

Of particular significance to tyre - curing, in one industrial plant the application of ultraviolet radiation in place of direct heating to cure resin coatings reduced the total energy required from 12720 MJ/hr to less than 160 MJ/hr (57). This is an example of supplying the process with the type of energy it requires.

H.6 Comment

The correction of inefficient use of energy at the point of consumption, offers one of the greatest but as yet unexploited opportunities for improving overall fuel efficiency. Vulcanisation of tyres highlights the classic case of known inefficiency, which to date has produced little interest beyond tentative investigation into the replacement of conductive heating by the micro-wave alternative.

It is recommended that, in planning efforts for improving fuel and energy efficiency, a rational system of measurement be used; one which reflects the changes in energy consumption attainable through various modifications in equipment and practices. The classical thermodynamic availability, constructed originally by Gibbs and further developed by Kennan (135), is believed a possible foundation for improved identification at source.

H.7 THE USE OF CONDENSATE MEASUREMENT IN THE EXPERIMENTAL DETERMINATION OF STEAM CONSUMPTION

The following experiments were carried out to determine the rates of steam consumption under specific conservation procedures. They relate to two exercises carried out at Fort Dunlop.

H.7.1 Comparison of TD Steam Traps and Condensate Control Systems on the Dome Steam of McLloyd Presses in Tyre 4 Department by the Condensate Collection Method (87)

a. Objective

To assess and compare the performance of a 1/2" TD3-2 Spirax Sarco Thermodynamic Steam Trap with that of the standard control system fitted to McLloyd presses in Tyre 4 Department.

b. Equipment

A B2 McLloyd press was fitted with a ½" TD3-2 steam trap followed by an atmosphere valve and a sight glass before connecting to the stop valve on the condensate main. This trap replaced the diaphragm valve control system, present on press B1, which operated from a temperature probe fitted into a cooling chamber collecting the dome steam condensate. As the temperature probe reacted to the colder condensate, the generated signal released air to a diaphragm valve, this opened allowing discharge to the main. As steam replaced discharged condensate, the probe again reacted through the controller to close the valve.

In contrast, the Thermodynamic trap exploited the Bernoulli theorem (68); that in a moving fluid, the total pressure was the same at all points and that this total was made up of dynamic and static pressure, a decrease in one producing an increase in the other. The flow of flashing condensate through the trap varied the static and dynamic pressure acting on a disc, so that it raised from its seat to discharge any condensate, but fell to prevent the passage of live steam.

In each test on a press, the atmosphere valve was connected to a copper coil immersed in a tank of cold water. The condensed liquid was collected in a second tank for observation of flow and quantity.

c. Tests

The standard press, B1 was examined first. The stop valve was closed to prevent condensate entering the main and at the start of the cure cycle the atmosphere valve was opened, thereby passing the hot condensate through the cooling coil to be collected as water. Observations of the rate and manner of flow of condensate were made during the cure cycle. The press was returned to its normal operation after each test.

The modified press was tested in a similar manner.

d. Observations and Conclusions

The condensate control system gave pulses of steam at relatively high velocity and pressure. The pulses occurred rapidly and were of long duration during the early stages of the cure cycle, but progressed to pulses of shorter duration and longer intervals as the cure time increased. This was to be expected as the press heated up during the cure, so producing less condensate and requiring less steam late in the cycle. Although no specific measurements were made, this observation highlighted the ineffective use of steam in tyre moulding where presses needed to be opened for loading, thus allowing the mould and steel structure to cool.

The ½" TD trap was found to perform adequately under similar conditions. Condensate was passed continuously in the initial stages of the cure but with varying flow rate. However, pressure and velocity of delivery was never as great as that of the control system. After the initial build-up of condensate early in the cycle, discharges progressed with the cure to normal pulsations at lengthening intervals towards the end of the cycle.

The condensate control system passed 59 to 77 litres of condensate whilst the trap gave 41 to 50 litres. Each of the figures were obtained during one cure cycle, and the difference between trap and control system figures could be due to:-

- slightly different cure times
- passing steam from the control system
- thermal inefficiency in press B1
- variation in effectiveness of condensate collection

As a consequence, the TD3-2 trap was shown to work efficiently as a substitute for the condense control system. To facilitate the evaluation of press thermal efficiency, it was necessary to revise the method of condensate collection and to examine varying conditions of press operation on the same press and over a constant time scale. This was carried out by E.G. Could commencing in November 1974, and continuing over the next seven months (88).

H.7.2 Steam Consumption Measurements for 40.5" Autoform Presses - Tyre 5 Department

The report described the experimental determination of the level of steam consumption, under normal production conditions, of a 40.5" Autoform Press: Tyre 5 Department. The press used was C6, fitted with typical two-piece mould, and situated sufficiently far from the ends of the line of presses to avoid any thermal influence from the cooler atmosphere. The tyre size (E70VR15) for the experiments was the same throughout. This experiment once again demonstrated the advantageous use of condensate collection in determining steam consumption.

The platens of the press were connected in series and supplied with steam at a controlled pressure; resultant condensate being discharged through a trap. A pressure vessel (25 litres) was connected after the trap, with two valves arranged so that the condensate could either be diverted into the vessel or follow its normal route to the condensate return main. Condensate was then collected over a curing cycle, the temperature measured and the contents of the vessel allowed to cool, then drained and weighed.

The steam used to heat the tyre internally produced condensate constituting two components:-

a. That produced by the tyre and bag which was completely collected by the lower sidewall of the tyre and discharged to the main drain at the end of the steam period.

b. That produced by the bagwell and its associated valves and pipes, which was continuously discharged to a circulating drain using a trap.

For the purposes of these experiments, only the second component was collected. Estimates were made for the former due to collection difficulties, confirmation of the values being obtained by experiment at a later stage.

In addition, the following measurements were taken:- cycle times, ambient temperatures at the front of the press and in the service trench; and the weights of the tyre cover.

The experimental procedure was repeated for the following conditions..

a. Normal operation of the standard press
b. The press in standby condition with the mould in both open and closed positions.
c. Additional lagging of different parts of the press
d. Dispensing with the circulating drain during the cure and retaining all the condensate in the bagwell for discharge at the end of the cycle.

The overall conclusions from the experiments were:

a. The total steam consumption of the unlagged press was equivalent to a power rating of 55.8 KW.
b. Worthwhile savings would be made by closing the press fully

under standby and warm-up conditions (6.9 kg/hr).

c. Removal of the trap from the bag drain system could give savings of 17.5% of internal steam consumption (1.84 kg per cure equivalent to 6.4 kg/hr).

d. Lagging over the top platens could save 11.7% of platen steam (1.13 kg per cure equivalent to 3.9 kg/hr).

e. The addition of annular lagging round the outside edge of the lower mould could give an additional platen steam saving of 4.1% (0.39 kg per cure equivalent to 1.3 kg/hr).

f. An extra layer of Sindanyo between the bottom platens and the press would give a reduction of 3.3% (0.32 kg per cure equivalent to 1.05 kg/hr).

g. Extra Sindanyo between both upper and lower platens and the press could give a saving of 14.7% (1.41 kg per cure equivalent to 4.9 kg/hr).

h. The combination of Sindanyo between upper and lower platen and the press, and the lagging over the top of the upper platens would give a saving of 21.1% (2.09 kg per cure equivalent to 7 kg/hr).

i. Comparison of g and h shows that the lagging over the platens provided an additional 7% saving.

j. The first cure on Monday after the weekend shutdown required a very large increase in steam, particularly for the bags (approximately 100% increase after allowance has been made for the three automatic cure extension). The preheating of the platens ensures that the increase is much less (approximately 20%).

k. The press appeared to use less steam in the afternoon, showing a tendency to vary with ambient temperature.

l. A cover weight variation of 10% did not appreciably affect the consumption of steam.

m. A leaking bag appeared to heat the platens and reduce platen steam input.

n. A comparison of these results with those for a 36" Bagomatic press showed good agreement for the platens but, as would be expected, the Autoform press was more economical in its internal heating requirements.

Work to date has established the validity of this experimental method as a means of measuring the steam consumed by any piece of plant and equipment. In addition, the technique was sensitive enough to determine variation in consumption brought about by some conservation action.

APPENDIX I

PRINCIPLES OF RADIATION AND THERMOGRAPHIC OPERATING PROCEDURES

I.1 Basic Principles of Thermal Radiation

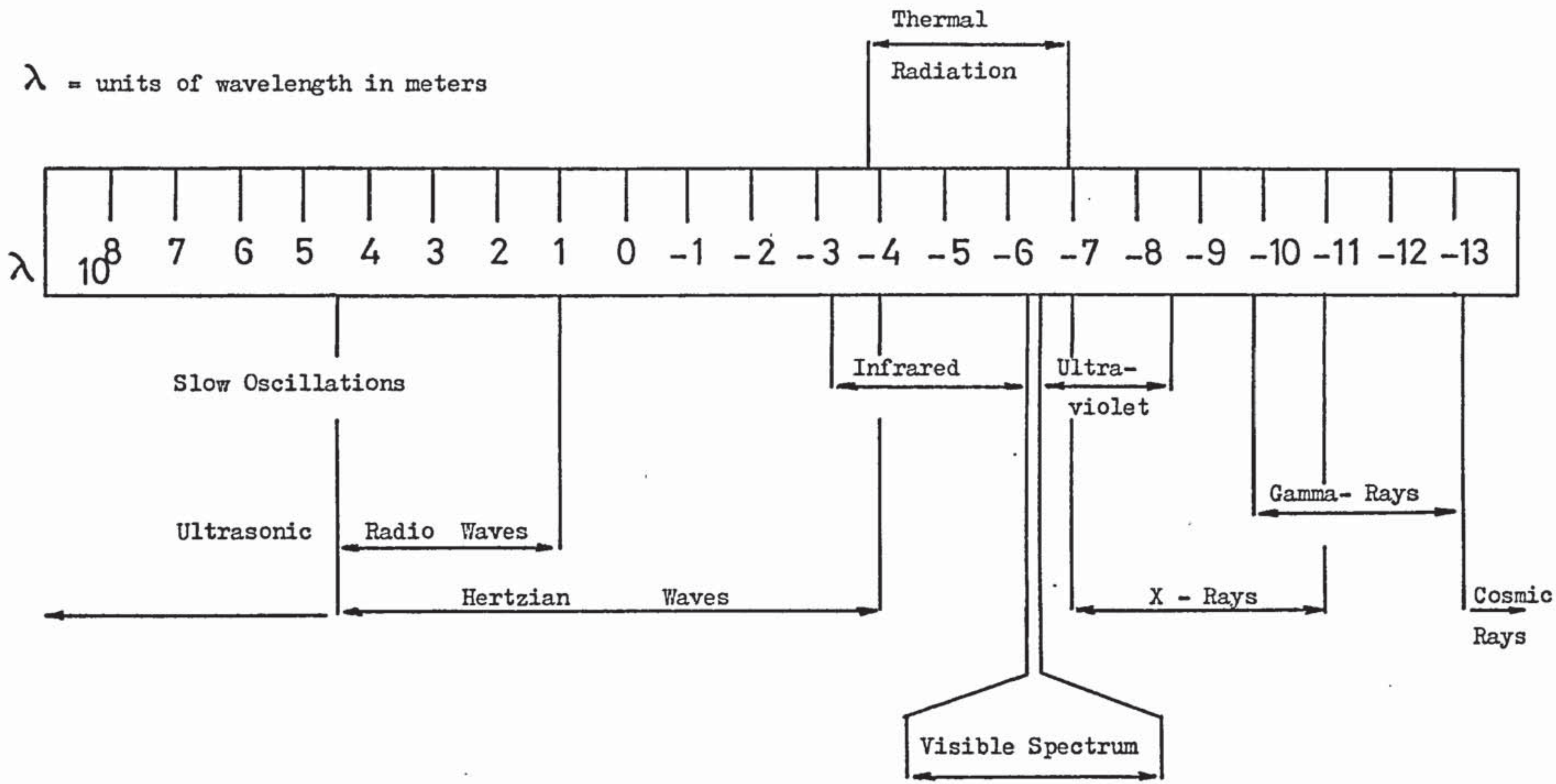
The transfer of heat by radiation is only one of numerous electromagnetic phenomena (Figure I1..1). The term 'radiation' is applied generally to all kinds of processes which transmit energy by means of electromagnetic waves. The entire spectrum of such waves can be subdivided, as shown, into classes according to wavelength or frequency and also according to application. Although the nature of radiation and its transport are not fully understood, it can be described satisfactorily by either wave or quantum theory. (155).

$$\lambda = c/v$$

Where c = velocity of light (constant), λ = wavelength, v = frequency.

Radiation in the wavelength range 0.1 to 100 μm when incident upon a body will heat it and consequently is called thermal radiation. This thermal radiation, in a uniform medium, can be said to travel in straight lines. Opaque bodies, therefore, cast shadows, inferring that a body cannot receive radiation directly from another unless it can 'see' it. This is an important limitation to thermography. All bodies at a temperature above absolute zero emit thermal radiation and consequently lose energy. (Prevost's principle of exchange (155)).

Figure II.1 The Electromagnetic Wave Spectrum



I.2. Absorption, Reflection and Transmission

When radiation falls upon a body (solid, liquid or gas), a fraction (α) is absorbed, (ρ) is reflected, and the remainder (τ) is transmitted through the body:

$$\alpha + \rho + \tau = 1$$

Solid materials, apart from glass, plastics etc., are opaque materials having a transmissivity (τ) = 0. Highly polished and smooth solids behave like a mirror, where the angle of reflection equals the angle of incidence. Reflections from most 'rough' industrial surfaces occur indiscriminately in all directions and are called 'diffuse'.

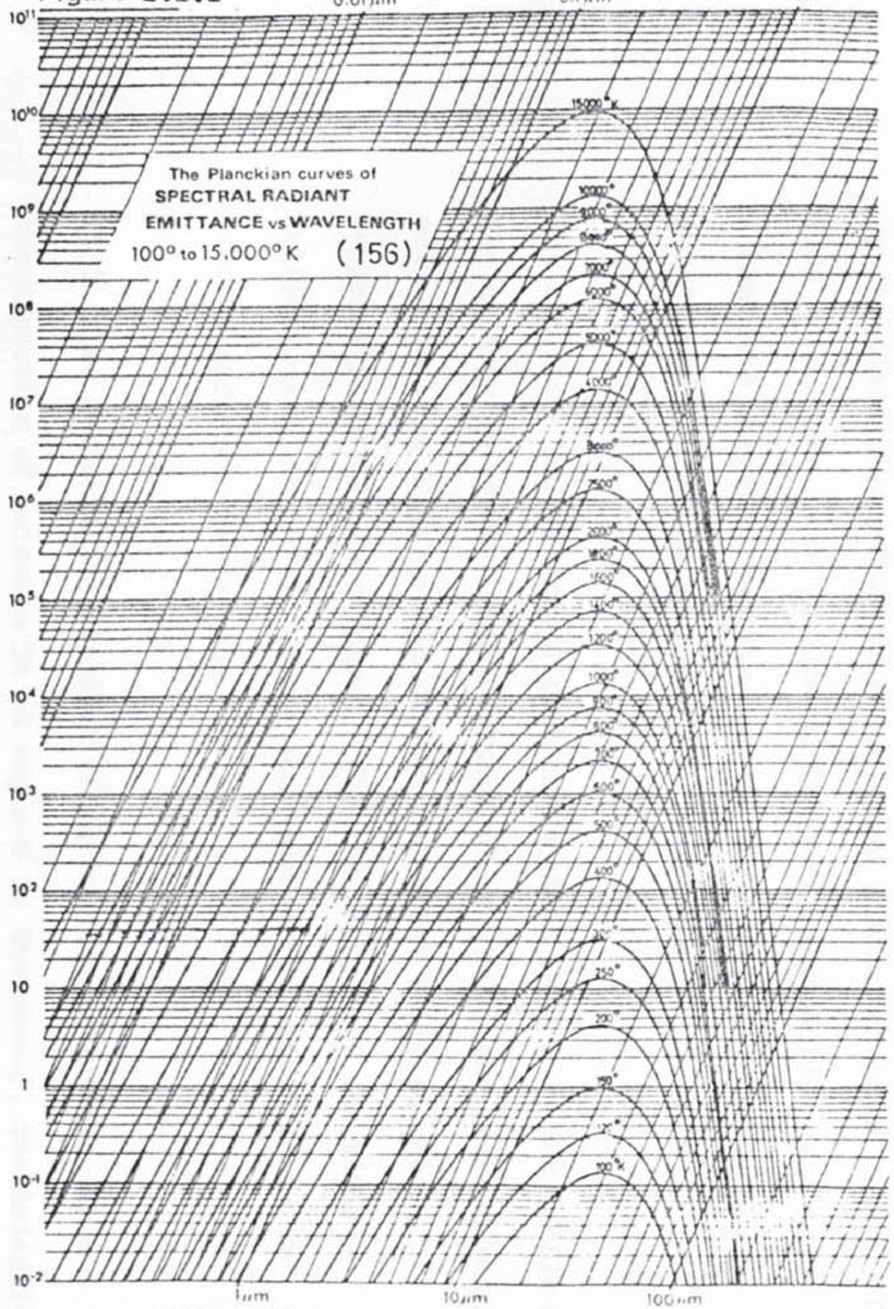
Kirchhoff's law (132) states that the monochromatic emissivity of a surface is equal to its monochromatic absorptivity for bodies whose emissivity do not vary with wavelength (black or grey bodies). Many industrial materials approximate to the grey body ideal. In many cases it is sufficiently accurate to assume that materials are non-selective emitters, i.e. they are grey, and therefore obey Kirchhoff's law.

$$\epsilon_\lambda = \alpha_\lambda$$

I.2.2 Black - Body Radiation

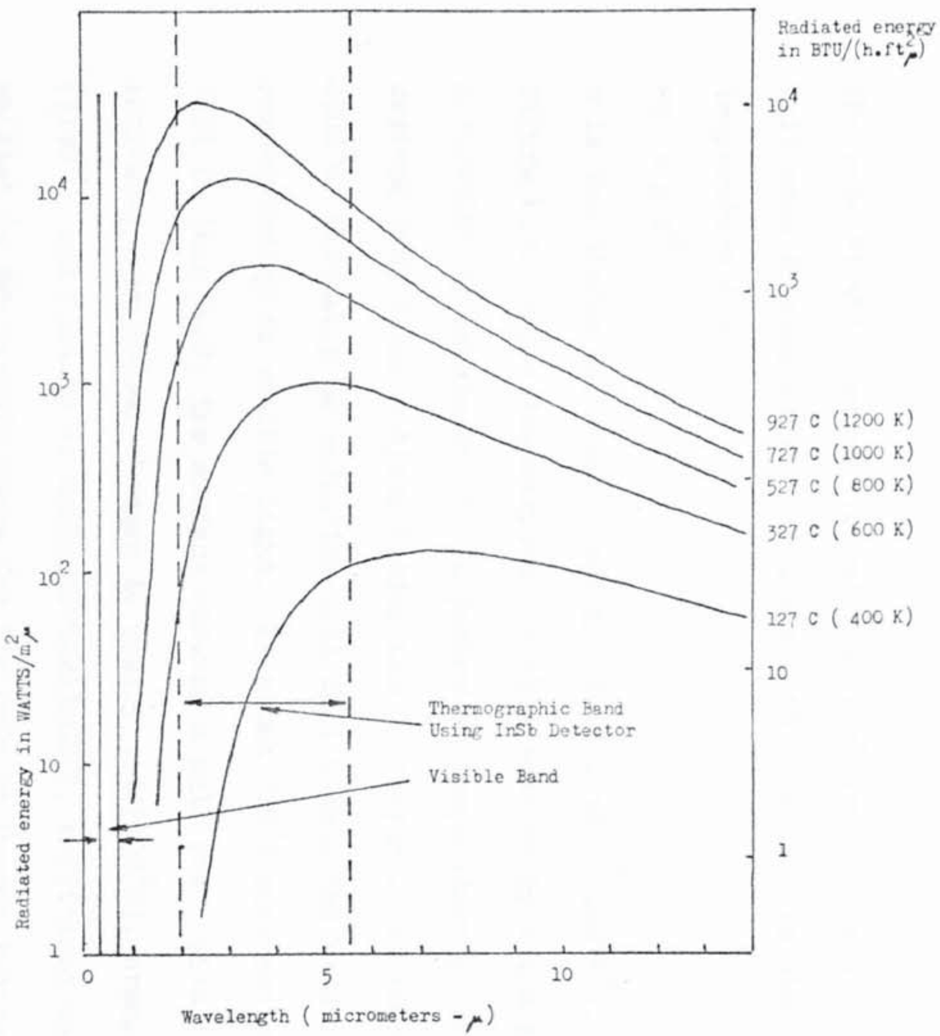
A surface which absorbs all the thermal radiation incident upon it is called a 'black surface' and the consequential body 'a black body'. In reality, the perfectly black body does not exist. A body coated with carbon black can be taken as a near - black surface. A black body will absorb all radiation incident upon it, reflecting and transmitting none and will emit, at any particular temperature, the maximum possible amount of thermal radiation.

Figure I.2.2



An interesting and very useful diagram of the Planckian curves is obtained by inclining the vertical lines of the log log representation so that the peaks of maximum spectral radiant emittance are aligned vertically. The entire range of temperatures from 100° to 15.000°K can thus be shown most conveniently with good separation between the curves even in the long wavelength direction.

Energy Distribution for Black Bodies at Various Temperatures



The rate at which energy is radiated (Eb) from a black body of unit area is proportioned to the fourth power of its absolute temperature (T).

$$Eb = \sigma T^4$$

σ is the Stefan Boltzmann constant ($56.7 \times 10^{-12} kW/m^2K^4$).

Figure I.2.2 shows the maximum possible emitted by a black body as a function of wavelength for a number of temperatures, and is derived from Plank's Distribution Law (132)(156). At temperatures $<500^{\circ}C$, virtually no radiation will fall within the band wavelength corresponding to visible light. At about $700^{\circ}C$ some radiation will fall in this band, the surface showing a dull red. With further increases, the colour changes to cherry red ($900^{\circ}C$), orange red ($1100^{\circ}C$) and finally at temperatures $>1400^{\circ}C$, sufficient energy is emitted in the visible range for the body to become 'white hot'. For example:- at $2500^{\circ}C$, the temperature of the element of the incandescent lamp, only 10% of the energy is emitted in the visible range, illustrating that such lamps are a more efficient source of heat than light. The wavelength at which maximum flux is emitted (λ max) is inversely proportional to the absolute temperature, a relationship known as Wien's displacement law (155).

The sun emits yellow light, peaking at about $0.5\mu m$ in the middle of the visible spectrum. At room temperature (300K) the peak of radiant emittance lies at $9.7\mu m$ in the far infrared; while at the temperature of liquid nitrogen (77K), the maximum of the almost insignificant amount of radiant emittance occurs at $38\mu m$ in the extreme infrared wavelengths.

It is also necessary to consider radiation intensity (I). When the direction of emission is at angle $\emptyset$ to the normal, the intensity of emission is given by Lamberts Law:

$I = Eb \cos\phi / \pi$ kW/m^{2}ster.

I.2.3 Real Surfaces

The absorptivity of a real body or surface is not the same for all wavelengths and all angles of incidence. Monochromatic absorptivity will vary with wavelength, incidence angle and temperature. Emissivity, reflectivity and transmissivity also have monochromatic counterparts. The emissivity of a real body or surface is defined as the ratio of the radiative flux (E) emitted by the body to that (Eb) emitted by a black body at the same temperature.

$\epsilon = E/Eb$

The emissivities of a number of surfaces are given in Table I.2.3. The values are approximate, since they depend very much upon the conditions of the surface. Most non-metalic substances have a high emissivity and are usually considered grey. Radiation from electrical conductors and polished metals have lower emissivities and vary considerably with wavelength; radiation leaving these surfaces is not diffuse; and reflected radiation may well be described by the ordinary laws of optics. Consequently, although the overall emissivities of metals are listed with those of other materials, some care must be taken in their use. In general, dirt and oxidation considerably increases the emissivities of most surfaces; these being poor conductors.

Over small temperature ranges, emissivities do not vary greatly. It is often necessary to adjust for larger ranges. Similarly correction for directional variation may be needed: $\epsilon/\epsilon n = 1.2$ for metallic surfaces and $\epsilon/\epsilon_n = 0.96$ for non-metallic surfaces (132), where ϵ = average emissivity throughout the hemispherical solid angle of 2π

Table I.2.3

Normal Total Emissivities of Various Surfaces

The following table of emissivities for the most part drawn up by C W Hurley and K G Kreider (157), represent a selection of more common industrial surfaces. The original source of the data was a compilation by H C Hottel (165), F Kreith (131) and H C Hottel and A F Sarofin (166). A survey of the literature reveals wide variances in the reported results, deviations from these values can therefore be expected.

When temperatures and emissivities appear in pairs separated by dashed, they correspond making linear interpretation possible.

Surface	°C	Emissivity
Metals and their Oxides		
Aluminum		
Polished	38-100	0.04-0.095
Commercial sheet	100	0.09
Heavily oxidised	93-504	0.20-0.31
Aluminum oxide	277-500	0.63-0.42
Aluminum oxide	500-827	0.42-0.26
Aluminum alloy 7075 cleaned with toluene, then methanol, repeatedly heated and cooled	232-482	0.22-0.16
Aluminum alloy 2024 cleaned with toluene, then methanol, repeatedly heated and cooled	232-488	0.17-0.15
24 - ST weathered surface roofing	38	0.22
Brass		
Polished	38-316	0.10
Rolled plate, natural surface	22	0.06
Dull plate	49-349	0.22
Oxidised by heating at 1110°F	200-600	0.61-0.59
Chromium, polished	38-1093	0.08-0.36
Copper		
Polished	117	0.023
Commercial, scraped shiny, but not mirrorlike	22	0.072
Plate, heated long time, covered with thick oxide layer	25	0.78
Plate heated at 1110°F	200-1093	0.57
Inconel		
Type X, cleaned with toluene, then methanol, repeatedly heated and cooled	232-882	0.55-0.78
Type B, cleaned with toluene, then methanol, repeatedly heated and cooled	232-882	0.35-0.55
Iron and Steel Metallic Surfaces		
Steel, polished	38	0.066

Surface	°C	Emissivity
Iron, polished	32-538	0.13
Cast iron, polished	200	0.21
Smooth Sheet iron	900-1038	0.55-0.60
Molten iron	1371	0.3-0.4
Mild steel, cleaned with toluene, then ethanol, repeatedly heated and cooled	232-1066	0.20-0.32
Iron and Steel Oxidised Surfaces		
Iron oxide	32-538	0.96-0.85
Iron Plate, completely rusted	19	0.69
Iron, dark grey surface	38	0.31
Rolled sheet steel	21	0.66
Cast iron, oxidised at 1100°F	200-1093	0.64-0.70
Steel, oxidised at 1100°F	200-1093	0.79
Iron oxide	500-1200	0.85-0.8[illegible]
Sheet steel, strong, rough oxide layer	24	0.80
Sheet steel, dense, shiny oxide layer	24	0.82
Cast iron, rough, strongly oxidised	38-249	0.95
Wrought iron, dull, oxidised	21-360	0.94
Steel plate, rough	38-371	0.94-0.97
Lead, oxidised at 300°F	200	0.63
Magnesium	32-538	0.07-0.18
Magnesium oxide	288-827	0.55-0.20
Magnesium oxide	900-1704	0.20
Molybdenum fillament	538	0.09
Monel 400 oxidised at 1110°F	200-1093	0.41-0.46
Monel K-500, cleaned with toluene, then ethanol, repeatedly heated and cooled	232-877	0.46-0.65
Nickel, polished	100	0.072
Nickel plate, oxidised by heating at 1110°F	200-1093	0.37-0.4[illegible]
Silocre polished	38	0.01
Stainless Steels		
Polished	100	0.074
Type 301 cleaned with toluene, then ethanol, repeatedly heated and cooled	232-950	0.57-0.[illegible]
Type 316, cleaned with toluene, then ethanol, repeatedly heated and cooled	232-871	0.57-0.[illegible]
Type 347, cleaned with toluene, then ethanol, repeatedly heated and cooled	232-900	0.52-0.[illegible]
Steel Tube, oxidised	260	0.[illegible]

Cont'd...

Surface	°C	Emissivity
Type 310, brown splotched, oxidised from furnace service	215-517	0.90-0.97
Tin, commercial tin-plated sheet iron	100	0.07-0.08
Tungsten filament	38-1371	0.05-0.18
Zinc		
Commercial 99.1% pure, polished	227-327	0.045-0.053
Galvanised sheet iron, fairly bright.	28	0.23
Galvanised sheet iron, grey oxidised	24	0.28
Refractories, Building Materials, Paints and Miscellaneous		
Alumina		
Mean grain size 10 microns	1010-1565	0.30-0.18
Mean grain size 50 microns	1010-1565	0.39-0.28
Mean grain size 100 microns	1010-1565	0.50-0.40
Asbestos board	23	0.96
Asbestos cement, red	1371	0.67
Asbestos paper	38-371	0.93-0.94
Asphalt	38	0.93
Brick		
Red, rough, but no gross irregularities	21	0.93
Building	1000	0.45
Fireclay	38-1000	0.9-0.75
Magnesite refractory brick	38-1000	0.9-0.38
Carbon		
Filament	1038-1404	0.526
Rough plate	100-320	0.77
Rough plate	320-500	0.77-0.72
Lampblack, rough deposit	100-500	0.84-0.78
Graphite, pressed, filed surface	249-510	0.98
Carborundum (87% SiC, density 2.3)	1010-1400	0.92-0.82
	20	0.92
Concrete tiles	1000	0.63
Enamel, white fused, on iron	19	0.90
Glass, pyrex, lead and soda	260-538	0.95-0.85
Glass, polished plate	21	0.94
Gypsum, 0.02 in. thick, on smooth or blackened plate	21	0.903
Ice	0	0.97
Marble, light grey polished	38	0.93
Oak, planed	21	0.90
Oil, lubricating (thin film on nickel base = 0	20	0.27
= 0.025 min	20	0.46
= 0.125	20	0.72

Surface	°C	Emissivity
Paints, Lacquers, Varnished		
Snow-white enamel varnish on rough iron plate	23	0.906
Black shiny lacquer, sprayed on iron	24	0.875
Black matte shellac	77-146	0.91
Black or white lacquer	38-93	0.80-0.95
Flat black lacquer	38-93	0.96-0.98
Oil paints, 16 different, all colours	100	0.92-0.96
Aluminum paints and lacquers, 10%. Al, 22% lacquer body on rough or smooth surfaces	100	0.52
Aluminum paint with silicone vehicle, 2 coats on Inconel	260	0.29
Other aluminum paints, varying age and aluminum content	100	0.27-0.67
Aluminum lacquer, varnish binder on rough plate	21	0.39
Alumigum paint, after heating to 620°F	149-316	0.35
Radiator paint, white, cream, bleach	100	0.79,0.77,0.84
Radiator paint, bronze	100	0.51
Lacquer coatings, clear, 0.001-0.015 in. thick on aluminum alloys	38-149	0.87-0.97
Clear silicone vehicle coatings 0.001-0.015 in. thick on mild steel	260	0.66
Plaster, rough lime	10-88	0.91
Porcelain, glazed	22	0.92
Quartz, rough, fused	21	0.93
Roofing board	38	0.93
Roofing paper	38	0.91
Rubber, hard, glossy plate	23	0.94
Rubber, soft, grey, rough, (reclaimed)	24	0.86
Sand	20	0.92
Skin, human	10	0.98
Soil, dry	20	0.92
Saturated with water	20	0.95
Silica, fused	38-1371	0.9-0.84
Silica, mean grain size 10microns	1010-1566	0.42-0.33
Silica, grain size 70-600 microns	1010-1866	0.62-0.46
Water	38	0.96
Wood	38	0.93

steradians, and ϵ_n is the emissivity in the direction normal to the surface. In practice average values are used.

I.2.4 Photon Emission

The energy emitted by a thermal radiator is not transferred as a continuous flow but rather as discrete energy 'jumps' or quanta called 'photons'. The energy of a photon Q is given by:

$$Q = \frac{hc}{\lambda} \qquad \text{(joules)}$$

Where: h = Plank's constant = 6.6×10^{-34} joule sec.

The radiation laws given earlier were all concerned with the energy of the radiation. They can, however, be modified to deal with the number of photons (Nb) rather than the energy. This is of interest where use is made of photon detectors, such as the AGA Thermovision instruments (156).

I.3 <u>Radiation Theory and Thermography</u>

An infrared detector is a device that absorbs IR energy and converts it to a signal, usually an electric voltage or current. There are two principal types: thermal detectors and photon detectors.

Thermal detectors rely on the temperature rise produced in an absorbing receiver. The most important thermal detector today is the thermistor bolometer. Such detectors exhibit 'flat', constant but slow response over a wide range of wavelength.

In contrast, photon detectors show distinctly different spectral responses between types of detector characterised by a sharp 'cut-off' in the long - wavelength range. These are composed of semi-conductor material, in which the release or transfer of electrons is directly associated with photon absorption. The energy of the photon is inversely proportional to the wavelength associated with it. The disappearance of photelectric activity above the cut-off point indicates the energy of the photons to be insufficient to free electrons; i.e. the photons must exceed the 'forbidden' energy gap (Eg in joules) in the semiconductor material. This cut-off wavelength is

$$\lambda_c = \frac{hc}{Eg} \text{ (m)}$$

In general Eg is increased by cooling the detector so that λ_c is decreased.

'Photoconductive' detectors determine Eg by the nature of the material itself. The effect of photon absorption is to 'free' electrons thereby increasing the detectors conductivity. The alternative detector - 'photovoltaic' - also has Eg determined by the material, but the radiation-generated charge-carriers are swept by the electric field in a p-n junction, thereby directly producing a voltage rather than a change in conductivity.

High speed scanning requires a detector with a very short response time. Photon detectors are more sensitive and have shorter response times than their thermal counterparts. Limited spectral response and the need for cooling (77K with liquid nitrogen) are their main drawbacks. The AGA Thermovision System 680 IR camera, used for this work, makes use of an indium antimonide (In Sg) detector which is rugged and stable. It is constructed integrally with a 100 cm^3 Dewar flask, which serves both as a container for the coolant and as a vacuum envelope for the detector element. Response times are shorter than a microsecond, but wavelength - response of the signal obtained has limits of 2 to 5.5 μm (Figure I.2.2). Whilst seemingly a serious disadvantage in comparison with the broad response of thermal detectors, (a factor of 25) greater sensitivity more than compensates for the deficiency.

Long wavelength detectors are presently being developed but these mostly require lower detector cooling temperatures. A widely accepted figure of merit for expressing the sensitivity of IR detectors is 'detectivity' (D). The higher this normalised value the better the detector. In the case of an ideal thermal detector, with perfectly flat spectral response, it is sufficient to state a single value of D. With photon detectors, D is wavelength dependent. The ultimate limit on D is set by the 'radiation noise' signal which is generated by the detector. This results from the statistical fluctuation of the radiation received and re-admitted by the detector itself. Theoretical limits of D are now being approached. With peak detectivities at wavelengths beyond $40 \mu m$.

I.4 Thermographic Equipment and Operating Principles

Thermography makes use of the natural IR radiation which varies with the surface temperature of the object. In principle, a camera scans the field of view and focuses the IR radiation on a sensitive detector which in turn converts the variations to electronic signals transferred via an interconnecting cable to a display unit (Figure I.4.1). After amplification, the signal is used to control the electron beam of a TV - type picture tube. The beam sweeps over the picture screen in synchronism with the camera scanner forming a

Figure I .4.1

SCHEMATIC DIAGRAM OF THERMOGRAPHIC SYSTEM

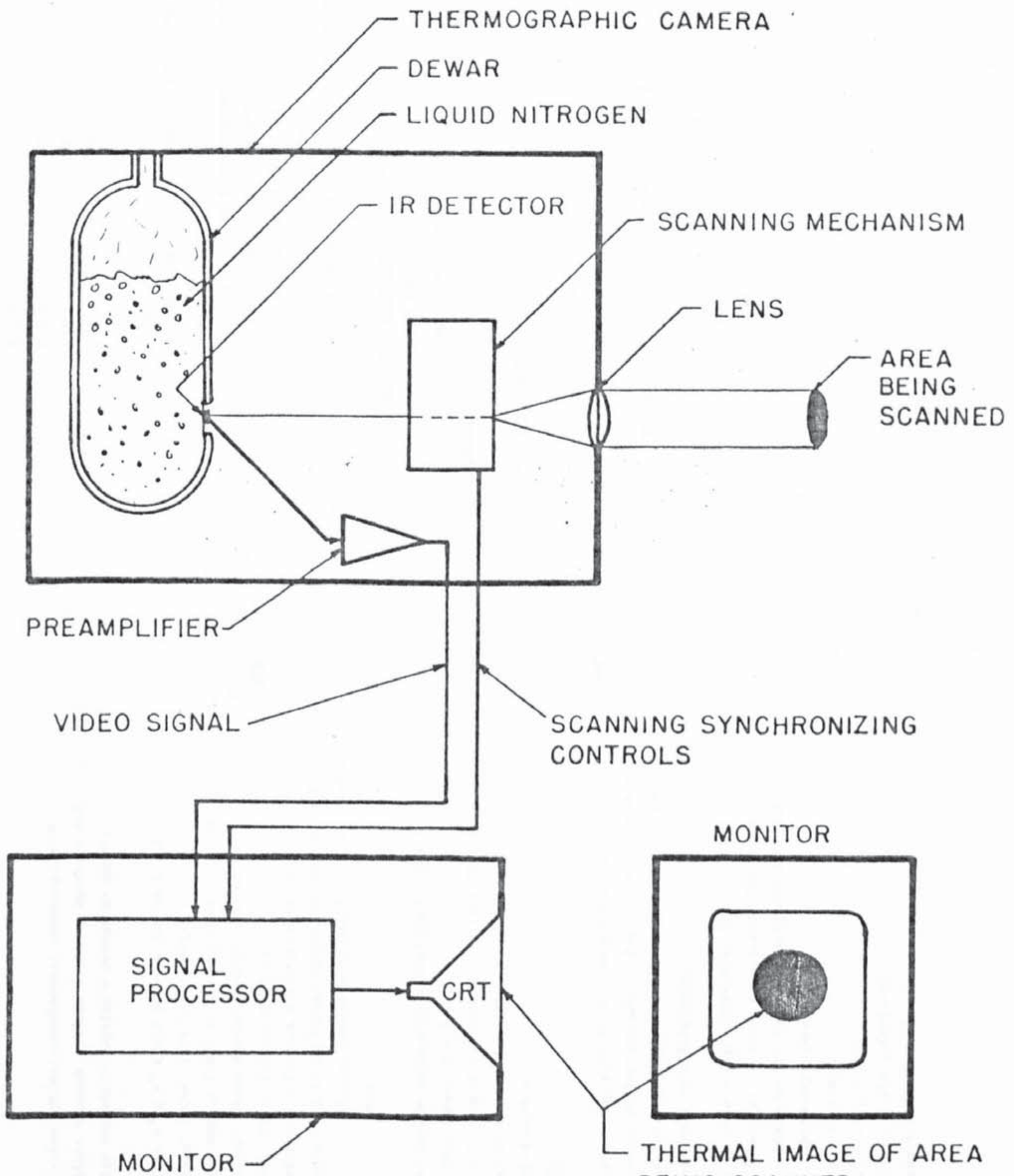


Table I.4.2 Equipment Specification

a) Camera Unit 680

- Type: Real-time optical/meachanical scanning, with straight through optics, built-in aperture and fitter selection. Optics - Germanium glass.

- Optics: IR lens 8^{o} x 8^{o} field of view 166 mm f/1.8
  Range of focus: 1.7m to infinity
  Instantaneous field of view: 1 mrad (50% contrast)
  Focusing: Moto driven (remote) and manual
  Maint: Quick-release bayonet
  Apertures: 7 f/stops selectable on camera unit
  Filters: Built in filter turret accepts up to 8 IR grey and/or spectral filters on camera unit

- Detector: Type: Indium antimonide (InSb) photovottaic
  Spectral Range: 2 - 5.6
  Coolant: Liquid nitrogen stored in a 100 cm^3 Dewar flask, 4 hours between refills
  Saphire window.

b) Display Unit 102B

- All-electronic display with TV-monitor picture tube utilising magnetic deflection and random - line interlacing, selectable picture size, dual - isotherm presentation and pre-set photographic recording made.

- Display: Picture tube - high definition type (10 kV accelerating potential), medium persistance (P4) phosphor
  Picture Size - 90x90 mm for direct viewing and 67x74 mm for photo-recording
  Field frequency- 16 p.sec.
  Line frequency - 1600 p.sec.
  Raster lines/frame - 210 interlaced
  Resolving power - 140 standard lines

- Temperature Measurement: Object temperature $-30^{o}C$ to $850^{o}C$ in 10 sensitivity steps and 7 f/stops

f/1.8	$-30^{o}C$	to	$190^{o}C$
f/2.5	0		240
f/3.6	50		300
f/5.1	80		390
f/7.2	100		500
f/10	140		660
f/14	200		850

  Temperature range extended to +2000C by inserting grey - filter
  Minimum deductable temperature difference: better than $0.2^{o}C$ at $30^{o}C$ object temperature
  Isotherm functions: Dual or single, variable 2-60% of selected temperature range
  Levels adjustable continuously and independently

- Photographic Recording: Camera adaptor fitting for Polaroid Land Camera Back.
  Pack film type 108 (ASA75)

c) System

- Operating Temperature: -15^{o} to $55^{o}C$

- Power Requirements: 115 or 230V AC I 10%, 50-400 Hz, 200 VA single phase

- Dimensions: See figure 6.4.2
  Interconnecting cables: 6 to 30 m

Figure I.4.3 Equipment Dimensions

AGA Thermovision 680

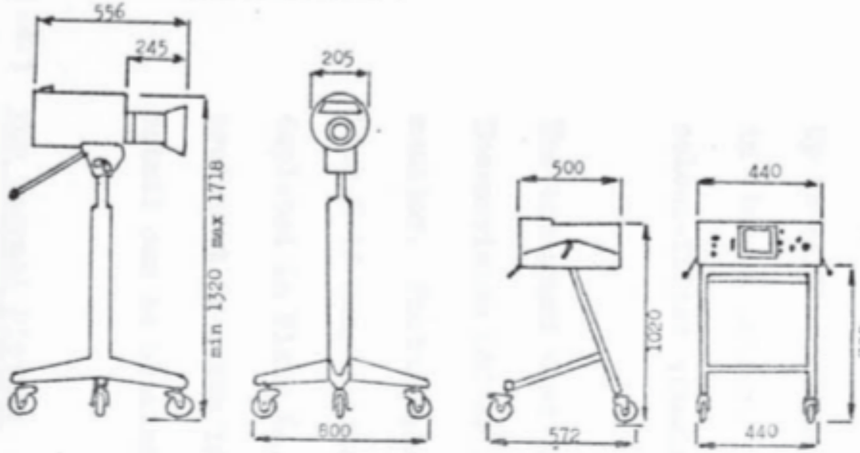


Figure I.4.4 Internal Optical Arrangements

Aston University

Illustration removed for copyright restrictions

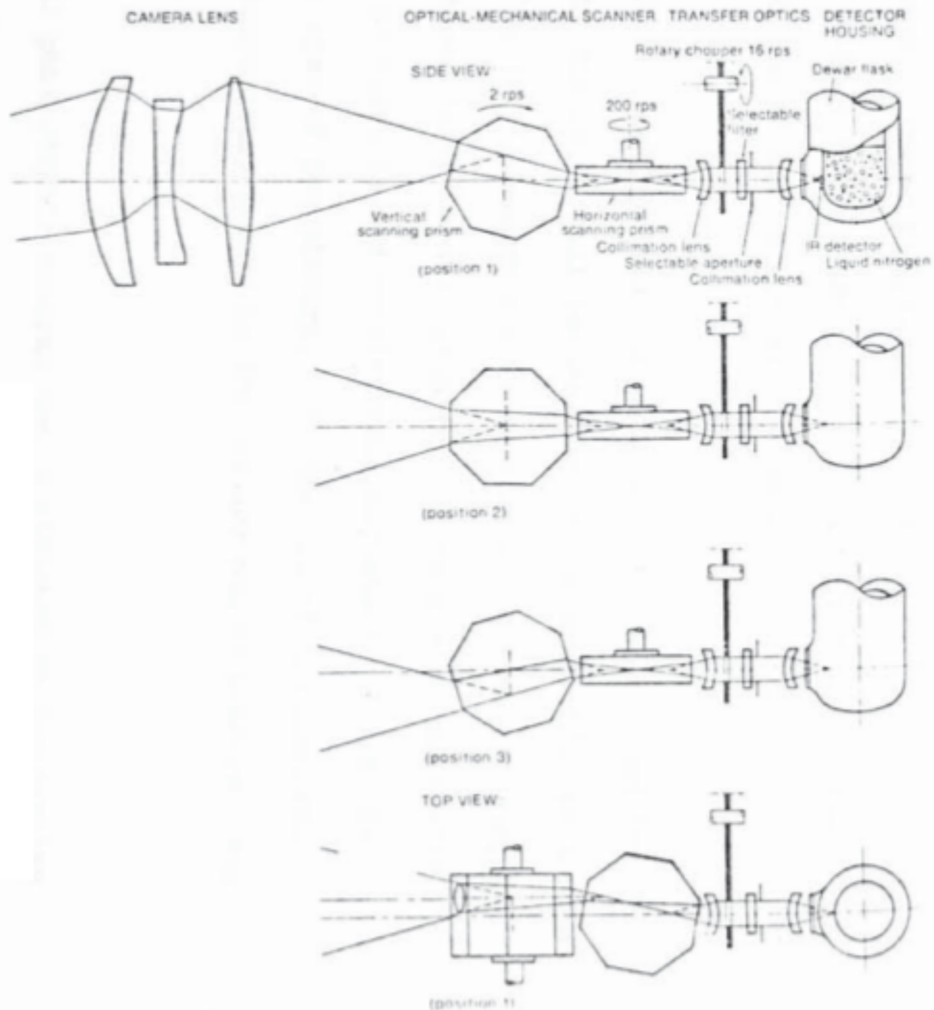
The System 680 Infrared Camera Unit, showing the internal arrangement of the electro-optical components.

AGA THERMOVISION 680 CAMERA

FIGURE I.4.5

OPTICAL PATHS IN CAMERA UNIT

Diagram of various optical paths which can occur within the System 680 Camera Unit due to optical-mechanical scanning.



thermal image of the object, in which the lighter areas represent details of higher temperature. The result is a live, or 'real-time' thermal picture of the object on the screen.

The display is provided with two 'isotherm' functions used for selecting isothermal (equal temperature) contours within the thermal picture. The two isotherms appear in saturate white, superimposed on the pictured 'grey' tones, with their levels adjustable either separately or together and continuously adjustable within the temperature span of the picture. With the aid of the isotherm function, temperature levels in the picture can be measured very accurately.

Conventional photographic cameras can be attached to the display unit to enable simultaneous viewing and photo-recording of the thermogram. An instant pack film is usually used for quick results. Up to eight isotherm levels can be recorded in one photograph, each in its own colour. This is achieved with the help of a special colour-filter attachment.

The equipment used for the Fort Dunlop experiments was the AGA Thermovision 680 camera unit in conjunction with the 103B Display monitor. Photographic recording was achieved by a Polaroid Land Back C-12 camera attached to a main frame adaptor. These are clearly depicted in Plate 6A. Fuller description of specification and equipment is given in the ensuing tables and diagrams. Further detail can be obtained from the AGA operating manual (156).

I.4.1 The Thermal Picture

The signal derived from the camera is amplified and used to modulate the intensity of the electron beam of the TV-monitor type picture tube in the display unit. The electron beam sweeps across the screen of the tube in synchronism with the scanning optics. This produces the thermal picture of the object being scanned. The front panel serves as the control console of the system.

Through proper selection of sensitivity ranges and camera aperture size the grey-tone thermogram is obtained. The particular sensitivity selection settings is shown by the indicator on the left and right vertical scales of the picture (See figure I.4.9).

A second control determines the temperature range. This control allows for adjustment to a precise temperature level. Temperatures within the range appear as shades of grey, completely black (cold) to completely white (hot). If a sensitivity range has been chosen which is a smaller span than the object temperature span, cool details 'black out' when the instrument is adjusted to warm details, and 'white out' for cooler detail adjustment. There is no set procedure for obtaining an optimum thermal picture. This is at the discretion of the operator.

When quantitative temperature measurements are required, a selected amount of the infrared radiation focused on the detector can be marked electronically to produce isothermal contours on the display screen. Whenever the detector video signal level corresponds to a selected isotherm level, the image is saturated white. The isothermal contours thus produced can be used to measure the exact amount of temperature variation existing between details of the thermal image of the object. Due to the highly non-linear nature of the temperature/radiation characteristic of the IR detector, the actual magnitude of the selected temperature span is a non-linear

FIGURE I.4.6

DISPLAY UNIT 102 B AND AUTOCOLOUR ATTACHMENT

Aston University

Illustration removed for copyright restrictions

The Model 102B Display unit for Thermovision System 680, shown with the special AGA Colour thermogram cameras: manually operated (left) and automatic (right).

function of the absolute temperature level. Because of this, the instrument is not calibrated directly in terms of temperature except for a limited range including that for the human body. Calibration curves are required to obtain actual temperature. .

The isotherm contours can be photographed in colour by means of the AGA Polaroid Land Pack film Autocolour attachment (Figure I.4.6). Up to eight different isotherms can be photographed, by multiple exposures over 4 - 12 seconds on a single colour film frame through various colour filters synchronised with automatically selected isothermal contours. The result is a complex surface temperature pattern of the object made up of individual isotherms.

I.4.2 Operation Procedure Summary

The following procedure was used to obtain an optimum thermal picture. (Figures I.4.7 and I.4.8). The camera was switched on, directed towards the object and roughly focused. Having selected the aperture and approximate sensitivity, the white and black levels were adjusted to give a full grey scale at the base of the thermal picture. Further adjustment of the picture black level produced an image, which was consequently focused to give optimum definition. The isotherm levels were then selected to provide appropriate contours, the makers showing on the grey scale. The width of the isotherm marker was then adjusted to a desired temperature span. Selection of the black position removed the grey zones leaving only the isotherm in preparation for the photographing of the colour thermograms. The polaroid mechanism was then activated to provide the final picture. It was usual to select one of the isotherms at a temperature corresponding to some known reference.

Illustration removed for copyright restrictions

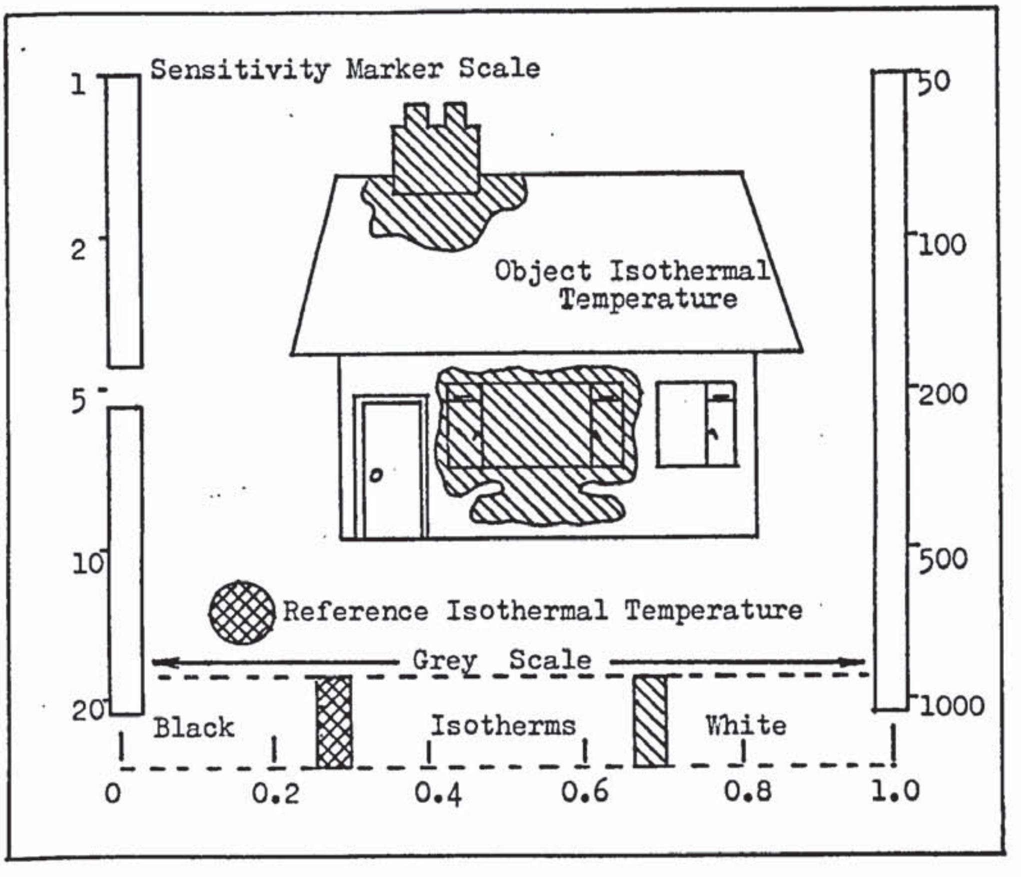
Figure I.4.8

Illustration removed for copyright restrictions

Figure I.4.7

Figure I.4.9

Example of a Thermogram Showing Two Isotherms (one a reference source) and the Sensitivity Marker Scale



I .4.3 Alternative Equipment

In addition to the described IR camera, AGA manufacture an alternative camera, the Thermovisiol 750. This equipment is compiled of similar basic components to the Thermovisiol 680 but can be powered from a re-chargable battery,thus being more readily transportable in normal industrial applications. The equipment constitutes a hand held cine-type camera attached to a monitor hung from the operators neck. This offers greater flexibility of use than the semi-transportable 680,albeit at the expense of accuracy. Like the 680, the display can easily be recorded photographically, although only in black and white.

AGA Infrared Systems are not the only suppliers of detection equipment. Barnes Engineering Co, Stamford Conn. has developed a thermographic instrument that will give a single amplitude trace out;not an entire thermogram. The camera generates a single trace showing temperature along a narrow band which can be photographed with an optical camera attachment (162). The detector constitutes an array of 100 LED's which react to an IR beam. No cooling is required but the scan speed is limited to 4 lines per second. The camera does not have the accuracy, resolution or convenience of the AGA systems, but is available at 1/7th the price.

The model 800 imaging camera offered by Spectrothern Corp., Santa Calif., illustrates a design having high resolution (528 lines/ frames) but low speed image formation. Images are formed in 10 distinct shades of grey at the rate of a frame a second. A mercury-cadmium-telluride (HgCdTe) photoconductive detector (8 to 14μm) is used. A unique feature is the cameras ability to display line scans along with the complete thermogram. The equivalent AGA system requires a separate monitor and display. The camera also relies on the use of liquid notrogen, has only semi-portability and is expensive.

Thermography had limited appeal in its early years because the equipment was heavy and the detector response slow. In the last decade, weight has been reduced, with portability, image speed and resolution improved. In agreement with R B Aronson (162), however, acceptance appears to be limited by cost and lack of understanding of what thermography can do. At the time of this work, Dunlop had not long purchased an AGA 680 monitor. It was, therefore, prudent that the experiments be carried out using this equipment.